Géographie physique et Quaternaire

Late Quaternary Sea Level Changes on Brock and Prince Patrick Islands, Western Canadian Arctic Archipelago

Les changements du niveau marin au Quaternaire supérieur, dans les îles Brock et du Prince-Patrick, dans l'ouest de l'archipel arctique canadien

Veränderungen des Meeresniveaus im späten Quaternär auf den lnseln Brock und Prince Patrick, arktisches Archipel im Westen Kanadas

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Résumé de l'article

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LATE QUATERNARY SEA LEVEL CHANGES ON BROCK AND PRINCE PATRICK ISLANDS, WESTERN CANADIAN ARCTIC ARCHIPELAGO*

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ABSTRACT Emerged shorelines are few and poorly defined on Prince Patrick and Brock islands. The sparse radiocarbon dates show emergence of only 10 m through the Holocene on the Arctic Ocean coast, increasing to > 20 m 100 km to the east. Hence, from Brock Island, representative of westernmost coasts, the sea level curve since the latest Pleistocene has a very low gradient, whereas on eastern Prince Patrick Island the curve takes the more typical exponential form. A decline in isobases towards the west is thus registered. Drowned estuaries, breached lakes, and coastal barriers, particularly in southwest Prince Patrick Island, suggest that the sea is now transgressing at a rate that decreases towards the north end of the island, hence there is also a component of tilt to the south. Delevelling is assumed to result from undefined ice loads, but may have a tectonic component. The sole prominent raised marine deposit is a ridge probably built in a period of more mobile sea ice, possibly at a time of stable or slightly rising sea level in the middle or early Holocene. It winds discontinuously along several hundred of kilometres of the shores of the Arctic Ocean and connecting channels, declining to the south.

RÉSUMÉ *Les changements du niveau marin au Quaternaire supérieur, dans les îles Brock et du Prince-Patrick, dans l'ouest de l'archipel arctique canadien.* Les rivages émergés sont peu nombreux et mal définis dans les îles Brock et du Prince-Patrick. Les rares datations au radiocarbone n'indiquent qu'une émergence de 10 m des côtes de l'océan Arctique, au cours de l'Holocène, s'accroissant à > 20 m, à 100 km vers l'est. Ainsi, à partir des côtes de l'île Brock, représentatives de la partie la plus occidentale, le niveau marin depuis le Pléistocène supérieur a un très faible gradient; par contre, dans la partie est de l'île du Prince-Patrick, la courbe du niveau marin a un caractère nettement exponentiel. On enregistre donc un abaissement des isobases vers l'ouest. Les estuaires submergés, les lacs ébréchés et les barrières littorales, surtout dans le sud-ouest de l'île du Prince-Patrick, semblent indiquer qu'il y a actuellement transgression marine à un taux qui décroît vers le nord de l'île; il y a donc aussi inclinaison vers le sud. On présume que le dénivelé découle de charges glaciaires indéterminées, mais peut aussi avoir une composante tectonique. Le seul dépôt marin soulevé d'importance est une crête probablement édifiée alors que la glace de mer était plus mobile, pendant que le niveau marin était stable ou légèrement en hausse, au début ou au milieu de l'Holocène. La crête serpente de façon irrégulière sur plusieurs centaines de kilomètres de côtes de l'océan Arctique et de chenaux adjacents, tout en s'abaissant vers le sud.

ZUSAMMENFASSUNG *Veränderungen des Meeresniveaus im späten Quaternär auf den Inseln Brock und Prince Patrick, arktisches Archipel im Westen Kanadas.* Aufgetauchte Uferlinien sind rar und kaum festgelegt auf den Inseln Prince Patrick und Brock. Die spärlichen Radiokarbondaten zeigen im Holozän ein Auftauchen an der arktischen Ozeanküste von nur 10 m, das 100 km östlich auf > 20 m ansteigt. So hat die Meeresniveaukurve von der Insel Brock ausgehend, welche für die am westlichsten gelegenen Küsten repräsentativ ist, seit dem spätesten Pleistozän ein sehr niedriges Gefälle, wohingegen die Kurve im östlichen Teil der Insel Prince Patrick die mehr typische exponentielle Form hat. Man registriert also eine Senkung der Isobasen nach Westen hin. Überflutete Gezeitenmündungen, geschartete Seen und Küstendamme, besonders im Westen der Prince Patrick-Insel, lassen vermuten, dass jetzt die horizontale Verlagerungsrate des Meeres zum Nordende der Insel hin abnimmt, folglich gibt es auch eine Neigung nach Süden hin. Man führt die Verstellung auf unbestimmte Eisfrachten zurück, doch könnte sie eine tektonische Komponente haben. Die einzige herausragende marine Auftauchablagerung ist eine Schwelle, die wohl in einer Periode mobileren Meereises gebaut wurde, möglicherweise in einer Zeit mit stabilem oder gering ansteigendem Meeresniveau im mittleren oder frühen Holozän. Sie windet sich diskontinuierlich über mehrere hundert Kilometer an den Küsten des arktischen Ozeans und der angrenzenden Kanäle entlang und senkt sich nach Süden.

* Geological Survey of Canada Contribution N° 43692

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INTRODUCTION

There is a general perception, based on few published observations, that on the westernmost Canadian Arctic islands (*i.e.* those bordering the Arctic Ocean, from Banks to Meighen islands, Fig. 1) little emergence and perhaps some submergence of coasts has occurred during the Holocene. In this respect, these islands are unlike most of the Arctic, where flights of raised beaches record continuous emergence reaching tens or hundreds of metres above sea level (asl) (Bird, 1967). This paper presents the first compilation of published radiocarbon dates from the westernmost Queen Elizabeth Islands, together with new information on Holocene and latest Pleistocene sea levels from Brock and Prince Patrick islands (Fig. 1). We also describe a unique paleoshore marker, generally referred to in this paper as 'the ridge'. This prominent feature, built by sea ice, parallels the coast for more than one hundred kilometres. For most of its length the ridge lies beyond conceivable reach of recent ice push. The results of these investigations of sea level change are compared with published models of marine limit and isobases for the Arctic.

Stefansson (1921) first remarked on the drowned creek estuaries on Banks Island; subsequently Manning (1956) recognized that peat submerged at normal high tide suggested that the west coast of Banks Island is sinking, while Tozer (1956) commented on the scarcity of emerged strandlines on Prince Patrick Island. Craig and Fyles (1960), on the basis of these and their own observations, suggested a transgression resulting from an eustatic sea level rise accompanying melting of the last ice sheets. They showed a drowned coastline, from Yukon to Borden Island (Craig and Fyles, 1965, Fig. 6). The first field survey of Quaternary landforms in the area covered by this paper was conducted in 1964 by Fyles (Fyles, 1965). His observations of 0-15 m emergence on the west coasts of Prince Patrick, Brock and Borden islands were widely disseminated by Prest *et al.* (1968). On northwest Prince Patrick Island, Pissart (1967) accounted for pingo growth near sea level with a hypothesis requiring a sea level fall from 12 m above to 10 m below present, followed by a transgression to the modern level.

Regional models showing temporal changes in relative sea level have been developed by extrapolating sea level data mostly collected elsewhere in the Arctic. All models show isobases over western islands paralleling the Arctic Ocean shelf and coasts (Fig 2). Farrand and Gajda (1962) projected a postglacial marine limit from the central and eastern archipelago to an elevation of 50-100 feet (15-30 m) on Prince Patrick Island (Fig. 2a), whereas Bird (1967) estimated less than 10 m. Isobases constructed by Andrews (1969) from shoreline emergence data for the archipelago and mainland, showed no emergence of the westernmost islands over the last 6 ka. Several exercises combined lithospheric models with either theoretical ice sheet loads or interpolated values from shoreline emergence curves. Using the emergence model, Walcott (1972) drew the zero (0 m) isobase for 7, 6, 4, and 2 ka trending northeast-southwest through western Melville Island, indicating submergence of the westernmost islands since at least 7 ka (Fig. 2b). In the model by Clark *et al.* (1978), the Laurentide Ice Sheet extended into the Queen Elizabeth Islands, and the westernmost islands fell into the Zone I/II transition (Fig. 2c) between Zone I (glaciated areas emerging) and Zone II (collapsing forebulge submerging). In Zone III the migrating forebulge causes initial emergence followed by submergence. The same pattern is shown by Andrews (1989, Fig. 8.6), who drew the present zero isobase east of Prince Patrick and Brock islands (Fig. 2d). Tushingham and Peltier (1991) appealed for more information on relative sea level change from this region, to permit better modelling of deglaciation and isostatic rebound. The history of glaciation on Prince Patrick and Brock islands similarly remains speculative, though most observers agree that (1) erratic boulders date from a pre-Wisconsinan continental glaciation and that (2) a thin local ice cap existed at a later date on Prince Patrick Island (Tozer and Thorsteinsson, 1964; Fyles, 1965; Pissart, 1967; Hodgson, 1990).

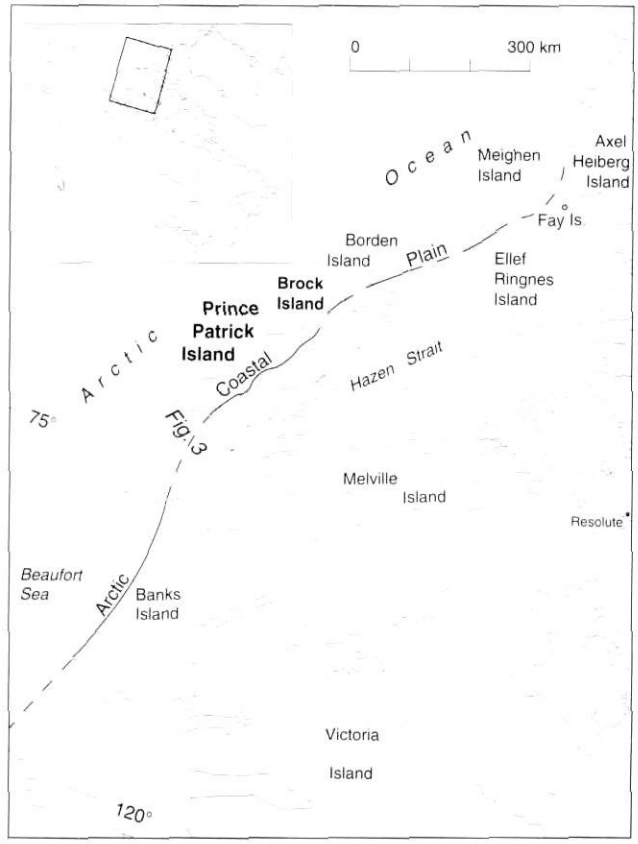

FIGURE 1. Location of western Canadian Arctic Archipelago, Arctic Coastal Plain and study area.

Localisation de l'archipel arctique occidental, de la plaine côtière arctique et de la région à l'étude.

The information on which this paper is based was collected in the course of a reconnaissance of the western archipelago by Fyles in 1964, during a further examination of Quaternary deposits and history by Hodgson in 1987 and 1989-92, and in the course of studies of coastal processes by Taylor in 1990 and 1992. Elevations of most shoreline landforms and marine deposits were measured from high tide level with an estimated accuracy of ± 1.0 m, using a Wallace and Tiernan altimeter. Surveys of the ridge were reduced to

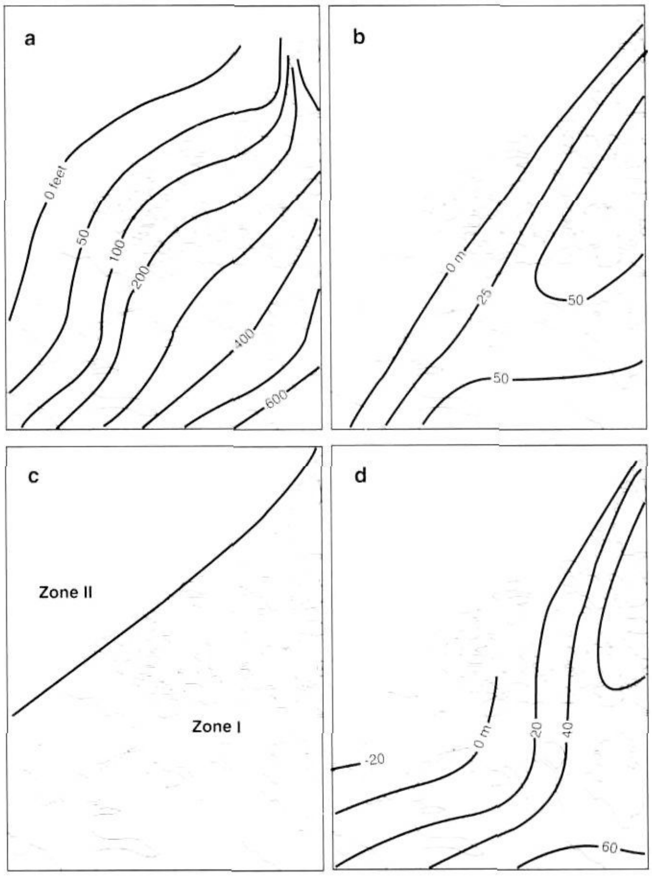

FIGURE 2. Sea level change, westernmost Queen Elizabeth Islands, modelled on data from other parts of the archipelago. a) Isobases for marine limit (modified from Fig. 1 in Farrand and Gadja, 1962); b) elevation of the 7 ka sea level, constructed using emergence curves and a lithospheric model (modified from Fig. 16 in Walcott, 1972); c) boundary of Zone I (emerging glaciated area) and Zone II (submerging collapsing forebulge) (adapted from Clark *et al.*, 1978); d) isobases on relative sea level changes since 7 ka, constructed from sea level curves (modified from Fig. 8.9, in Andrews, 1989).

Changements du niveau marin, extrémité ouest de l'archipel de la Reine-Elisabeth, modélisée à partir de données en provenance d'autres parties de l'archipel. a) Isobases des limites marines (fig. 1 modifiée de Farrand et Gajda, 1962); b) altitudes du niveau marin à 7 ka, à partir des courbes d'émersion et d'un modèle lithosphérique (fig. 16 modifiée de Walcott, 1972); c) limite de la zone I (zone englacée en émersion) et de la zone II (submersion du bourrelet périphérique affaissé) (adapté de Clark et al., *1978); d) isobases du niveau marin relatif depuis 7 ka, établies à partir des courbes du niveau marin (fig. 8.9 modifée de Andrews, 1989).*

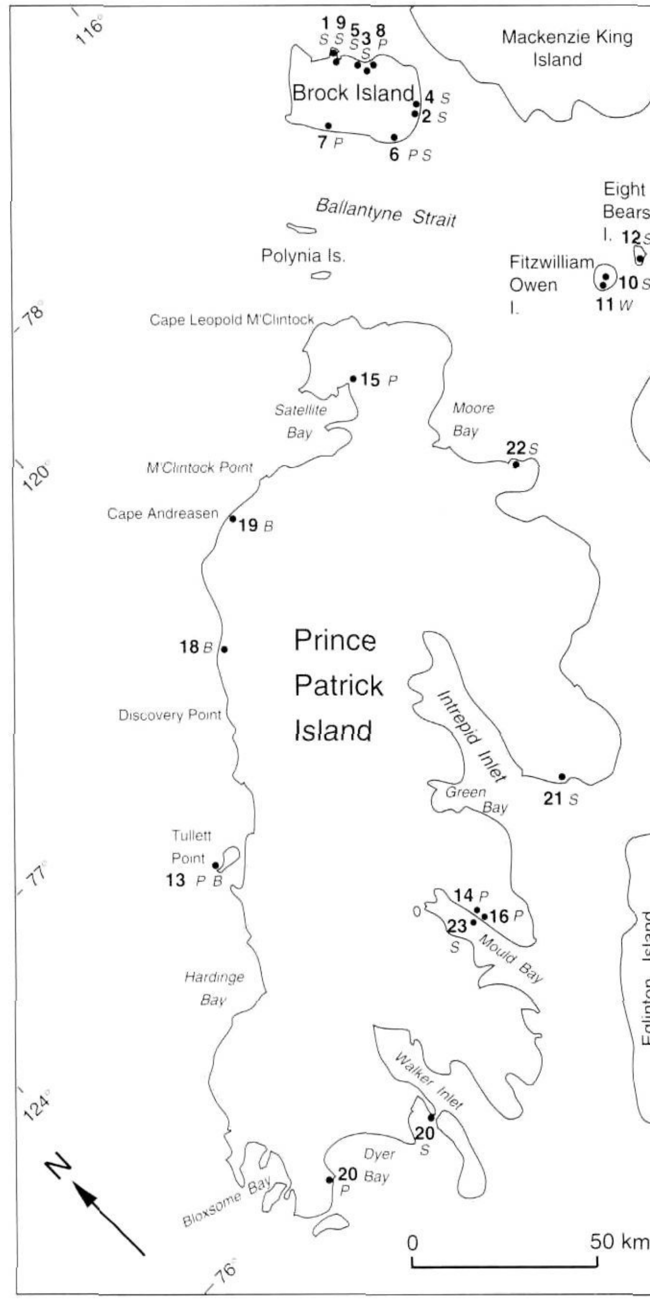

FIGURE 3. Place names of Prince Patrick, Brock and adjacent small islands; sites (1-24) of samples from which radiocarbon ages have been determined (see Table I). B = whale bone; P = plant, material; S = shells; W = driftwood.

Toponymie et localisation des sites d'échantillonnage (1-24) d'où proviennent les datations au radiocarbone (tabl. I). B = os de baleine; P = plante; S = coquillages; W = bois flotté.

mean sea level. The spring tidal range at Mould Bay (Fig. 3) is 0.5 m and increases to 0.8 m on northern Ellef Ringnes Island (CHS, 1990).

PHYSIOGRAPHY

The Arctic Coastal Plain, which is coincident with the sandy Tertiary Beaufort Formation, is divided by submarine channels between Meighen Island in the north east and Banks Island in the south west (Fig. 1). On western Prince Patrick Island (Fig. 4), the Beaufort Formation is mostly unconsolidated sand (Fyles, 1990; Devaney, 1991). Towards the southwest coast, this segment of the Arctic Coastal Plain is particularly low (< 10 m asl). On southeast Prince Patrick Island, resistant to weak Paleozoic clastic rocks form relatively rugged relief of up to 280 m, whereas the rolling landscape of the northeast is underlain by generally weak Mesozoic clastic rocks (Harrison *el al.*, 1988). Brock Island is low (maximum elevation 70 m) and composed of Beaufort

Formation sands in the west and partially indurated Triassic clastic rocks in the east.

The submarine topography, for the most part, resembles the onshore topography (CHS, 1984). The Queen Elizabeth Islands inner shelf is very shallow (Fig. 4), with water depths of less than 20 m extending 15-20 km west of Prince Patrick Island and Brock Island. An exception is Satellite Bay (Fig. 4), where the shelf is cut by a channel nearly 200 m deep. The channel between the two islands is less than 100 m deep, whereas most interisland channels of the archipelago are very deep with depths ranging from 200 to > 400 m. Along the east sides of the islands, many bays and inlets are greater than 100 m depth and some contain depressions exceeding 200 m. Knowledge of bathymetry beyond spot soundings is limited (Pelletier, 1964; Vilks, 1965).

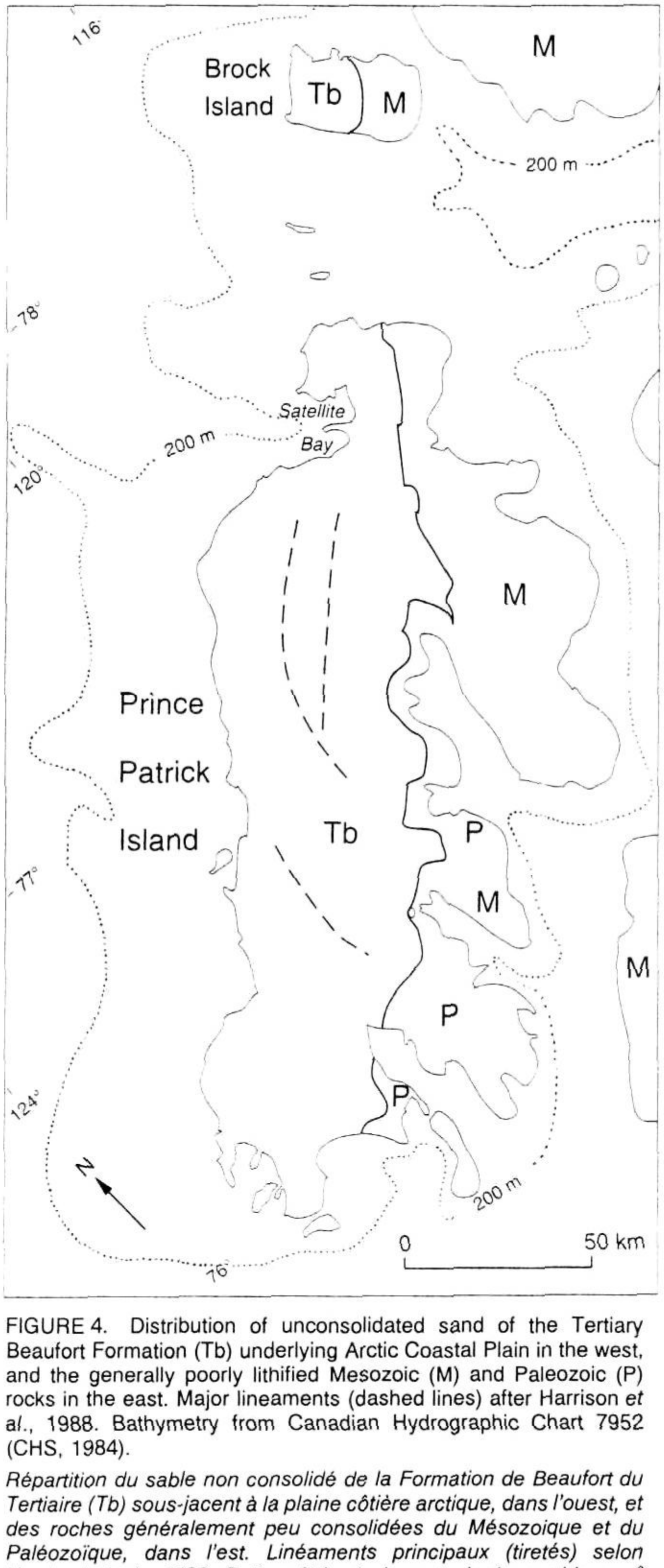

FIGURE 4. Distribution of unconsolidated sand of the Tertiary Beaufort Formation (Tb) underlying Arctic Coastal Plain in the west, and the generally poorly lithified Mesozoic (M) and Paleozoic (P) rocks in the east. Major lineaments (dashed lines) after Harrison *et al.*, 1988. Bathymetry from Canadian Hydrographic Chart 7952 (CHS, 1984).

Répartition du sable non consolidé de la Formation de Beaufort du Tertiaire (Tb) sous-jacent à la plaine côtière arctique, dans l'ouest, et des roches généralement peu consolidées du Mésozoïque et du Paléozoïque, dans l'est. Linéaments principaux (tiretés) selon Harrison et al., *1988. Bathymétrie de la carte hydrographique n° 7952 (CHS, 1984).*

REGIONAL INDICATORS OF SEA LEVEL CHANGE

Well-defined raised beaches, which are a widespread indicator of emergence in Arctic Canada (Bird, 1967), are uncommon in the westernmost islands. Wave generation is minimal or absent due to the inhibiting role of sea ice, which covers more than 7/10ths of the marine channels in most years (Markham, 1981). Open water is restricted to the heads of bays and inlets, and a narrow shore lead elsewhere. This rarity of beaches or even any evidence of marine washing all but precludes identification of marine limits. Generally, the most reliable indicator of marine limit in the Arctic is an ice-contact (glaciomarine) delta (Andrews, 1986); this landform, too, is rarely found in the westernmost islands, though it is hardly surprising, given the absence of other strong glacial indicators.

Organic deposits suitable for radiocarbon dating of paleo-sea levels are also rare. Molluscs are absent between present sea level and the assumed upper limit of submergence over large sections of the islands, which is predictable given the vigorous sea ice action on shores. Raised deposits of shells have not been found along shores of Mould Bay but living shells are numerous in nearshore waters of the bay (MacDonald, 1954, site 24, Table I). Distribution of Quaternary molluscs appears also to be influenced by physical or chemical properties of the pre-Quaternary substrate. For example, the surface of the quartz sand that forms most of the Beaufort Formation is barren of shells, whereas, shells grew on adjacent sediment derived from the sandy marine Triassic Schei Point Group on Brock Island and on Cretaceous marine shales on eastern Prince Patrick Island.

Driftwood is rare on modern and raised shores of the islands, unlike the relative abundance in the central Arctic Archipelago. Driftwood entry to coastal waters is inhibited by shorefast ice and the present oceanographic circulation pattern which controls the slow melt and export of sea ice. Rare bowhead whale skeletons along western Prince Patrick Island (Fig. 3, Table I, sites 13b-d, 18, 19) are presumably from the Bering Sea stock. We assume that since at least 3000 BP whales have travelled along the Arctic Ocean continental shelf in leads similar to the system that presently lies 1-30 km offshore (Markham, 1981; Smith and Rigby, 1981). Whales of the Davis Strait stock, which provide abundant beached skeletons on emerged shores of the central and eastern Arctic, probably have not ranged among northwesternmost islands since the middle Holocene (Dyke and Morris, 1990), if at all.

The most useful criterion for submergence is the occurrence below high water of *in situ* terrestrial vegetation (especially peat) suitable for radiocarbon dating. In the westernmost islands such occurrences are rare because preservation or detection of submerged terrestrial deposits is hindered by the sparsity of present and past (postglacial) vegetation cover, the intense scouring of the inshore bottom by sea ice, the widespread presence of shore ice and the micro-tidal range. Less quantitative morphological and stratigraphic evidence of marine submergence includes flooded lakes, estuaries, and drowned beaches and backshore surfaces. Erosion and exposure of former tundra surfaces beneath sea ice-built ridges and other foreshore deposits suggests a stable or rising relative sea level.

SEA ICE-BUILT RIDGE

A large prominent ridge of sediment winds discontinuously along the Arctic Coastal Plain close to the shore of the Arctic Ocean and the adjoining channels, from Dyer Bay on southern Prince Patrick Island to Borden Island (Figs. 1, 5). Ridges of similar size and morphology have been identified on airphotos along short sections of the Arctic Ocean coast farther north (on Borden, Ellef Ringnes and Meighen islands) but have not been examined in the field. These ridges are orders of magnitude larger than any wave-built features, modern or raised, in the area. Where best developed, the ridge has a straight to broadly sinuous form, broken only by small streams (Fig. 6). It rings a number of offshore islands, including the Polynia Islands (Hudson *et al.*, 1981), and it forms the core of several other small islands. The ridge (Fig. 7a) is up to 50 m wide and crests up to 14 m asl from a base 0.5 to 6 m asl. It lies between the modern shore and hundreds of metres inland, depending on the local coast gradient (Taylor and Hodgson, 1991). Double ridges are obvious at two locations. An almost unbroken ridge rings the Polynia Islands at an elevation of 4 m; an older, discontinuous ridge lies 5-8 m asl (Fig. 7b). In contrast, two ridges parallel each other several hundred metres apart at the same elevation, at the edge of a large delta near M'Clintock Point, Prince Patrick Island (Fig. 5).

Observations of sea ice actively modifying ridges at the present shoreline and examination of sedimentary structures within ridges that lie inland suggest that sea ice pressure is the principal building force. Inshore floating ice is forced landward by winds and mobile pack ice and possibly upward by 'tidal jacking' of inshore waters during the passage of storms across the Arctic Ocean (Kozo and Togerson, 1988; Kozo and Eppler, 1992). When this occurs the ice either grounds just offshore, buckles and forms large ice pileups, or more commonly the ice is deflected upward at the shoreline pushing with it any thawed sediment that it contacts. The resultant ridge builds upward and landward through repeated thin accumulations of ice thrust sediment. Therefore the large size of the ridges observed along the Arctic ocean coasts of Prince Patrick and Brock islands suggest that they are best developed during a stable or slightly rising sea level. Detailed discussions of the mechanics of sea ice pileup and rideup are discussed by Kovacs and Sodhi (1980) and Reimnitz *et al.* (1990). Relative sea level at the time of ridge formation would have to be at least 1.0 to 1.5 m above the base of the ridge to allow sea ice to float onshore. For example, at Cape Leopold M'Clintock where the coastal gradient is very low, relative sea level at the time of ridge formation would have been 5 m asl or higher.

Normal wave-built features in the region are very small and easily erased by sea ice, wind, fluvial and slope processes; therefore, the ridge provides the only regional indicator of paleoshorelines. On northern Prince Patrick and Brock islands the ridge lies up to 300 m inland (Fig. 8) but it lies progressively closer to the shore farther south until by Discovery Point it coincides with the present shoreline. Here it is being modified by sea ice.

EVIDENCE OF SEA LEVEL CHANGE

BROCK ISLAND

On the southeast coast of the island a faint marine washing limit on frost-shattered bedrock was observed at one site 16-17 m asl, whereas poorly-formed or preserved beach ridges are present below this, particularly at 11 m. A raised delta (11 m asl) in a misfit valley in the east centre of the island was built by drainage from a former island-centre ice cap. This is the only unequivocal glaciomarine landform found on the westernmost islands. A single ridge is conspicuous around much of the island on coasts of all aspects except southeast-facing, from several metres to 1.5 km inland (Fig. 5). Ridge top elevations are commonly 5 to 8 m, exceptionally 9 m. There is very limited evidence of recent submergence, such as drowned modern channels on some deltas. One river examined on the east coast was tidal to 1 km inland, between banks cut into an older (Holocene) delta (site 8, Fig. 3).

Shell samples collected from the surface of bedrock and beach material, and shell and plant material excavated from stream cutbanks, are listed in Table I and are shown on Figures 3 and 9a. The oldest shells recovered from the island, at 30 m asl (site 1), dated 38 590 ± 1340 BP (GSC-381) and may have been transported by a regional ice sheet (Fyles *in* Lowdon *et al.*, 1967). One of three shell fragments found at 17 m asl, at the faint washing limit (site 2a), yielded an AMS age of 27 860 ± 210 BP (TO-3561). It is unknown whether this sample records the related sea level or whether it was glacier transported. An age of 14 600 ± 340 BP (GSC-5511), was obtained by conventional radiocarbon dating for shell fragments found 11 m asl (at site 2b), downslope from the 17 m sample. This may be the age of all the fragments at site 2b, in which case it is the oldest 'post-Late Wisconsinan' shell sample from the western archipelago. However, the presence of old shells upslope cautions that mixing may have occurred. Shell fragments at 9 m asl, 3 km away (site 4), yielded an age of 10 580 ± 260 BP (GSC-352). The oldest clearly finite age shells, yielding an age of 10 700 ± 120 BP (GSC-5148, site 3) were collected 1 m asl, however the former relative sea level is unknown. In the vicinity, shells that locally carpet the surface of probable beach deposits (6.5 m asl) yielded an age of 10 000 ± 90 BP (GSC-5150, site 5). Allochtonous terrestrial moss in silty sand strata exposed in the same cutbank as the site 3 shells, but 500 m seawards,

TABLE I

Radiocarbon ages from westernmost Queen Elizabeth Islands[1]

Site (Fig. 3)	14C age (years BP)[2]	$\sigma^{13}C$	Laboratory No. Collector No.	Material	Location	Elevation/ related sea level (m)	Geological environment	Comments	Collector	References
Brock Island										
1	38 590 ± 1340		**GSC-381** FG-64-202c	Marine shells: *Hiatella arctica*.and unid. sp.	NE Brock Island (89D/14) 77°58.5'N, 114°03'W	30 m	Shells in inclined 1 m sand stratum between sandstone and gravelly sand (Tertiary?)	Glacial ice-thrust moraine?	J.G. Fyles, 1964	Lowdon *et al.*, 1967
2a	27 860 ± 210	0.0‰	**TO-3561** HCA-92-15.8.2b	Marine shell fragment: *Hiatella arctica*?	S. Brock Island (89D/10) 77°44.7'N, 113°14'W	17 m	Rare shell fragments among granules, pebbles	Beach deposit?	D.A. Hodgson, J.R. Devaney, 1992	-
2b	14 600 ± 340	+2.4‰	**GSC-5511** HCA-92-15.8.2c	Marine shell fragments: *Hiatella arctica*?	S. Brock Island (89D/10) 77°44.7'N, 113°14'W	11 m	Rare shell fragments among granules, pebbles	Beach deposit	D.A. Hodgson, J.R. Devaney, 1992	-
3	10 700 ± 120	-0.2‰	**GSC-5148** HCA-90-13.7.4	Marine shells: *Hiatella arctica*	E Brock Island (89D/15) 77°54.0'N, 113°55.0'W	1 m/ >6 m	Rare shells in 1-2 cm stony stratum over 30 m length of 6 m high exposure of stratified sand	Below terrace (>6 m asl) 500 m inland from GSC-5181	D.A. Hodgson, 1990	-
4	10 580 ± 260		**GSC-352** FG-64-203b	Marine shells: *Hiatella arctica*	S Brock Island (89D/10) 77°43.5'N, 113°55'W	9 m/ ≥ 9 m	Shell fragments on pebble beach	Highest beach 17 m asl	J.G. Fyles, 1964	Lowdon *et al.*, 1967
5	10 000 ± 90	+0.7‰	**GSC-5150** HCA-90-13.7.5	Marine shells: *Hiatella arctica*	NE Brock Island (89D/15) 77°55.7'N, 113°55.0'W	6.5 m/ >6.5 m	Abundant shells in beach gravel and silt over rock ledge	Highest beaches <10 m asl	D.A. Hodgson, 1990	-
6a	8830 ± 90	-25.1‰	**GSC-5175** HCA-90-14.7.4	Plant material	S Brock Island (89D/11) 77°43.5'N, 114°20.0'W	2 m/ >5.5 m	Organic mats in mottled reduced silt; below 4 m marine sediment that includes TO-2292	Deltaic?	D.A. Hodgson, 1990	-
6b	6650 ± 60	0‰	**TO-2292** HCA-90-14.7.4	Marine shells: *Macoma* sp.	As GSC-5175	3.75/ >5.5 m	Rare shells (paired) in stratified silty sand; overlies GSC-5175	Deltaic?; overlain by >2 m sediment	D.A. Hodgson, 1990	-
7	5830 ± 130	-24.7‰	**GSC-5109** HCA-90-12.7.5	Plant material	W Brock Island (89D/14) 77°49.5'N, 114°42.0'W	3 m/ ≥3 m	Organic strata above intertidal silty sand; overlain?? by sea ice-built ridge cresting 6.5 m asl	Maximum age of ridge?; possibly ridge material slumped over older organic material	R.B. Taylor and D.A. Hodgson, 1990	-
8	5310 ± 70	-24.3‰	**GSC-5181** HCA-90-13.7.3	Compressed moss	E Brock Island (89D/15) 77°54.5'N, 113°54.0'W	2 m/ >4 m?	Moss mat to 1 cm thick over 30 m length of 4 m high exposure of stratified silty sand in terrace. Moss 2 m asl	Allochtonous. Probably waterlaid into sea ≥4 m	D.A. Hodgson, 1990	-
9	3650 ± 130		**GSC-323** FG-64-202d	Marine shells: *Hiatella arctica*	NE Brock Island (89D/14) 77°58.5'N, 114°03.0'W	6 m/ <6 m	Shell fragments on sea ice-pushed ridge	Raised by ice push?	J.G. Fyles, 1964	Lowdon *et al.*, 1967
Fitzwilliam Owen and Eight Bears islands										
10	10 100 ±150		**GSC-1123**	Marine shells: *Hiatella arctica*	Fitzwilliam Owen Island (89D/2) 77°07.5'N, 113°45'W	20 m/ ≥20 m	Whole shells and fragments in layer between sandy silt and clay	Shells widespread to 25 m asl	M Kuc, 1968	Kuc, 1971a; Lowdon *et al.*, 1971
11	7850 ± 140	-22.8‰	**GSC-1171**	Driftwood log: *Picea* or *Larix*, probably *Larix* sp.; id. R.J. Mott	Fitzwilliam Owen Island (89D/2) 77°07.5'N, 113°45'W	10 m/ ≥10 m	Upright log in marine silt and clay; on flat at foot of steep slope	Highest driftwood on island; possibly moved downslope	M Kuc, 1968	Blake, 1972; Kuc, 1971a; Lowdon *et al.*, 1971
12	2690 ±130		**GSC-326** FG-64-43c	Marine shells: *Astarte borealis*, *Hiatella arctica*, *and Mya truncata*	SW corner of Eight Bears Island (89D/2) 77°06'N, 113°28'W	12 m <12 m	In black clay sea ice-pushed ridge		J.G. Fyles, 1964	McNeely, 1989
Prince Patrick Island										
Terrestrial plant material										
13a	8910 ± 160		**GSC-473** FG-64-217b	Plant detritus, unidentified	Tullett Point, Prince Patrick Island (99A/10) 76°44'N, 121°11'W	1.5 m/ <1.5 m	15 cm thick layer in sea ice-built ridge 1.5 m asl (*not* below SL as reported by McNeely, 1989)	Maximum age of ridge. Organics possibly underlie ridge, or were emplaced by recent ice push	J.G. Fyles, 1964	McNeely, 1989

14	8460 ± 150		**GSC-364** FG-64-241a	Moss peat	3 km SE of Mould Bay station, Prince Patrick Island (89B/4) 76°13.7'N, 119°17'W	10 m/ <7 m	At 2.8 m depth, base of gullied peat over silt	Minimum age of 7 m sea level	J.G. Fyles, 1964	Kuc, 1971b; McNeely, 1989
15	7090 ± 150		**GSC-854**	Organic detritus	NE Satellite Bay, Prince Patrick Island (89C/8) 77°23.5'N, 116°35'W	3.5 m/ <5 m	2 m below surface of elongate pingo; buried by melt of underlying ice wedge	Postdates growth of pingo which developed when sea level lower than present	A Pissart, 1966	Pissart, 1967; Lowdon and Blake, 1968
16a	2940 ± 60	-25‰	**TO-1559** HCA-89-14.7.2-145	*Drepanocladus* moss (id. L. Ovenden)	2 km S of Mould Bay station, Prince Patrick Island (89B/4) 76°13.5'N, 119°19.5'W	Surface 2.5 m/ <1 m	At 172 cm depth in borehole in river terrace	Minimum age of 1 m sea level	D.A. Hodgson, 1989	-
16b	2480 ± 60	-25‰	**TO-2289** HCA-89-14.7.2-15	*Drepanocladus* moss (id. L. Ovenden)	2 km S of Mould Bay station, Prince Patrick Island (89B/4) 76°13.5'N, 119°19.5'W	Surface 2.5 m/ <2 m	At 42 cm depth in borehole in river terrace	140 cm peat accumulation in 500 years	D.A. Hodgson, 1989	-
17	580 ± 110	-26.1‰	**GSC-5501** HCA-92-17.8.2c	Moss	W. Dyer Bay, Prince Patrick Island (98H/15) 75°59'N, 122°105'W	2.4 m	Mosses in subhorizontal stratum along 100 m of coastal bluff under sea ice-built ridge	Tundra surface that predates ridge	D.A. Hodgson and R.B. Taylor, 1992	-
Whalebone										
18	3050 ± 130		**GSC-361** FG-64-220a	Bowhead whale vertebra; 'organic' fraction	21 km NE of Discovery Point, Prince Patrick Island (89C/4) 77°10.2'N, 119°27'W	3 m	Bones on pebbly sand 3 m high sea ice-built ridge, 60 m inland	Minimum age of ridge	J.G. Fyles, 1964	McNeely, 1989
19	2820 ± 130		**GSC-362** FG-64-234b	Bowhead whale jaw; 'organic' fraction	Cape Andreasen, Prince Patrick Island (89C/6) 77°21.5'N, 118°48'W	2.5 m	On moss covered surface 15 m inland	Net emergence since 2.8 BP	J.G. Fyles, 1964	McNeely, 1989
13b	1110 ± 130		**GSC-355** FG-64-217d	Bowhead whale baleen	Tullett Point, Prince Patrick Island (99A/10) 76°44'N, 121°11'W	4.5 m/ <4 m	On crest and faces of sea ice-built ridge being reworked by modern ice	Contemporaneous with or younger than ridge	J.G. Fyles, 1964	Dyck et al., 1966
13c	980 ± 140		**GSC-488** FG-64-217c	Bowhead whale ear-bone; collagen fraction	As GSC-355.	As GSC-355	As GSC-355	As GSC-355. The dense bone provides the most reliable date from the 3 fractions	As GSC-355	As GSC-355
13d	930 ± 130		**GSC-489** FG-64-217e	Bowhead whale limb bone; collagen fraction	As GSC-355	As GSC-355	AS GSC-355	As GSC-355	As GSC-355	As GSC-355
Marine shells										
20	11 660 ± 370		**GSC-354** FG-64-13a	Marine shells: *Hiatella arctica*	SW corner of peninsula, 9 km NE of Domville Pt., Prince Patrick Island (98H/16) 75°57'N, 120°59'W	3-6 m	Shell fragments on surface of sandstone rubble beaches		J.G. Fyles, 1964	McNeely, 1989
21	11 160 ± 150		**GSC-260** FG-64-27a	Marine shells: *Hiatella arctica*	2 km upriver, 15 km NW of Wilkie Point, Prince Patrick Island (89B/7) 76°21.0'N, 117°48'W	10 m/ >24 m	Stony sand and silt with abundant shells below planar sand and silt beds; below reported 30 m delta terrace	Highest clearly marine feature on Prince Patrick I. Remeasured section top 24 m asl, delta surface 26 m	J.G. Fyles, 1964	Lowdon *et al.*, 1967
22	11 100 ± 110	+1.61‰	**GSC-5539** HCA-92-14.8.9	Marine shells: *Hiatella arctica*	2 km upriver, 7 km NW of Wilkie Point, Prince Patrick Island (89B/7) 76°17.5.0'N, 117°34'W	7 m ≥8 m	Abundant shells in granular deltaic deposit		D.A. Hodgson and R.B. Taylor, 1992	-
23	10 600 ± 110	+1.2‰	**GSC-5170** HCA-90-9.7.2	Marine shells: *Hiatella arctica*	5 km SW of Cape Hemphill, Prince Patrick Island (89A/13) 76°55.5'N, 115°59.0'W	11.5 m/ >14 m	Abundant shells in river cut in deltaic clayey silt and sand	Overlying terrace 14 m asl, highest delta 16 m	D.A. Hodgson, 1990	-
24	320 ± 150		**GSC-474**	Marine shells: *Buccinum* sp.	Offshore from Mould Bay station, Prince Patrick Island (89B/4) 76°14'N, 119°23'W	10 to 24 m below sea level	Dredged alive	Reservoir effect	S.D. MacDonald (CMN), 1952	Blake, 1988

[1]Locations, elevations and comments for some samples have been revised using original or new data and differ from published data

[2]GSC dates: $\sigma^{13}C$ base given where age corrected for isotopic fractionation; error represents 95% probability

TO (IsoTrace) dates: all ages corrected for isotopic fractionation to a base of $\sigma^{13}C$ = -25‰; additionally for marine shells a marine reservoir correction of 410 years is applied, equivalent to a fractionation correction to a base of $\sigma^{13}C$ = -0‰; error represents 68.3% probability

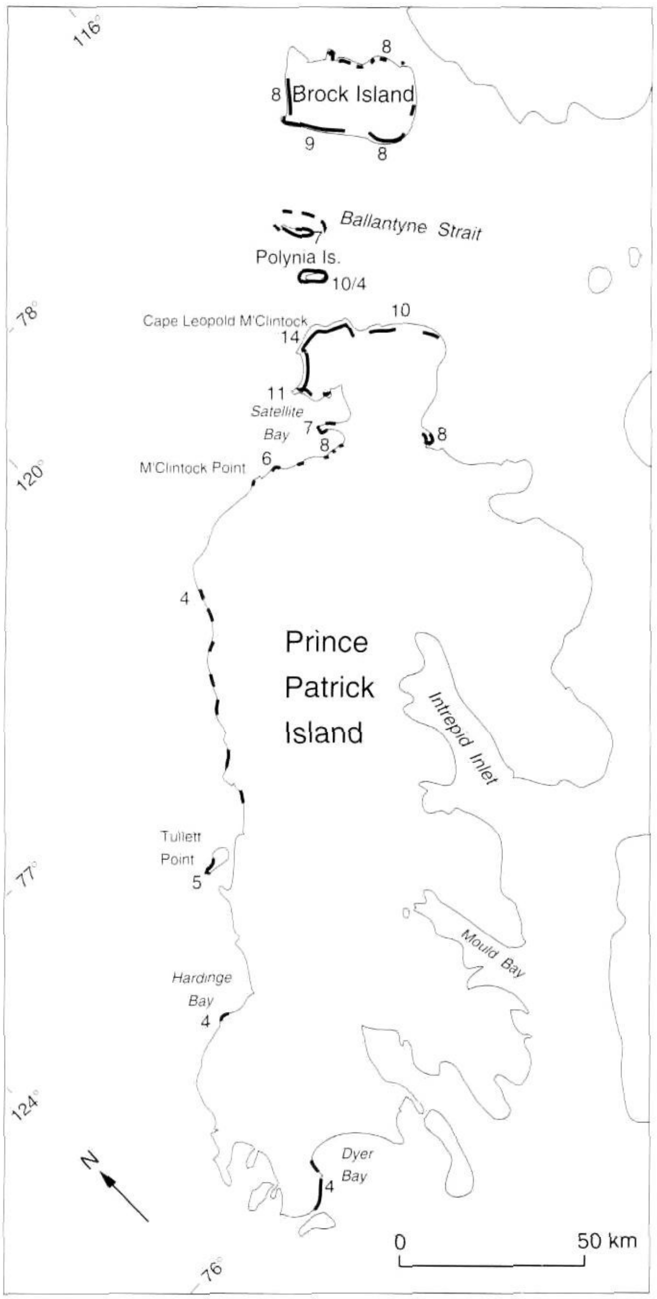

FIGURE 5. A 3-5 m high ridge of sediment built by the sea ice thrusting onshore forms a unique shoreline marker along the Arctic Ocean and adjacent channels. In the south and central part of the region the ridge forms part of the present shoreline but in the north (with the exception of Polynia Islands) the ridge lies as much as 400 m inland. Ridge crest elevations indicated on the figure were measured with altimeter above high tide. Aerial and ground photos of the ridge are shown on Figures 6 and 7.

Une crête de sédiments de 3 à 5 m de haut édifée par la poussée de la glace de mer sur le rivage constitue un repère le long du rivage de l'océan Arctique et des chenaux adjacents. Dans les parties sud et centrale de la région, la crête se confond au rivage actuel, mais au nord (les îles Polynia, exceptées). la crête se situe jusqu'à 400 m à l'intérieur. Les altitudes données sur la figure ont été mesurées au-dessus du niveau de la mer avec un altimètre. Photographies de la crête aux figures 6 et 7.

dated 5310 ± 70 BP (GSC-5181, site 8). The convolute bedding of the frozen sediments containing the moss suggests subaqueous deposition (below sea level) and subsequent dewatering. Near the southern extremity of Brock Island, mats of plant material (together with shells) dated 8830 ± 90 BP (GSC-5175, site 6). These were collected 2 m below shelly silty sand dated 6650 ± 60 BP (TO-2292), in beds probably of deltaic origin. The section top is 5.5 m asl, which is therefore the minimum related sea level at 6.5 ka. A lens of compressed moss dated 5830 ± 130 BP (GSC-5109, site 7) was found 3 m asl in silty sand (fluvial or marine) exposed in a cut through the seaward slope of the ridge 300 m inland on the west coast (Fig. 8). The allochtonous moss was deposited in sediment just upslope from and adjacent to well sorted sands interpreted as upper foreshore, *i.e.* swash, deposits (Taylor and Hodgson, 1991). It has not been possible to establish a clear relationship between the age of the sample and the time of the ridging.

ISLANDS IN BALLANTYNE STRAIT

Polynia Islands — The two main islands at the west end of the strait are dominated by two ridges (Figs. 7b, 8). The outer ridge nearly encircles the islands and is separated from the inner ridge by a lagoon of variable width. The outer ridge crests at 3-5 m asl and the inner, less continuous, ridge crests at 5-8 m asl. No dateable material related to marine events was found on these islands, hence the age of the two shore ridges could not be determined. The seaward slope of the outer ridge is subject to intermittent ice ride-up, however, frost cracks on its crest have not been disturbed for many years. A comparison between 1960 and 1990 photography shows no major changes in the ridge form or position. The smooth, linear morphology of the outer ridge suggests that while some parts were the product of sea ice shearing as floes moved through Ballantyne Strait, most of it was the product of sea ice ride-up.

Fitzwilliam Owen and Eight Bears islands — These two low islands at the southeast end of Ballantyne Strait exhibit few raised marine landforrns. Nevertheless, driftwood and marine shells were found below the marine limit (at least 25 m asl, Kuc, 1971a; Fig. 9b). On Fitzwilliam Owen Island, shells collected from the surface 20 m asl dated 10 100 ± 150 BP (GSC-1123, site 10) and a driftwood log from 10 m asl dated 7850 ± 140 BP (GSC-1171, site 11). Shells on Eight Bears Island, in an isolated ice-pushed mound, 12 m asl dated 2690 ± 130 yr (GSC-326, site 12); these shells and their matrix appeared little disturbed even though they almost certainly were thrust above their related sea level. Older ridges were not observed on either island.

PRINCE PATRICK ISLAND

Northwest and west coasts
(Ballantyne Strait to Hardinge Bay)

Evidence of a former sea level above the ridge was found only at the head of Satellite Bay, the single deep embayment on the west side of the island. Fluvial terraces at Satellite Bay, first reported by Pissart (1967), terminate as deltas 12-15 m asl; a lower series of deltas lie 5-6 m asl. On the west coast, terraces common in middle and upper portions of river courses, have been destroyed near the coast by braid deltas, and cannot be related to former sea levels. Thus a continuum of delta morphologies exists along the west coast, ranging from completely drowned river mouths in the south (described in the next section) to the emerged delta terraces around Satellite Bay, despite the similarity of river basins along this coast. Smooth arcuate shaped delta fronts near site 18 (Fig. 3) suggest that marine and fluvial processes are in equilibrium here, and that this may be a 'hinge' zone where sediment discharge and sea level have been more stable (J.P.M. Syvitski, pers. com., 1992).

The dominant raised marine landform in the northwest is the ridge, which is best developed between Satellite Bay and the northeast limit of the Beaufort Formation, from where it continues on poorly consolidated Mesozoic rocks to the east end of Ballantyne Strait (Fig. 5). The ridge lies several hundred metres inland, has a base about 4 m asl and crests 5-14 m asl, forming the height of land around Cape Leopold M'Clintock (Figs. 5, 6). Around Satellite Bay, the ridge is discontinuous, the crest is lower (4-10 m), and it commonly lies within 100 m of the present shore. On the west coast from M'Clintock Point to Tullett Point, the ridge becomes less continuous, crest heights decrease to 4 m or less and the ridge becomes progressively closer to the present shore. Rare sections of the ridge are present south of Tullett Point; they also crest 4 m asl. Only north of M'Clintock Point do faint beach ridges occur, between present sea level and the base of the ridge.

Raised marine shells were not found on Arctic Ocean shores of Prince Patrick Island (although molluscs do grow in inshore waters: shells were observed in upthrust sea ice and in piles left onshore by sea birds). The most significant organic deposit is a detrital plant layer, dated 8910 ± 160 BP

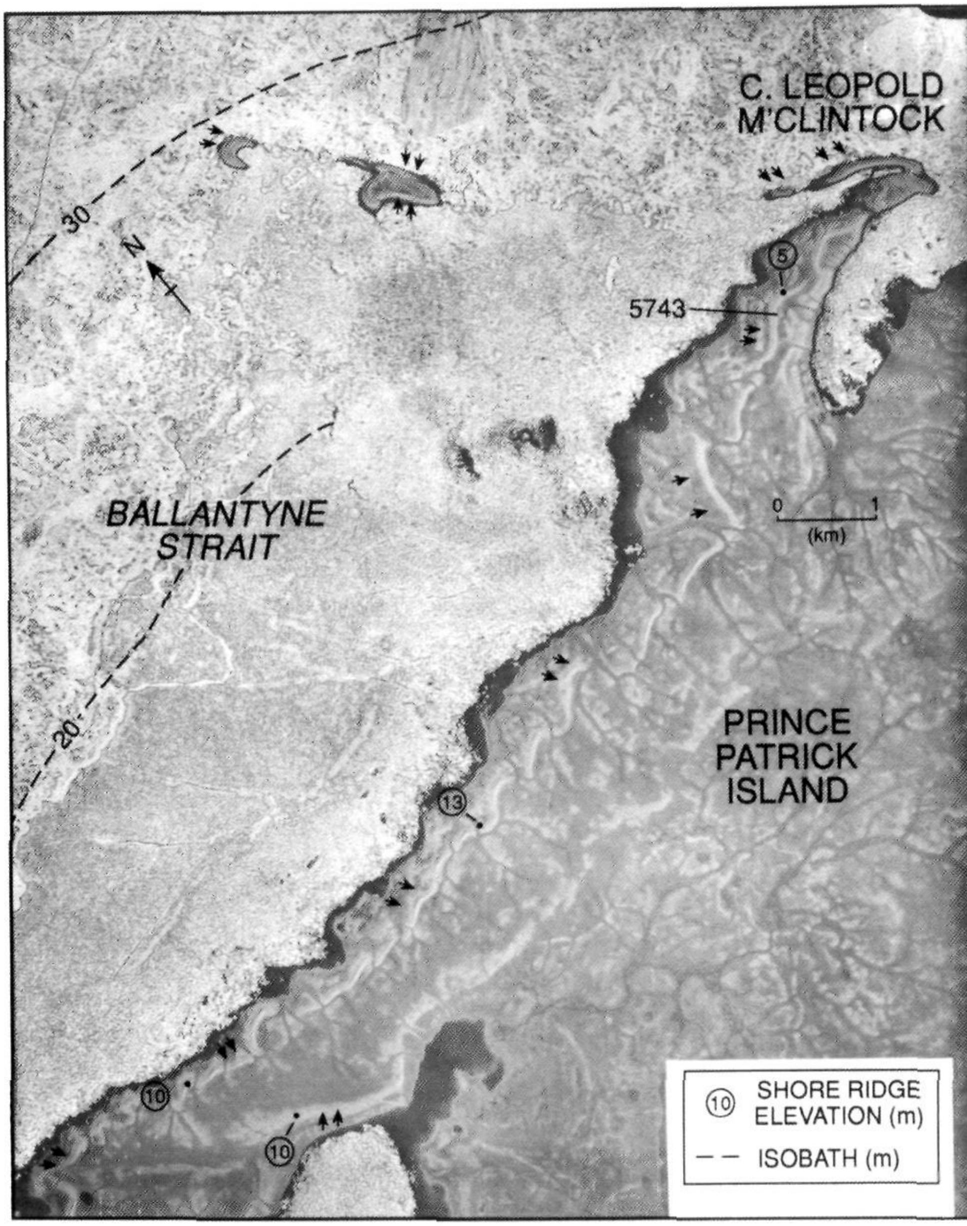

FIGURE 6. Aerial view of northern Prince Patrick Island showing the position and elevation of the sea ice-built ridge (arrows) in relation to present shoreline. The ridge is also visible on the offshore islands. The cross sectional profile at site 5743 is shown on Figure 8 (photo A17138-2, 1960, National Air Photo Library, Ottawa).

Vue aérienne du nord de l'île du Prince-Patrick montrant l'emplacement et l'altitude de la crête édifiée par la glace de mer (flèches) par rapport au rivage actuel. La crête est également visible sur les îles du large. Le profil transversal du site 5743 est donné à la figure 8 (photo A17138-2, 1960, photothèque nationale, Ottawa).

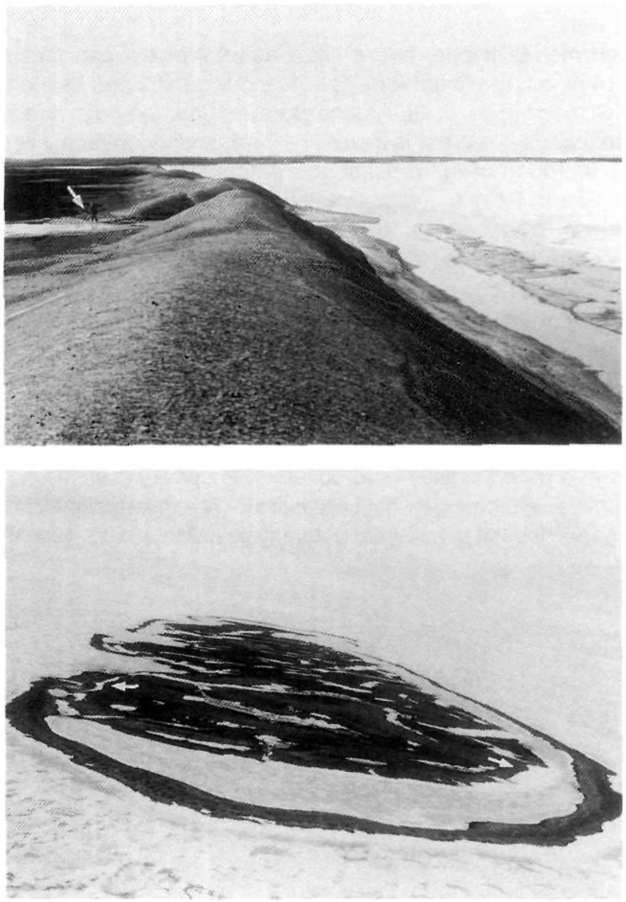

FIGURE 7. a) Ground view of the sea ice-built ridge at the present shoreline on west-central Prince Patrick Island (person indicated by arrow). b) Aerial view (July, 1990) of the sand and gravel ridge that encircles the southern of the two Polynia Islands, Ballantyne Strait. The island is 1 km wide. The ridge at the present shoreline is 30-50 m wide, and extends to 4 m asl. A second less continuous ridge lies at 5-8 m asl (arrows).

a) Vue du sol de la crête édifiée par la glace de mer sur le rivage actuel, dans le centre-ouest de l'île du Prince-Patrick (personnage pointé par la flèche). b) vue aérienne (juillet 1990) de la crête de sable et de gravier qui ceinture l'île méridionale des deux îles Polynia, dans le détroit de Ballantyne. L'île mesure 1 km de largeur. La crête située sur le rivage actuel mesure 30-50 m de largeur et jusqu'à 4 m au-dessus du niveau de la mer. Une deuxième crête discontinue se situe à 5-8 m au-dessus du niveau de la mer (flèches).

(GSC-473, site 13), within the ridge at Tullett Point. If this represents the former land surface under the ridge, then sea level was lower than 2 m (the collection height) at 8.9 ka (Fig. 9c). However, the thickness of the detrital layer (15 cm) in what is a very sparsely vegetated region suggests that it may have been redeposited in a nearshore or deltaic deposit below related sea level (*cf.* Brock Island sites 6,7,8), indicating a sea level higher than present at 8.9 ka. A third option is that the deposit was thrust from an unknown level during construction of the ridge. Whatever the origin, the 8910 BP date provides a maximum age for the ridge. A minimum age for the ridge is provided by whales thrust onto segments of the ridge near Discovery Point and at Tullett Point (Fig. 3). Skeletons dated 3050 ± 130 BP (GSC-361, site 18) and 980 ± 140 BP (GSC-488, site 13) respectively. Whalebone dated 2820 ± 130 BP (GSC-362, site 19) was found 15 m inland at Cape Andreason (Fig. 3). Finally, organic (plant?) material, dated 7090 ± 150 BP (GSC-854, site 15), was collected by A. Pissart at an elevation of 3.5 m at the northeast corner of Satellite Bay. This sample does not seem to be of value in sea level studies because surrounding strata have been moved vertically by the growth and decay of a pingo (Pissart, 1967).

Southwest (Hardinge to Dyer bays)

The plan form of the present shore changes from smooth, wide delta plains with discontinuous barrier islands north of Hardinge Bay, to a very intricate pattern of partially submerged narrow spits, barriers, shoals, delta channels and breached lakes in the southwest. This can be partly explained by the larger rivers that occur farther north depositing more sediment on the shore, whereas the more complex shoreline in Hardinge and Bloxsome bays may only reflect the extremely low cross shore gradient in the south. However, during calm weather in August 1992 it was common to find beaches, barriers and adjacent tundra surfaces ankle deep in sea water. In contrast, southeast-facing Dyer Bay shores are rimmed by a sharp crested ridge at the edge of the eroded tundra surface. Moss dated 580 ± 110 BP (GSC-5501, site 17), exposed beneath the seaward face of the ridge, indicates recent ridge-building here.

Southeast (Walker Inlet to Mould Bay)

Only a trace of raised marine deposits was found, despite widespread ground traverses. Terraces are common in major

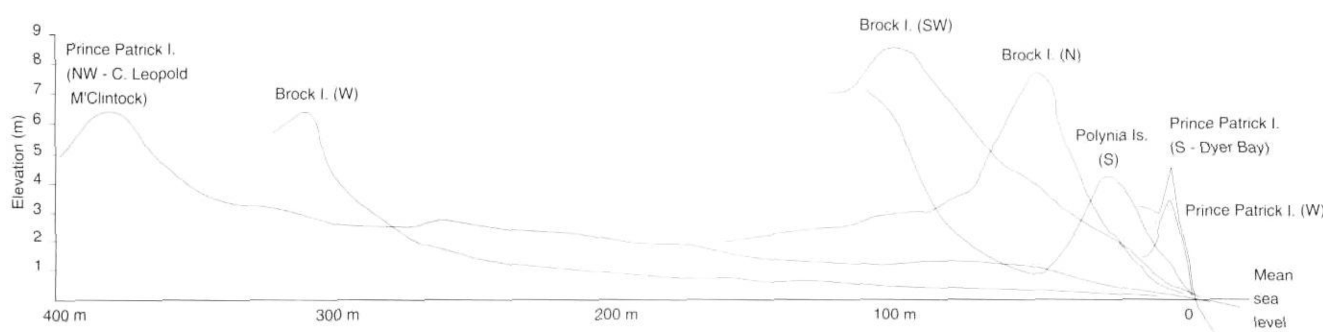

FIGURE 8. Cross-sectional profiles of sea-built ridges surveyed on Brock, Polynia and Prince Patrick islands. The Prince Patrick Island (W and S) ridges are presently being modified by sea ice.

Profils transversaux des crêtes édifiées par la glace marine tels qu'observés dans les îles Brock et du Prince-Patrick. Les crêtes de l'île du Prince-Patrick (W et S) sont en voie de transformation.

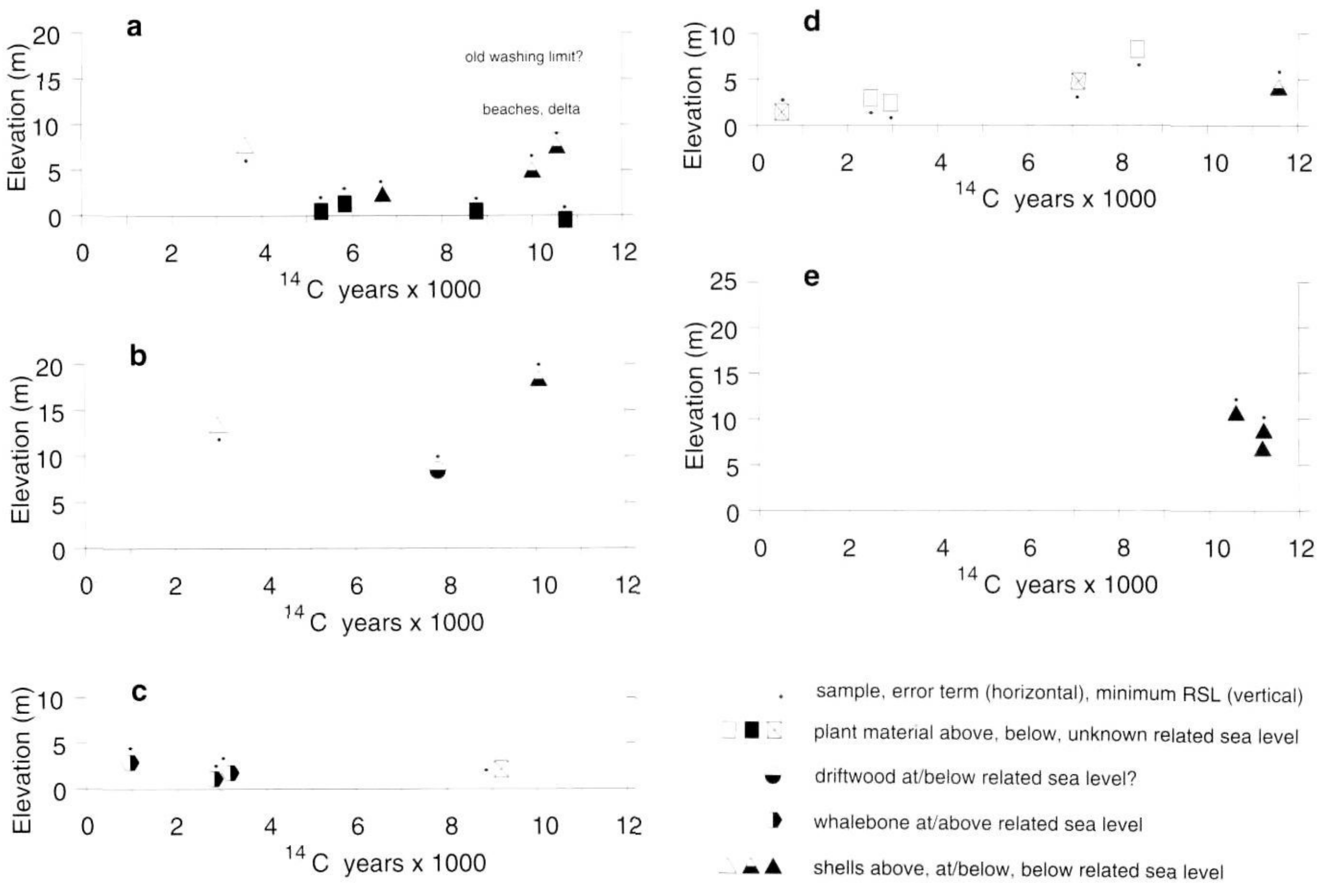

FIGURE 9. Radiocarbon age/elevation for samples collected on (a) Brock Island, (b) Fitzwilliam Owen and Eight Bears islands, (c) west Prince Patrick Island, (d) southeast Prince Patrick Island and (e) northwest Prince Patrick Island (constructed from data in Table I).

Datations au radiocarbone et altitude des échantillons recueillis (a) à l'île Brock, (b) aux îles Fitzwilliam Owen et Eight Bears, (c) à l'ouest de l'île du Prince-Patrick, (d) au sud-est de l'île du Prince-Patrick et (e) au nord-est de l'île du Prince-Patrick (à partir des données du tabl. I).

valleys, especially around upper Walker Inlet, however, they appear to run to present sea level, or are truncated well inland by modern channels (except at the head of Mould Bay, which is discussed with Intrepid Inlet). Pocket peat bogs are unusually abundant in the hilly terrain around Mould Bay weather station (site 14, Fig. 3) and their basal dates indicate when sea level could have last stood as high as the altitude of the sample (Fig. 9d). Moss peat from 7 m asl at the base of a 2.8 m thick deposit yielded an age of 8460 ± 150 BP (GSC-364, site 14; Kuc, 1971b). Moss peat collected 0.8 m asl at the base of 1.7 m of peat dated 2940 ± 60 BP (TO-1559, site 16); peat 42 cm below the surface of the same deposit dated 2480 ± 60 BP (TO-2289). The single collection of shells along this coast yielded one of the oldest finite ages from these islands, 11 660 ± 370 BP (GSC-354, site 20, Fig. 3). The shells were found at 3-6 m asl on the surface of poorly-developed beaches along a narrow, seasonally ice-free strait (unusual in this area) between Dyer Bay and Walker Inlet. Drowned river mouths and the presence of modern beaches built on top of backshore colluvium provide the only evidence of recent submergence in the area.

Northeast (Intrepid Inlet to Ballantyne Strait)

Degraded delta surfaces between 23 and 40 m asl occur on the western shores of Intrepid Inlet and Green Bay, at the head of Mould Bay and southeast of Intrepid Inlet. They are not necessarily all of the same age or origin. The highest terraces on the west side of Intrepid Inlet possibly were associated with the margin of an inland ice cap. Organic deposits were found only southeast of Intrepid Inlet. The delta at site 21 (Fig. 3) is inexplicably large for its drainage basin, though no glacial influence was observed. Shells taken here from massive deltaic beds below a 24 m terrace yielded an age of 11 160 ± 150 BP (GSC-260). Equally abundant shells a further 10 km to the southeast, at 7 m asl, dated 11 100 ± 110 BP (GSC-5539, site 22). The most extensive terraces run east from close to the central divide of the island to 8 m asl at Landing Lake (northwest Mould Bay), 9, 14 and 18 m asl at Green Bay, and 10, 13, 15, and 18 m asl farther north on the west side of Intrepid Inlet. Terraces left by prograding deltas on easternmost coasts of Prince Patrick Island fall from 16-18 m asl to present sea level. Shells were found in abundance at several locations on the latter coast, including a sample dated 10 600 ± 110 BP (GSC-5170, site 23) under a 14 m delta terrace (Fig. 9e). Low-level beaches and possible wave-cut notches occur up to 5 m asl, except in Moore Bay where they are 8-9 m. The only evidence of coastal drowning is a series of submerged narrow barrier beaches along the east shore of Intrepid Inlet.

REMAINDER OF THE ARCTIC COASTAL PLAIN

Meighen Island — No raised shorelines were observed at the north end of the island though intermittent segments of a massive ridge (ice-built?) are present from the modern shore to 100 m inland. At the south end, 50 km away, strandlines rise to 20-30 m asl; shells at 12 m asl dated 8610 ± 190 BP (GSC-619, Blake, 1970). A further 25 km south, beaches rise to at least 40 m asl, and possibly to 50-60 m asl on the Fay Islands (Fig. 1). Offshore, a change in sponge zonation on the Arctic margin was interpreted to be the result of a related sea level change (RSL) of 40-60 m during the past 1000 years (Van Wagoner *et al.*,1989). There is no evidence on land of such a dramatic change, nor is it likely to have taken place, given present knowledge of glacioisostasy and eustasy.

Northern Ellef Ringnes Island — Raised shorelines have not been observed on airphotos of the northern peninsula, underlain by Beaufort Formation sands, but beaches were reported to 40 m asl on Cretaceous rocks of the east coast (St-Onge, 1965). Rare segments of broad ridges, cresting 3-8 m asl, occur at and just inland from the modern shore, on the east and west shores of the northem peninsula. Airphotos indicate that they are the product of sea ice thrusting onshore, like those on Prince Patrick Island. The scarcity of ridges is attributed to the shallow inshore waters and a decrease in sea ice pressures because of the position of Ellef Ringnes Island relative to the Beaufort Gyre in the Arctic Ocean.

Borden Island — Clear indicators of sea level change were not observed on airphotos of the island; possible submergence of the east coast is indicated by embayments closed by coastal barriers. On the western peninsula, a ridge intermittently parallels the modern shore, in places several hundred metres inland. Offshore from Jenness Island, a ridge appears to be partly submerged.

Western Banks Island — The entire west coast was transgressed to about 20 m asl by the Meek Point Sea, argued by Vincent (1992) to predate the Late Wisconsinan. No record has been recognized of later raised shorelines, however, there are abundant indicators of recent submergence. For example, Fyles *in* Thorsteinsson and Tozer (1962, p. 14) observed that "The large rivers enter the Beaufort Sea through wide swampy deltas which barely fill the mouths of valleys. Estuaries at the mouths of small rivers carrying less sediment have clearly been drowned by the sea". One or more ridges (wave built or ice built?) are common offshore from shallow embayments.

Western mainland — Along the Beaufort Sea coast there is no evidence for sea levels higher than present since the Late Wisconsinan (Forbes, 1980); shores generally have been submerging for the last 20 000 years, except, perhaps, for an interval during passage of a glacially-induced forebulge (Hill *et al.*, 1985).

DISCUSSION OF SEA LEVEL CHANGES

The emergence data presented above is combined into two plots: Figure 10i covers the Arctic Coastal Plain of Prince Patrick and Brock islands (Fig. 1), and immediately adjacent lowland within 35 km of the Arctic Ocean shore; Figure 10ii includes eastern Prince Patrick Island and adjacent small islands 50-90 km from Arctic Ocean shores.

West (Fig. 10i) — There are indicators of higher sea levels of unknown age to at least 17 m on Brock Island, though no evidence has been found of a preceding stillstand or transgression. Sea levels relative to the present (RSL) are reasonably well documented for Brock Island between 11 and 5 ka (Fig. 9a). During this time, there was a small overall fall in RSL from 9 to 5 m asl. However, insufficient observations were made to preclude the possibility that sea level fluctuated 2-3 m, or remained stable for periods, within the overall trend. It is possible that Brock Island is now submerging. Evidence of sea levels to 12 or 15 m was observed on northwest Prince Patrick Island; again, age is unknown. On the west coast, the only raised marine material found was whalebone younger than 3 ka which possibly was elevated by sea ice. Modern landforms indicate a relatively stable west-central coast, whereas on the southwest coast of Prince Patrick Island, all indicators point to a coast submerging and the sea transgressing at present. Emergence of southeast Prince Patrick Island continued from at least 11.6 BP (elevation > 6 m), to no more than 1 m asl at 2.9 BP (Fig. 9d). Over the last 3 ka, either sea level remained stable or it fell below the present level and rose again recently. If the ridge in the vicinity of Cape Leopold M'Clintock was built when sea level was at least 5 m asl, as suggested above, then the ridge must be middle Holocene or older.

East (Fig. 10ii) — The sparse data suggests an emergence curve (Fig. 10ii) with a form more closely approaching exponential curves found elsewhere in the Queen Elizabeth Islands (Hodgson, 1989) than the pattern on the Arctic Coastal Plain. Sea level may have fallen 20 m between 11 and 8 ka (this assumes driftwood at site 11 on Fitzwilliam Owen Island has not moved downslope). Shells from the 24 m delta at site 21, which was aggrading at 11.2 ka, together with the 10.6 ka shells from site 23, similarly suggest relatively rapid emergence of eastern Prince Patrick Island around 11 ka (Fig. 9e). Emergence of Fitzwilliam Owen and Eight Bears islands likely has continued to the present.

FACTORS IN SEA LEVEL CHANGE

Sea level emergence curves are regarded as proxies for rates of crustal uplift for much of the Arctic Archipelago during the Holocene. This is acceptable because the other component of emergence is eustatic change, which has been small relative to the recently initiated and sizeable glacial rebound. Additionally, as England (1992) pointed out, over the last two decades the methods of geophysical modelling have tended to discourage Quaternary scientists from integrating a specific amount of eustatic sea level rise with postglacial emergence in order to calculate crustal uplift. However, in the westernmost archipelago, where emergence has been relatively small throughout the last 10 ka, the amount of eustatic sea level rise becomes very significant, nearly matching uplift. A eustatic rise of 35 m occurred over northern latitudes between 10 and 7.5 ka according to Tushingham and Peltier's (1991) Ice-3G model (radiocarbon years, converted from sidereal years; *cf.* Tushingham, 1991a, b). A further 15 m

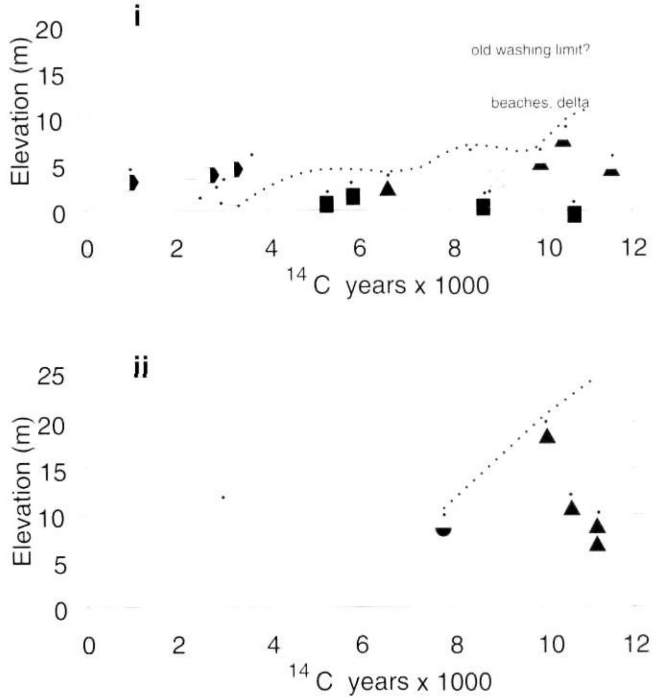

FIGURE 10. Composite sea level data (from Fig. 9) for (i) Brock Island and the Arctic Coastal Plain of Prince Patrick Island (from Figs. 9a, c and d) and (ii) the eastern shores of Prince Patrick, and Fitzwilliam Owen and Eight Bear islands (from Figs. 9b and e). Same symbols as Figure 9, plus dotted lines shows minimum sea level indicated by samples (this is not necessarily a sea level curve).

Données composites du niveau marin (tirées de la fig. 9) pour (i) l'île Brock et la plaine côtière de l'île du Prince-Patrick (fig. 9A,C et d) et (ii) les côtes est de l'île du Prince-Patrick et des îles Fitzwilliam Owen et Eight Bear (fig. 9b et e). Les symboles sont les mêmes qu'à la figure 9; les tiretés représente le niveau minimal indiqué par les échantillons (il ne s'agit pas nécessairement d'une courbe du niveau marin).

rise has occurred since 7.5 ka. Consequently the 10 m emergence on western Prince Patrick Island, added to 50 m of eustatic sea level rise, yields a net uplift of 60 m since 10 ka BP. The 20 m of emergence in the east coupled to 50 m of eustatic change yields uplift of 70 m since 10 ka.

In order to explain 60-70 m of Holocene uplift in the westernmost archipelago, two factors (glacioisostasy and tectonics) need to be considered. As emphasized by England (1992) these factors are not mutually exclusive. The major ice load on the southern Arctic Archipelago, responsible for most glacial rebound, was the Late Wisconsinan Laurentide Ice Sheet (Dyke and Dredge, 1989; Vincent, 1989). The northern margin of this ice sheet reached the southwest extremity of Melville Island before 11.7 ka, more likely as a floating glacier tongue rather than grounded ice, and overlapped southern Melville Island as a grounded ice sheet prior to 11.8 ka and again as an ice shelf *ca.* 10 ka (Hodgson *et al.*, 1984; Hodgson, in press) or possibly 11.7 ka (Dyke, 1987). Thus the floating margin of the ice sheet was at least 100 km southeast of southern Prince Patrick Island and 300 km from Brock Island, and the grounded margin even more distant. Assuming a 200 km wide peripheral depression (Walcott, 1970), little or no uplift resulting from the last advance of the Laurentide Ice Sheet should be expected over northern Prince Patrick or Brock islands.

Within the Queen Elizabeth Islands, most recent studies accept discrete ice caps over the larger island groups (England, 1976; Dyke and Prest, 1987). A Late Wisconsinan ice cap was inferred by Hodgson (1992) to have covered much of western Melville Island before retreat prior to 10 ka. This ice cap was responsible for all or part of 70 m of emergence recorded in the centre of that island, and probably for at least 30 m on the northwest shore. Hence, with 50 m of eustatic rise since 10 ka, the local ice cap produced up to 120 m of uplift. The margin of this ice cap was 50 km from eastern Prince Patrick Island at its closest, and 150 km from the Arctic Ocean shore.

The eastward rise in marine limit and the eastward reduction of its age (by several thousand years from western to central islands) formed part of the data used by Blake (1970) to hypothesize that the Innuitian Ice Sheet covered the Queen Elizabeth Islands during the last glaciation. This ice sheet was portrayed by Prest (1969) and Denton and Hughes (1981). Emergence attributed to it was modelled by Tushingham (1991a), who also weighed the possibility of a thin cold-based ice sheet covering only the eastern archipelago. RSL curves calculated by Tushingham (1991a) for both hypothetical ice sheets showed submergence of Hazen Strait (Fig. 1) since at least 12 ka, even though the contradictory emergence data from those islands was incorporated in the models. Tushingham's models are inappropriate for the western islands because, as England *et al.* (1991) pointed out, local ice caps were omitted on the western islands in the thin-ice model, and both models incorrectly assume deglaciation started around 15 ka. This date is many thousands of years older than the timing shown by the radiocarbon record from the archipelago, and hence calculations include a larger eustatic sea level rise than is warranted. If the emergence of the westernmost archipelago is entirely glacioisostatic, then local ice caps (*e.g.* Melville Island, Hodgson, 1992) must have occurred on Prince Patrick and possibly neighbouring islands. It is curious that of many late Pleistocene and Holocene sea level curves assembled from elsewhere in the world by Pirazzoli (1991), only plots from western Norway (formerly under the margin of the Fennoscandian Ice Sheet) resemble the shallow gradient of the RSL curves shown on Figure 10i (*i.e.* slow emergence continuing through much of the Holocene).

Vertical tectonic movement of individual islands of the western archipelago, along Tertiary faults that remained active into the Quaternary, was hypothesized by Tozer and Thorsteinsson (1964). A possible tectonic component in emergence of the northeast archipelago was discussed by England (1987, 1992), and for the central archipelago by Dyke *et al.* (1991) and Dyke (1993). On a local scale, on central Prince Patrick Island, Tozer and Thorsteinsson (1964) and Harrison *et al.* (1988) showed numerous lineations crossing the Beaufort Formation (Fig. 4). Several of these linear features have topographic expression in the form of scarps to 10 m high that are considered by the authors of this paper to be fault scarps. The faults do not displace fluvial terraces

(Fyles, 1965) and thus may not have been active during the Holocene.

On a regional scale, assuming the ridge synchronous, then it has been delevelled since formation by tectonic or glacioisostatic forces. The maximum upwarping of about 5 m is centered over northern Prince Patrick Island/Ballantyne Strait with an axis orthogonal to most depictions of isobases, and to the alignment of the continental shelf and Arctic Coastal Plain.

CLIMATIC IMPLICATIONS OF SHORELINE FEATURES

Raised marine shells with radiocarbon ages of 10-12 ka are locally abundant on Brock and Prince Patrick islands, as well as adjacent areas including western Melville Island (Hodgson, 1992) and Lougheed Island (Hodgson, 1981). Species are typical for Pleistocene and Holocene deposits in the archipelago: *Hiatella arctica, Mya truncata, Macoma calcarea* and *Portlandia arctica*. Shells of Holocene age are far less common, presumably indicating that conditions for shell growth were more favourable in the latest Pleistocene. These conditions might have included warmer water and (or) a reduced sea ice cover. On the other hand, meltwater spreading as overflow from the disintegrating Laurentide Ice Sheet in Parry Channel could have evacuated summer sea ice and carried nutrients northwest, in a reversal of the present direction of interisland flow (Dyke and Morris, 1990; Andrews *et al.*, 1993). Sedimentological and micropaleontological analyses of cores from the continental shelf to the northeast indicate greatly increased open water around 10 ka, relative to the subsequent Holocene, which Hein and Mudie (1991) suggest coincides with retreat of glaciers on and around Axel Heiberg Island.

Whale skeletons scattered along the northwest coast of Prince Patrick Island (dated 3, 2.8 and 1 ka) indicate either more open inshore waters at these times or a more stable Arctic Ocean lead system (Smith and Rigby, 1981). However, this period coincides with a decrease in whale abundance in the central Arctic islands because of greater ice cover attributed to a strong Neoglacial cooling (Dyke and Morris, 1990). The general absence of wave-built shore features, when the slow rate of emergence would favour their development (Andrews, 1970), points to a year-round sea ice cover through most of the Holocene.

The continuity and size of the ridge on the Arctic Coastal Plain suggests sea ice to be the main building force. Where the ridge intersects the present shoreline it is being modified again by sea ice ride-up. The absence of other ice-built ridges on these shores for the intervening period suggests changing sea ice dynamics. Possibly there has been a renewal of the atmospheric conditions, *e.g.* passage of storms, that controlled the formation of megaleads and ice motion along the western archipelago when the original ridge was formed.

CONCLUSIONS

Sea level curves developed for the study area broadly confirm that in the latest Pleistocene, crustal uplift in the westernmost Arctic Archipelago marginally exceeded eustatic sea level rise, in a response to poorly understood local, regional or continental glacier retreat and (or) tectonic forces. A subsequent sea level fall of 10 m or less through the Holocene reflects an unusual balance between eustasy and uplift. The overall decline in RSL has clearly been replaced by a rising sea level in the southwest and probably also on the rest of the Arctic Coastal Plain of Prince Patrick and Brock islands. Drowned beaches, barriers, flooded lakes and river mouths occur along southwestern shores of Prince Patrick Island. Submergence possibly is occurring farther east as well. Thus, in addition to the decline of isobases towards the Arctic Ocean shown by earlier models, there is evidence of a strong component of dip to the southwest, orthogonal to the conventional pattern. The sparsity of dateable material could mask minor trangressions during the Holocene.

A prominent ice-built ridge, probably middle Holocene or older in age, is viewed as the product of increased movement of inshore Arctic Ocean sea ice onto west facing shores and through the adjacent channels. The timing possibly coincided with a climatic change, or with a short period of stable sea level or transgression in the middle or early Holocene. Extensive sea ice cover existed throughout most of the Holocene, preventing wave generation and beach development, notwithstanding the slow rate of sea level change.

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