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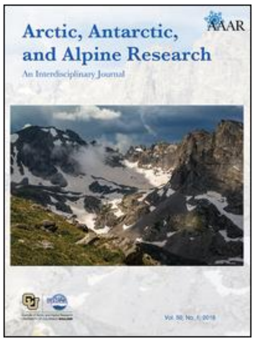

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RELATIVE SEA LEVEL CHRONOLOGY DETERMINED FROM RAISED MARINE SEDIMENTS AND COASTAL ISOLATION BASINS, NORTHEASTERN ELLESMERE ISLAND, ARCTIC CANADA

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ABSTRACT

A new relative sea level curve for the Robeson Channel area contrasts with previously published curves for the area by inferring that rapid emergence may have commenced at ca. 7400 BP, as much as 1200 yr earlier than previously predicted. Subsequently, uplift may have occurred at much lower rates from ca. 6000 BP to present. A comparison of shell dates used for the relative sea level curve and dates on disseminated total organic carbon (TOC) fraction from lacustrine and marine sediments from sediment cores from emerged coastal lakes shows wide discrepancies. Furthermore, several inifinite TOC dates (>27,750 to >40,600 BP) from glaciomarine sediments may imply that the region was ice-free during the last glacial maximum, but the validity of the TOC dates from the sediment cores is questionable due to variable contamination with redeposited detrital organic matter.

INTRODUCTION

Northeastern Ellesmere Island is separated from northwest Greenland by Robeson Channel, in places by as little as 24 km (Figure 1). Thus, it is a critical location for studying past interactions of Greenland and Ellesmere Island ice masses and evaluating models of High Arctic ice extent during the Last Glacial Maximum (LGM, ca. 18,000 BP). According to the "maximum" ice model, the Canadian Arctic Archipelago was covered by the Innuitian Ice Sheet at ca. 18,000 BP, and was confluent with the Laurentide Ice Sheet to the south and the northwest Greenland Ice Sheet over northern Nares Strait (Blake, 1970; Hughes et al., 1977; Denton and Hughes, 1981). Conversely, the "minimum" ice extent model depicts a more limited expansion of highland and plateau ice masses separated by ice-free areas (cf. Dyke and Prest, 1987). In this model interior Ellesmere Island ice, part of the Franklin Ice Complex, expanded only onto the Hazen Plateau and to major fiordheads (England, 1976a, 1983) while northwest Greenland ice expanded into Hall Basin (England, 1985) leaving an ice-free corridor as much as 100 km wide at the glacial maximum. In the isostatic downwarp between the two ice sheets, the "full-glacial sea" (England, 1983) transgressed into coastal lowland basins along Robeson Channel. Resulting marine limit shorelines (at approximately 110 to 120 m asl) date between 8000 and 11,000 BP (England, 1983; Retelle, 1986a). Holocene marine deposits overlie drift of a previous glaciation tentatively associated with the advance of Greenland ice onto Ellesmere Island. The age of this advance was estimated to be ≥80,000 BP (England et al., 1978; Retelle, 1986a).

Cores of lacustrine and marine sediments from the coastal zone in this area serve two purposes. First, a minimum estimate for the duration of marine sedimentation in the ice-free corridor may be established by radiometric dating of the basal portions of marine sediments in the cores. Second, dating of the marine to lacustrine transitions in the cores (cf. Kaland et al., 1984; Svendsen and Mangerud, 1987) allows comparisons to be made with the isostatic uplift chronology determined from studies of radiocarbon-dated raised marine features (England, 1982, 1983; England and Bednarski, 1986).

In this paper, we examine the relative sea level chronology along a section of Robeson Channel on northeastern Ellesmere Island, N.W.T., by comparing radiocarbon dates on shells from raised marine sediments with dates from organic matter and shells in marine-to-lacustrine isolation sequences in sediments obtained by coring in three

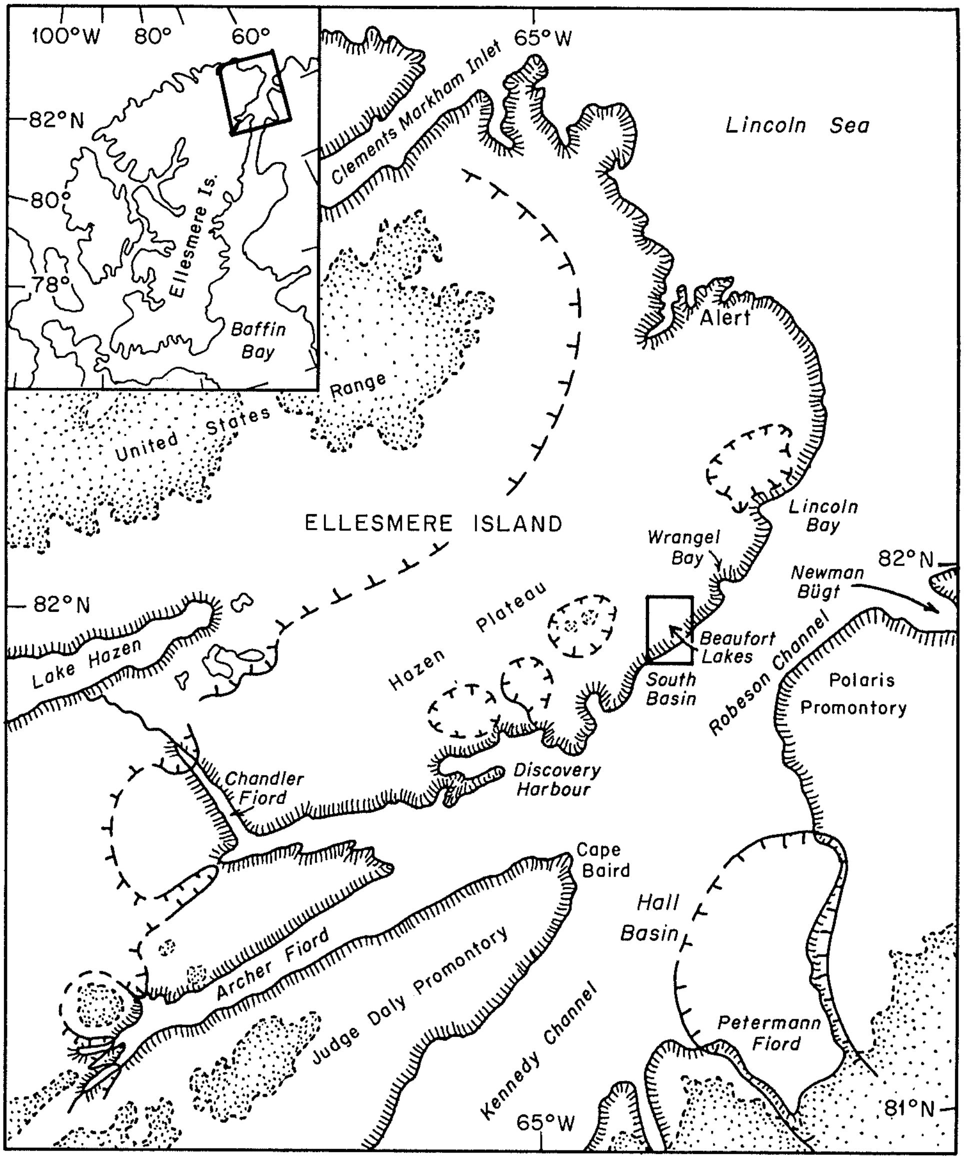

FIGURE 1. Location map of the field area on northeastern Ellesmere Island bordering Robeson Channel. Shaded pattern denotes present glacier ice. Hatchured pattern denotes last glacial ice margins proposed by England (1983).

interconnected lake basins situated below the Holocene marine limit. The primary result of this study is a new relative sea level curve for the Robeson Channel area. The new curve conflicts with the previously published emergence curve for the area (England, 1983) and suggests that sea level may have been as much as 60 m lower at ca. 6000 BP than predicted by the previous study. A second result of the study is a critique of radiocarbon dates on the total organic carbon (TOC) fraction of lake sediments obtained by coring emerged lakes. The TOC fraction of the sediments yielded substantially older dates, relative to shells contained within the sediments and correlative dated raised marine sediments. We demonstrate that the samples from the basin are, in part, contaminated by old carbon and the TOC dates are suspect. However, several samples of marine sediments from the base of the sediment cores yielded infinite ages and imply that the area may have been ice-free during the Last Glacial Maximum.

Field Area

The study area is located on northeastern Ellesmere Island along Robeson Channel (Figure 1). Coastal embayments and fiords in this region are incised into the western edge of the Hazen Plateau. The bedrock of the plateau consists primarily of interbedded calcareous and dolomitic graywacke, siltstone, and shale of the lower Paleozoic Imina Formation (Trettin, 1971). Locally on the plateau, generally flat-lying outliers of Tertiary-age Eureka Sound Formation unconformably overlie the steeply dipping lower Paleozoic rocks. These outliers are nonmarine, poorly lithified sediments and consist principally of conglomerates, sandstones, siltstones, and shales. Coal beds up to 6 m thick have been mapped in this unit at Watercourse Bay, 10 km north of Lady Franklin Bay (Miall, 1982) and up to 3 m thick in Tertiary age sediments near Lake Hazen, approximately 90 km to the west (Christie, 1976).

The dissected plateau upland is a sparsely vegetated xeric environment, where thin, blocky till and felsenmeer mantle the bedrock topography. Interior valleys are floored with glaciofluvial and glaciolacustrine deposits and are more vegetated than the bordering uplands. The lowlands below the marine limit contain fossiliferous marine sediments overlying till and bedrock.

Sediment coring was undertaken at three lakes below the Holocene marine limit (116 m asl) in a coastal embayment along Robeson Channel (Figure 2). The three lakes, informally referred to as Beaufort Lakes 1, 2, and 3, are located at 12, 34, and 39 m asl, respectively. Lakes 2 and 3 appear to have emerged as one lake from the sea; a prominent sill at 40 m asl surrounds the margins of both lakes. One of several terraces, ranging in elevation from 13 to 20 m asl, may have served as the isolation threshold for Lake 1.

The three lakes range in size from approximately 0.5 km in length to a maximum of 1.5 km and are as much as 30 m deep. Lake 2, the farthest inland, is the largest and deepest and receives the major inflow into the basin from two streams that are fed primarily by snowmelt from mid-June to early August. Lake 3 is the smallest and shallowest (10 m) of the three lakes and has no major inlet stream. Lake 1 receives the combined inflow from Lakes 3 and 2.

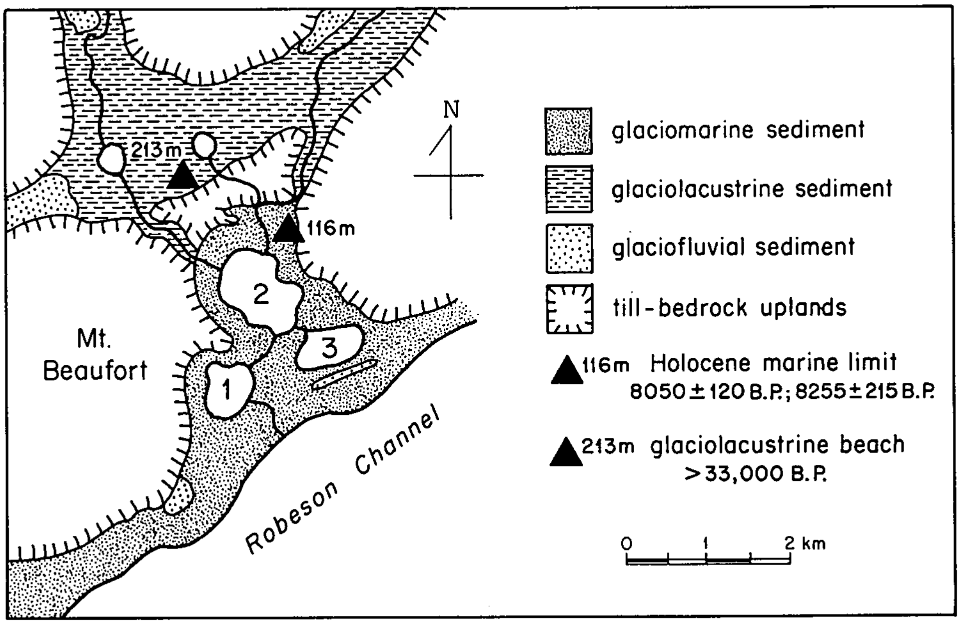

Figure 2. Map of the Beaufort Lakes basin showing surficial geology and location of Lakes 1, 2, and 3 at elevations of 12, 34, and 39 m asl. Triangles show locations of dates on shells at marine limit (116 m asl) and organic material from inland proglacial lake (213 m asl).

METHODS

Cores were removed from the lakes with a modified Livingstone corer driven into the sediment with a chain jack hoist. Consecutive core sections were recovered by repeated drives through the same cased hole. The cores were extruded in the field and wrapped in plastic film and aluminum foil. Wrapped cores were placed in aluminum troughs in insulated core boxes and stored at +4°C.

Samples for radiocarbon dating were cut from the cores in 6- to 7-cm lengths. The outer few millimeters of sediment were trimmed off to eliminate contamination by smearing during coring or extrusion. The total organic carbon (TOC) fraction of the sediment was dated at the University of Saskatchewan and Smithsonian Institution radiocarbon laboratories. Pretreatment of the sediment samples included immersion in HCl to eliminate carbonate and boiling in 2% NaOH. The NaOH-soluble fraction was removed and the fraction insoluble in NaOH was retained for dating.

Shells from raised marine deposits were collected from surface gravels on beaches and from silts below the marine limit. Elevations of the lake basin thresholds were determined by levelling survey. Shoreline and other raised marine deposits were measured with a Paulin microaltimeter and are hereafter noted in meters above sea level. An average of three to five elevation measurements (pressure and temperature corrected) were obtained for each sample station.

Three in situ shells from the core sediments were dated at the National Science Foundation Tandem Accelerator Mass Spectrometer (TAMS) radiocarbon dating facility at the University of Arizona at Tucson and at the University of Toronto Tandem Accelerator Laboratory ("Isotrace"). Samples were pretreated by immersion in HCl (20% leach).

RELATIVE SEA LEVEL HISTORY

The Holocene isostatic emergence chronology for northeastern Ellesmere Island has been studied by England (1976b, 1983) and by England and Bednarski (1986). England (1976a) originally constructed a series of uplift curves that were corrected for eustatic sea level and were similar in form to other "normal" uplift curves for sites in the Canadian Arctic (Andrews, 1968, 1970). However, England (1983) presented a new series of relative sea level (RSL) curves that consist of three segments (Figure 3, dashed curves CB and AL). Segment C of the curves represents a period of stable relative sea level and, by inference, isostatic and eustatic stability when the Greenland and Ellesmere Island ice masses stood at their last glacial limit. Segment B represents initial ice recession with minor isostatic adjustment. During Segment A, rapid emergence occurred at about 2 to 4 m 100 yr^{-1}, as a response to recession of the combined Ellesmere and Greenland ice sheets.

The shape of the curves, and hence timing of emergence periods, varies geographically due to proximity to the dominant load of the Greenland Ice Sheet (curve CB, Figure 3) versus the Ellesmere Island ice mass (curve AL, Figure 3).

In this present study, a new relative sea level curve is presented for the Robeson Channel area (Figure 3, solid line RC). The upper portion of the curve is constrained by radiocarbon dates on shells from raised marine sediments. The portion of the curve below 40 m asl is controlled by three TAMS radiocarbon dates on marine shells from isolation basin sediments. The new Robeson Channel relative sea level curve is compared with the Cape Baird (CB, Figure 3; one of a nest of similar-shaped curves for the area around and south of Beaufort Lakes) and Alert (Al, Figure 3) relative sea level curves presented in England (1983).

Raised Marine Sediments

Raised marine sediments occur in the inlets and valleys of the field area up to the marine limit of 116 m (England, 1983; Retelle, 1986a). The marine limit shoreline is defined by gravelly beach sediments that overlie the till-veneered bedrock of the valley sides in Beaufort Lakes, South Basin, and the outer portions of Wrangel and Lincoln bays (Figure 1) (Retelle, 1986a). In inner Wrangel Bay, an undated delta complex probably graded to the highest Holocene sea level. Inner Lincoln Bay was occupied by plateau ice until after sea level fell from marine limit. After retreat of the plateau lobe, beaches were cut into the ice-proximal faces of kame deltas that built into an inland lake (Retelle, 1986a).

Discontinuous outcrops of fine-grained sediment flank and fill the floors of the inlets and valleys up to marine limit. The silts and fine sands are commonly overlain by a gravel lag that represents an erosional concentrate and in some cases distinct strandlines. Single and paired mollusc shells occur on the surface lag; paired valves are commonly found in growth position within the silt.

Several previously published dates (England, 1983) and four new dates on shells from raised marine deposits define the upper segment of the RSL curve. Glaciomarine silts at 90 to 95 m, that grade upward to a gravelly washing limit at 116 m asl at Beaufort Lakes contain in situ shells dated at 8020 ± 120 (GSC-3041) and 8255 ± 215 BP (S-1990). These dates were interpreted to represent the age of the marine limit along Robeson Channel, equivalent to segment C of the "abnormal" relative sea level curve presented for the area (England, 1983). In outer Lincoln Bay, glaciomarine silts are exposed below 100 m where a poorly defined gravel beach is overrun by solifluted till from the steep slope above. Silts at 91 m contained *Bathyarca glacialis* and *Portlandia arctica* in growth position which dated 8600 ± 90 BP (SI-5551). The sample most likely dates off-shore sedimentation when the sea stood at the marine limit at or above 100 m.

Two shell samples from the South Basin which dated 7390 ± 90 BP (SI-5553) and 7490 ± 70 BP (SI-5554) are from glaciomarine sediments that overlie the "old" till topography. Sample SI-5553 was taken from a gravel beach at 111 m, whereas SI-5554 was a collection of in situ paired valves of *Hiatella arctica, Mya truncata,* and *Portlandia arctica* found in silts at 65 m that are topographically below a gravel beach at 110 m (Table 1).

Two samples from inner Lincoln Bay are different from those cited above. The first collection (*Portlandia arctica*) was recovered from glaciomarine silt overlying ice-contact stratified drift deposited in inner Lincoln Bay from a spillover lobe of plateau ice (Retelle, 1986a). The shells were in growth position in silt at 82 m asl below a gravel beach platform (88 m) cut into the proximal, or ice-contact, face of the delta and dated 7265 ± 215 BP (SI-5552). Secondly, in situ shells from silts at 78 m (below a 90-m gravel beach) in a cirque basin 10 km north of Lincoln Bay dated 7345 ± 75 BP (SI-5550). These sediments overlie a moraine deposited by the same plateau ice cap that spilled over into inner Lincoln Bay. Together, the latter two samples show that the sea was excluded from Lincoln Bay until plateau ice retreated from its maximum extent at ca. 7300 to 7400 BP.

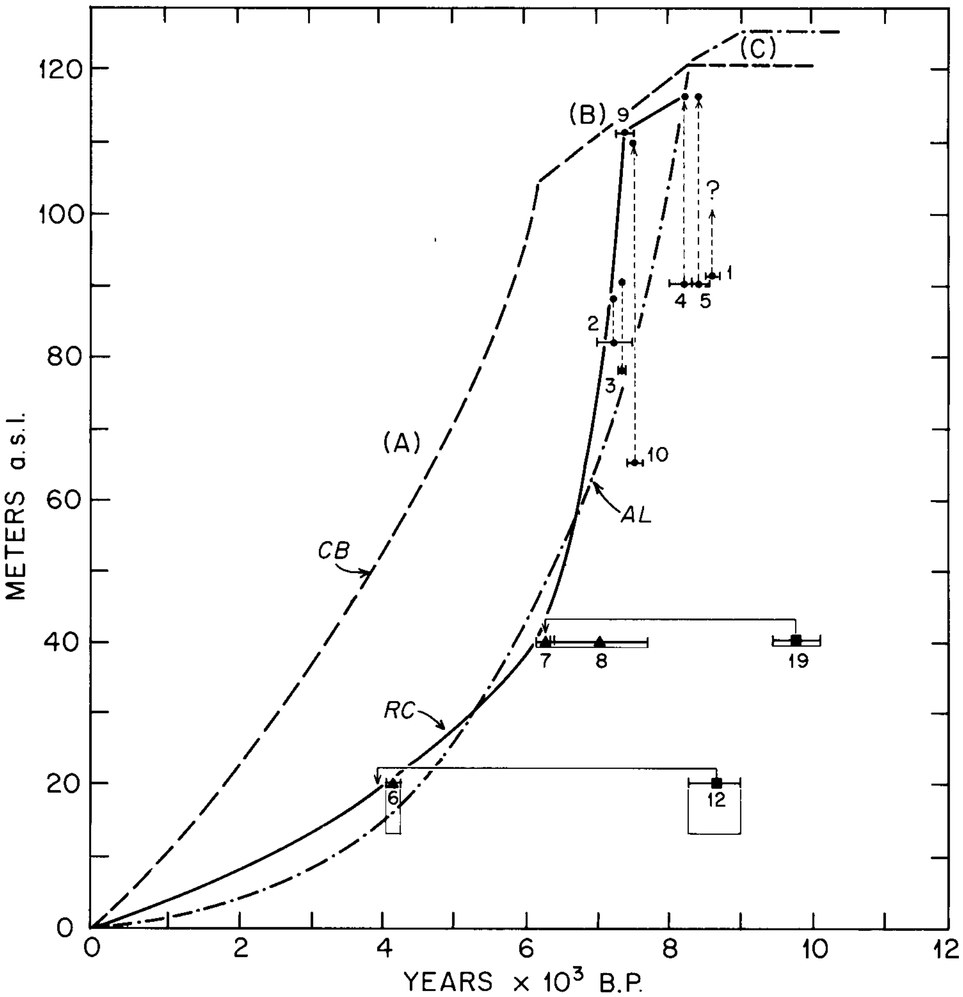

FIGURE 3. Relative sea level curves for northern Ellesmere Island. Revised curve for Robeson Channel area is solid line RC. Dashed lines are Cape Baird curve (CB) and Alert curve (Al) from England (1983). Curve segments (A), (B), and (C) are after England (1983). Radiocarbon dates are numbered as in Tables 1 and 2. Dates on shells from raised marine deposits are solid dots. Solid triangles are TAMS dates on shells from Beaufort Lakes sediment cores. Solid squares are TOC dates from isolation horizons in sediment cores. Rectangles drawn for dates (7, 8, 19, 6, 12) represent elevation range of terraces that may have served as threshold for basin isolation. All dates are quoted with standard deviation of 1 sigma except Geological Survey of Canada (GSC) dates which have 2 sigma. Dashed lines from TOC date to curves represent correction factor applied by subtracting "apparent" surface age of sediment.

Table 1
Radiocarbon dates on shells

Site	Laboratory no.[c]	Material	Age BP	Stratigraphy	Related relative sea level (m)
1. Lincoln Bay	SI-5551	Shells	8600 ± 90	Marine silt, 91 m	≥100
2. Lincoln Bay	SI-5552	Shells	7265 ± 215	Marine silt, 82 m	88
3. Lincoln Bay	SI-5550	Shells	7345 ± 75	Marine silt, 78 m	90
4. Beaufort Lakes[a]	SI-1990	Shells	8255 ± 215	Marine silt, 90 m	≤116
5. Beaufort Lakes[a,b]	GSC-3041	Shells	8450 ± 120	Marine silt, 90 m	≤116
6. Beaufort Lakes[b]	TO-205	1 paired valve	4150 ± 60	Marine silt from core (185 cm)	≥ 20
7. Beaufort Lakes[b]	TO-206	1 paired valve	6280 ± 70	Marine silt from core (210 cm)	≥ 40
8. Beaufort Lakes	AA-656	1 paired valve	7060 ± 670	Marine silt from core (220 cm)	≥ 40
9. South Basin	SI-5553	Shells	7390 ± 90	Beach gravel, 111 m	111
10. South Basin	SI-5554	Shells	7490 ± 70	Marine silt, 65 m	≤110

[a]Previously reported in England (1983).
[b]Shell dates from Geological Survey of Canada and Isotrace Laboratory (University of Toronto) are here normalized to -25‰, similar to other dates which were not corrected.
[c]Laboratory identification (for Tables 1 and 2). SI = Smithsonian Institution; GSC = Geological Survey of Canada; AA = University of Arizona TAMS facility; TO = University of Toronto, Isotrace Accelerator Laboratory; S = University of Saskatchewan, Saskatoon, Canada.

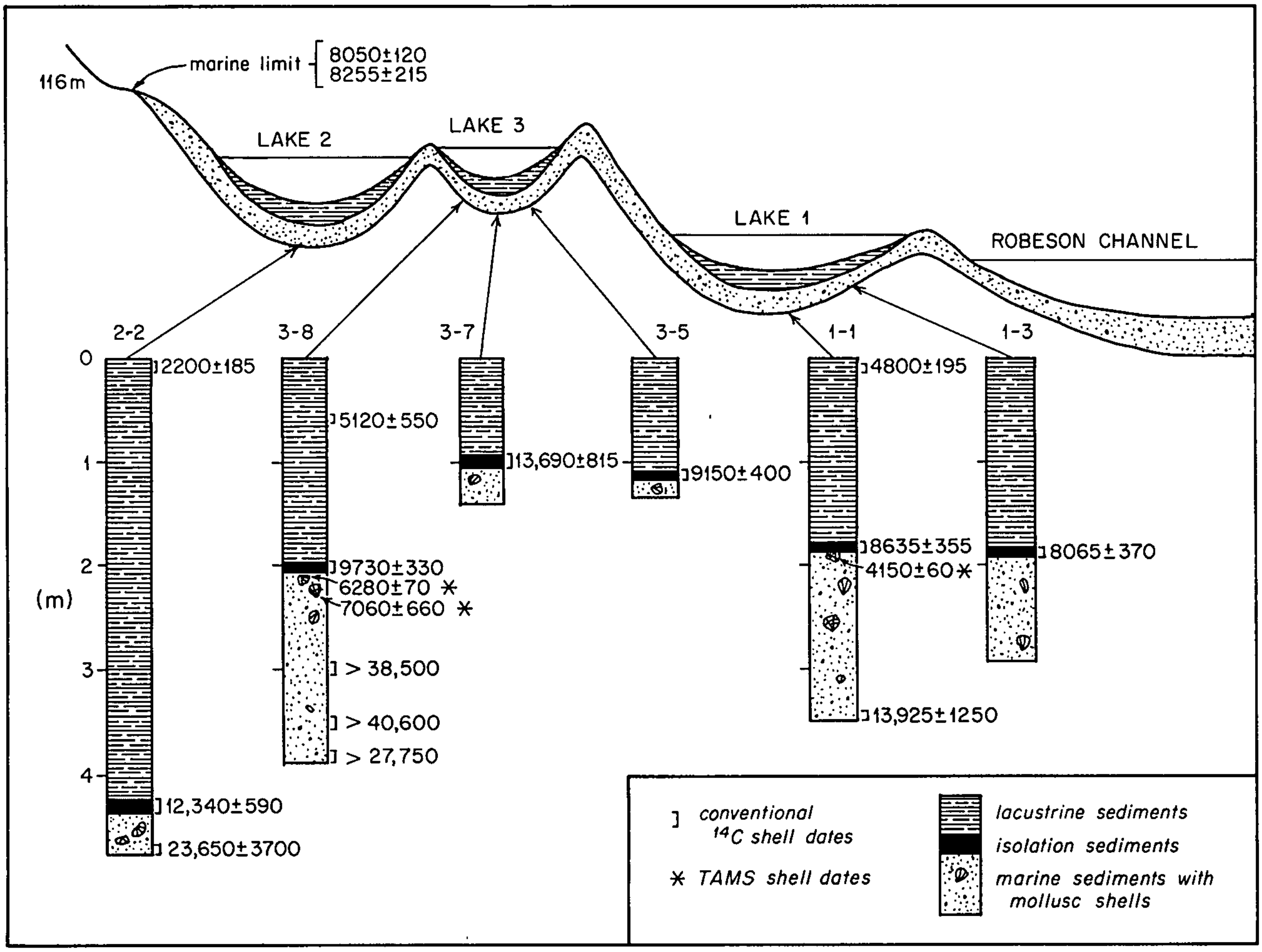

Figure 4. Radiocarbon dates on total organic fraction from sediment cores from Beaufort Lakes. Dates with asterisk in cores 3-8 and 1-1 were done by TAMS method. Dates at 116 m are from shells in raised marine sediments.

TABLE 2

Radiocarbon dates on total organic carbon fraction of sediment from cores recovered from the Beaufort Lakes

Site	Core	Interval (cm)	Lab no.	Material	Age BP	Stratigraphy[a]	Relative sea level (m)
11. Lake 1	1	6– 12	SI-5885	Clayey silt	4800± 195	L	12; ≤20
12.	1	177±183	S-2339	Black sulfidic silt	8635± 355	L-M	>12; ≤20
13.	1	345–350	S-2340	Sandy silt	13925±1250	M	>12
14.	3	182–188	S-2341	Black sulfidic silt	8065± 370	L-M	>12; ≤20
15. Lake 2	2	6– 12	SI-5886	Clayey silt	2200± 185	L	>34
16.	2	426–432	S-2342	Black sulfidic silt	12340± 590	L-M	>34
17.	2	475–480	S-2343	Sandy silt	23650±3700	M	34
18. Lake 3	8	55– 56	S-2345	Organic silt	5120± 550	L	>39
19.	8	198–205	S-2346	Black sulfidic silt	9730± 330	L-M	40
20.	8	297–305	SI-	Sandy silt	>38,500	M	>39
21.	8	350–355	SI-	Sandy silt	>40,600	M	>39
22.	8	391–395	S-2347	Sandy silt	>27,500	M	>39
23.	7	95–101	S-2344	Black sulfidic silt	13690± 815	L-M	40
24.	5	122–128	SI-5888	Black sulfidic silt	9150± 400	L-M	40

[a]L = lake sediment; L-M = lacustrine-marine transition; M = marine sediment.

ISOLATION BASIN SEDIMENTS

Each of the three lakes in the Beaufort Lakes embayment contains a sequence of glaciomarine sediments overlain by lacustrine sediments (Figure 4). The two units are separated by a distinctive isolation contact that marks the isostatic emergence of the basin from the sea (Retelle, 1986b).

Glaciomarine sediments in the cores from each basin are mottled and massive, sandy to clayey silt with occasional dropstones and marine molluscs. The nearshore glaciomarine sediments were deposited in the coastal embayment in water depths less than 100 m.

The glaciomarine sediments are overlain by a thin (4 to 6 cm) unit of laminated to massive black sulfidic silt which separates them from the lacustrine sediments above (Figure 4). This transitional facies represents either estuarine conditions with occasional exchange of fresh and marine waters during emergence of the basin, or possibly meromictic conditions as the threshold of the basin prevented the outflow of marine water (Retelle, 1986b).

The upper, or lacustrine unit in the cores is a well-laminated clayey silt. These sediments, as well as the transition and marine units, are relatively poor in organic material and consist primarily of quartz, feldspar, calcite, and phyllosilicates.

DATING OF SEDIMENTS

Radiocarbon dates were obtained on the total organic carbon (TOC) fraction from all three units recovered in the sediment cores (Table 1, Figure 4). Although the radiocarbon dates are internally consistent within the cores, i.e., they increase in age downcore, several conflicts are apparent. First, the isolation contact in three cores from Lake 3 yielded two distinctly different ages for the emergence of the basin. In cores 3-8 and 3-5, dates of 9730±330 (S-2346) and 9150±400 BP (SI-5888) conflict with a date of 13,690±815 (S-2344) from core 3-7. Moreover, the isolation contact in Lake 2 (core 2-2), which presumably emerged simultaneously with Lake 3, dated 12,340±590 BP (S-2342). Second, the entire suite of TOC dates from the isolation contacts of the lakes, whose basin thresholds are at 12 to 40 m asl, are at least as old as dated shells from the marine limit (116 m) at Beaufort Lakes which dated between 8000 and 8200 BP resulting in a disparity between the TOC dates from the sediment cores and the emergence curves derived from shell dates from raised marine sediments (Figure 3).

To test whether the TOC samples were contaminated by "old" carbon, several samples near the tops of the cores were dated (Table 2, Figure 4). The 6 to 12 cm levels in cores from Lakes 1 and 2 gave ages of 4800±195 (SI-5885) and 2200±185 BP (SI-5886), respectively. (An additional surface sediment sample [0 to 6 cm] was submitted from core 3-5, but it contained insufficient carbon for analysis.) In core 3-8, at 55 to 56 cm, fibrous organic matter dated 5120±550 BP (S-2345).

Age-depth diagrams for cores from the three lakes show that the apparent sedimentation rate decreases abruptly in the upper few centimeters of the cores (Figure 5). However, if the apparent ages of the surface sediment are applied as calibration factors to the isolation zone TOC dates (i.e., by subtracting the TOC date of the surface sediments from the TOC date of the isolation zone sediments) the corrected ages for Lakes 1 and 3 plot close to the revised relative sea level curve for the area (Figure 3). Thus, it is suggested that the TOC dates are affected, to varying extents, by contamination with old carbon.

The possible sources of contamination include inert dissolved carbon from the local calcareous bedrock (hard-water effect) and redeposited detrital organic matter from surficial sediments of various ages (cf. Nelson and Carter, 1987). Preliminary pollen analyses indicated that the percentage of exotic grains in the core sediments ranges from 15 to 40% (Backman, pers. comm., 1984). The assemblage includes spruce and alder (species commonly attributed in arctic regions to airborne transport from treeline (Short and Nichols, 1977) plus several temperate hardwood species originally thought to be laboratory contaminants. Subsequently, pollen analysis was conducted on organic-rich beach sediments (dated >33,000 BP; S-2182) from the upland proglacial lake 5 km to the west of Lake 2 (Retelle, 1986a). The assemblage from this site (Table 3) includes primarily temperate hardwoods that have also been found in outcrops of Tertiary-age coal at various locations on northeastern Ellesmere Island (Christie, 1964). Additionally, microscopic examination of lake and marine sediments showed that charcoal comprises a significant proportion of the detrital fraction (Feyling-Hanssen, pers. comm., 1984). On this basis, we believe that the TOC data are affected by old (isotopically dead) carbon.

Three valves of the mollusc *Portlandia arctica* were

TABLE 3

Pollen analysis from upland proglacial lake shore organic material, upper Beaufort Lakes basin

	%	% local	% exotic
Local			
Salix	4.2	7.6	–
Ericaceae	8.6	15.6	–
Ranunculaceae	1.6	2.9	–
Gramineae	12.0	21.8	–
Trilete spore	3.4	6.2	–
Monolete spore	25.4	45.9	–
		100.0	
Exotic			
Juglans	4.4	–	11.6
Castanea	4.2	–	10.9
Picea	8.1	–	21.2
Pinus	8.4	–	21.9
Betula	3.6	–	9.6
Alnus	5.2	–	13.7
Corylus	3.1	–	8.2
Carya	1.0	–	2.7
	100.0	100.0	

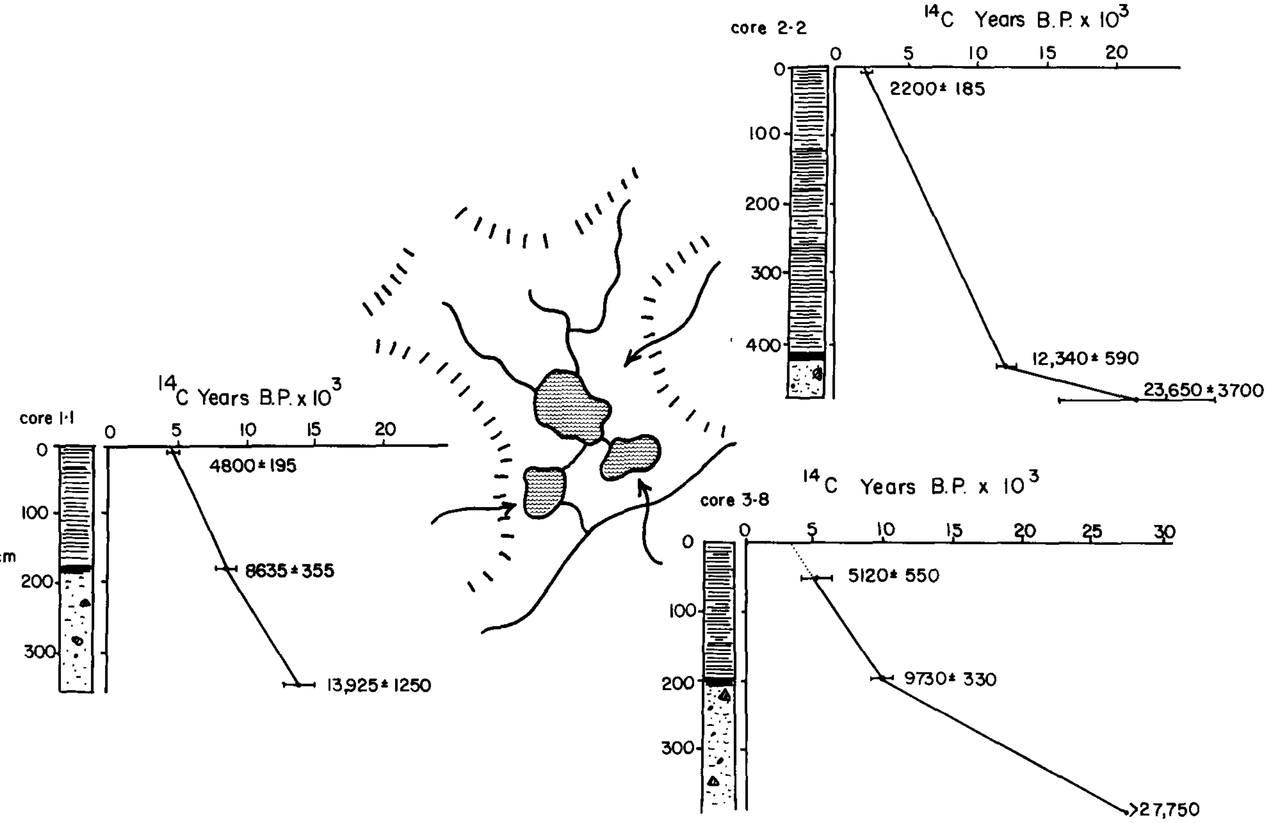

FIGURE 5. Age-depth plot of dates on total organic fraction from sediment cores from Lakes 1, 2, and 3. Apparent surface ages of sediments are determined by extrapolating from uppermost TOC date in cores from each lake giving ages for surface sediment of 4700, 2200, and 3500 BP for Lakes 1, 2, and 3, respectively.

dated by the tandem accelerator mass spectroscopy (TAMS) method to provide an independent check on the TOC dates. The samples selected from the cores for dating were paired valves in growth position that retained periostracum. The mollusc shells were sampled as close as possible to the marine-to-lacustrine sediment contact.

Results of the TAMS dating are shown in Figures 3 and 4 and Table 1. Two shells were dated from core 3-8. A paired valve from the 220-cm level dated 7060 ± 670 BP (AA-656), whereas another paired valve at the 210-cm level dated 6280 ± 70 BP (TO-206). These compare with a date on the TOC fraction of sediments from the isolation horizon (198 to200 cm) of 9730 ± 330 BP. In core 1-1 (Figure 4), a shell at 185 cm dated 4150 ± 60 (TO-205), whereas the TOC date from the associated isolation contact at 177 to 183 cm was 8635 ± 355 BP (S-2339).

We recognize that the bivalves are shallow burrowers and therefore live in older sediment. TOC dates should therefore be somewhat older than TAMS dates on the burrowing molluscs. However, the mollusc shells submitted for TAMS dating in this study were selected as close as possible to the marine to lacustrine isolation contact. The depth of two of the samples (TO-205; AA-656) was only 2 and 8 cm, respectively, below the isolation contact. Therefore, unless an unconformity exists above the horizon containing the mollusc, or the sedimentation rate is very low, the TAMS dates are considered the most reliable age estimates for the isostatic emergence of the basin from sea level. Furthermore, the "corrected" ages for TOC dates in cores 3-8 and 1-1 are very close to ages from TAMS.

Paleomagnetic Inclination

To test if any unconformities exist between the isolation sediments and the dated molluscs, the paleomagnetic stratigraphy of the core horizons was examined (Figure 6). The magnetic latitude of this site is approximately 86.5°. Natural inclinations in sediments from this site are

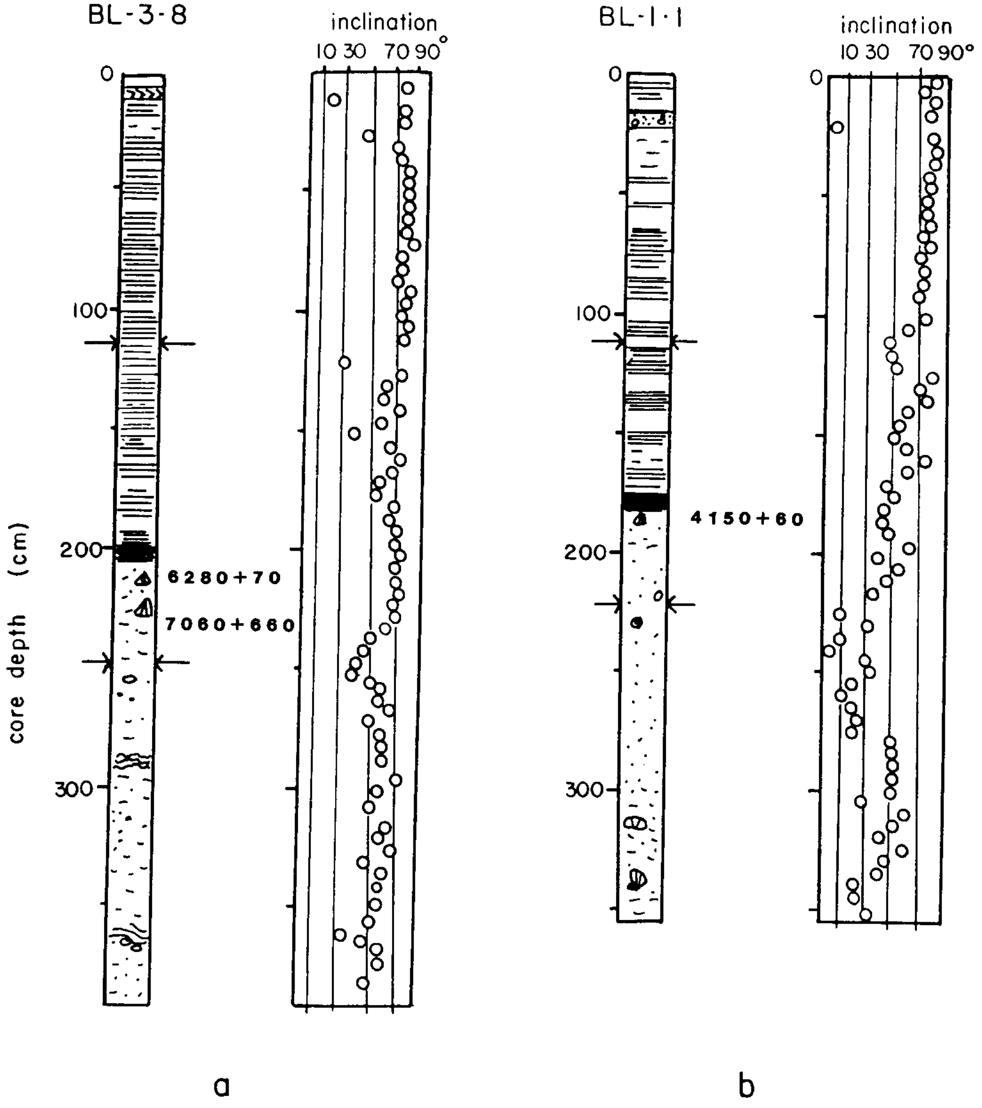

Figure 6. Paleomagnetic and lithostratigraphy of (a) sediment core 3-8 (Lake 3) and (b) core 1-1 (Lake 1). Arrows along stratigraphic log denote ends of core segments. See Figure 4 for explanation of symbols for sediment cores.

≥80° except where the sediment has been deformed by iceberg prodding or scouring, or where slumping of the sediment has created folds or other unconformities. In addition, because of the process of recovering sediments with a Livingstone corer, where repeated thrusts are required to obtain a continuous core of multiple 1.0- to 1.5-m segments in stiff sediment, deformation of sediments at the core segment boundaries is common. The deformation, shown schematically in the stratigraphic column, is seen in a pronounced shallowing of the magnetic inclination (Figure 6a). At several core segment intersections inclination drops as low as 0°.

At 20 cm depth in core 3-8, lacustrine sediment is overturned in a recumbent fold as a result of slumping of a portion of the lake floor. Inclination shallows from approximately 80 to 10° in the 10-cm section of the core. Massive silt below the fold is also deformed, with the inclination shallowing to 50°.

At 370 cm depth in the core, a 10-cm bed of contorted laminae containing a pod of fine gravel also exhibits inclination shallowing to 40°. This coarse sediment and inclination change may represent either an unconformity or deformation produced by ice rafting or iceberg prodding. The remainder of the stratigraphy in the core appears to be conformable. The shell samples dated by the TAMS method are located in the middle of a section of core where the inclination has remained stable (around 80°) for approximately 50 cm and through the isolation zone, implying that the sequence has remained conformable through the emergence of the basin.

In core 1-2, the interpretation is not as clear (Figure 6b). The accelerator-dated shell (TO-205; 4150±60 BP) was sampled within a zone of low inclination located in the middle of a core segment. It is not clear whether the deviation from high to low inclination through the lower portion of the lacustrine to marine sections of the core has resulted from coring deformation or natural processes; therefore, the magnetostratigraphy cannot be used to qualify the accelerator dates as demonstrated in Lake 3.

Relative Sea Level Curve

A relative sea level curve constructed with conventionally dated shells from raised marine sediments and TAMS-dated shells from lake sediment cores from the Robeson Channel area is shown in Figure 3 (solid line RC). The upper segment of the curve is gently sloping, similar to segment B of the Cape Baird (CB) and Alert (AL) curves of England (1983).

Approximately 5% (6 m) of the total emergence (116 m) takes place in the first 900 yr of emergence at an an average rate of approximately 0.7 m 100 yr^{-1}. Subsequently, emergence occurred at a much faster rate from ca. 7400 to 6200 BP (approximately 6 m 100 yr^{-1}). Thereafter, the rate of relative sea level change decreased from approximately 6200 BP to the present.

The latter two stages of emergence differ from those predicted for the area by the Cape Baird curve of England (1983). The striking difference between the Cape Baird curve and the curve presented in this study is the fast rate of emergence after 7400 BP indicated by the Robeson Channel curve. The new curve depicts initial emergence of Beaufort Lake 3 (40 m asl) at ca. 6200 BP in contrast to the Cape Baird curve which shows sea level at that time still above 100 m.

DISCUSSION

This study addresses two important aspects of the late Quaternary history of the Robeson Channel area: the Holocene relative sea level history of the region, and the extent of ice during the last glacial maximum.

Relative Sea Level History

The relative sea level curve shown here conflicts with that presented by England (1983). The upper portion of the Robeson Channel emergence curve suggests that slow initial emergence occurred at a similar time and rate as at Cape Baird (CB, Figure 3), but the transition to rapid emergence in Robeson Channel occurred after the transition at Alert but before the transition at Cape Baird (Figure 3). This may be because the Robeson Channel area was in a transitional zone between Greenland-controlled and Ellesmere Island-controlled emergence (England, 1983) until 6000 BP. The new data suggest that the Beaufort Lake basins in Robeson Channel emerged from 2000 to 3000 yr earlier than previously predicted. After 6000 BP emergence was apparently controlled by Ellesmere Island ice recession.

Isobase maps for the area (England, 1982; England and Bednarski, 1986) have shown that emergence from 8000 to 6000 BP along Robeson Channel is strongly controlled by the load of the Greenland Ice Sheet. The new data from Beaufort Lakes suggests that the effects of the Greenland ice load may not be as extensive over this area of coastline as was previously suspected. The emergence of Beaufort Lake 3 at 6000 BP implies that relative sea level was 40 m asl at that time, comparable to sites at Alert and Clements Markham Inlet (England and Bednarski, 1986). The 6000 BP, 40-m isobase may therefore mimic the coastline, or more correctly, the shape of the Ellesmere ice load, at least as far south as the Beaufort Lakes area. This would produce a steep gradient to the south and east in the 60-, 80-, and 100-m isobases, reflecting the combined ice loads but dominated by Greenland ice. A second interpretation necessitates significant faulting sometime after 7400 BP to accommodate the new data from the Robeson Channel area in light of the existing data for the region (England, 1983; England and Bednarski, 1986). Although no evidence of faulting of Holocene deposits was observed while mapping in this area (Retelle, 1986), recent research by England (1987) outlines the growing need for understanding the link between tectonics and geomorphic evolution of the Robeson Channel area.

Ice Extent During the Last Glacial Maximum

Radiocarbon dates on the TOC fraction of glaciomarine sediments from Beaufort Lake 3 span age estimates from >27,750 to >40,600 BP (Figure 4). Taken at face value, these infinite dates imply that glaciomarine sediments were deposited in the Beaufort Lakes embayment before and during the last glacial maximum. Several studies over the past decade have documented geological evidence for an ice-free corridor between interior Ellesmere Island and northwest Greenland ice during the last glacial maximum (England, 1976a, 1983, 1985; England and Bradley, 1978; England et al., 1978, 1981; Retelle, 1986a). If the dates are valid, they place serious restrictions on the opposing ice extent model that depicts a maximum ice cover over northern Nares Strait at this time (Blake, 1970; Hughes et al., 1977; Denton and Hughes, 1981). However, in recent years, several studies, including this study, have demonstrated problems in radiocarbon dating the total organic carbon fraction in sediments, when compared to shell dates from the same time-stratigraphic unit (Fillon et al., 1981; Andrews et al., 1985). The discrepancies in the dates have been attributed to the type of laboratory pretreatment (Olsson, 1979), the availability of contemporaneous organic material in the catchment (Bjorck and Hakansson, 1982), or the "hard-water effect" (Shotton, 1972; Karrow and Anderson, 1975).

Several authors have expressed various problems dealing with dating the NaOH-insoluble or NaOH-soluble fraction of the sediment (cf. Kaland et al., 1984). We felt that dating the soluble fraction would yield dates that were too young and perhaps contaminated by humic acids. Additionally, since coal on the Hazen Plateau is of sub-bituminous grade (Christie, 1976; Miall, 1982), the NaOH pretreatment should remove any low grade coal which might contaminate the lake sediments (Wittenberg, pers. comm., 1984). It is possible, however, that not all such coal was removed, leading to erroneously old age estimates.

Tops of cores from Beaufort Lakes have low apparent sedimentation rates, especially in Lakes 1 and 2. Although the sedimentation rates may have decreased somewhat due to late Holocene climatic cooling (cf. Fredskild, 1970, 1973), it is likely that the old dates reflect, to some extent, contamination by old carbon. It also appears that the amount of contamination or the supply of old carbon is neither consistent between the three lakes, nor constant over time in an individual basin. Instead, the amount of contamination may have been affected by changes in the morphometry, hydrology, and chemistry of the basins, which have evolved from nearshore marine through density-stratified lakes to freshwater lakes (Retelle, 1986b).

The environmental changes are most apparent in sediments from Lake 2. While the difference between the TOC date at the isolation contact and date of emergence predicted by the new relative sea level curve are greatest in the Lake 2 basin (Figure 4) the apparent age of the surface sediment in Lake 2 is the youngest of the three lakes (Figure 5). During marine submergence of the basins, the shorelines developed on till and bedrock uplands. Streams entering the basin redeposited "old" sediments from earlier upland proglacial lakes. Upon initial emergence of the basin from the sea, and subsequent lowering of Lake 2 to its 35-m level, the fringing lowlands began to contribute contemporaneous vegetation. Lake 2, with a broad fringing lowland and greater sediment influx, progressively received more modern vegetation than the bedrock basins of Lakes 1 and 3. In Lakes 1 and 3, however, the supply of old carbon has apparently remained constant between emergence and the present, as most of the modern vegetation is trapped in the larger Lake 2 basin.

If the amount of contamination by "old" carbon has remained constant, then it may be possible to subtract the apparent age of the surface sediments as a calibration factor to the TOC dates on the isolation horizon in Lakes 1 and 3. This method certainly does not apply to Lake 2 where greater changes have occurred since initial emergence of the basin. Consequently, a standard "calibration" of TOC dates determined by TAMS dating of in situ molluscs may not be appropriate in lacustrine systems where physical, chemical, and biological changes influence the organic carbon accumulation in sediments and hence the amount of possible contamination by older carbon. Andrews et al. (1985) suggest that a relationship exists between the TOC dates and shell dates such that a constant correction factor can be applied to the TOC date. However, this is probably not a universally applicable relationship and must be determined for each individual environmental study.

It is probably equally difficult to evaluate or calibrate the infinite TOC dates from the lower sections of the Beaufort Lake 3 core. Unfortunately, no mollusc shells were located in lower sections of this core for TAMS dating. Simple calibration of the TOC dates, by subtracting the estimated 3500 yr reservoir age for the sediments (Figure 5) still places the age estimates within the time frame of the last glacial maximum (late Wisconsinan); however, as previously stated, it is uncertain to what extent corrections of this type are valid. Linear extrapolation of sedimentation rates are also not valid downcore due to an abrupt facies change in the lower meter of core 3-8. It has been speculated (Retelle, 1986b) that this facies change, from barren silt (below 3.4 m) to fossiliferous gravelly and sandy silt (above 3.4 m) may represent the change from full glacial conditions with pervasive landfast sea ice to a more climatically favorable time when ice rafting and faunal occupation was prevalent (cf. England, 1983; Stewart and England, 1983).

SUMMARY

A new relative sea level curve from the Robeson Channel area demonstrates that rapid emergence began at 7400 BP, approximately 1200 yr earlier than shown by previous studies (England, 1983). Accordingly, at ca. 6000 BP, relative sea level may have been as much as 60 m lower than previously shown. This is similar to several sites on the north coast of Ellesmere Island whose emergence history is controlled by recession of Ellesmere Island ice caps (England and Bednarski, 1986). Alternatively, the major elevation differences between the Robeson Channel area and region new Cape Baird to the south may be the result of Holocene tectonic movement.

The results from this study indicate that although dates on organic material from lake sediments may be reliable in areas where modern vegetation is abundant, dates on sediments containing low levels of organic material should be regarded with caution. Because of environmental conditions, it may sometimes be difficult to interpret age-depth relations from sediment cores.

Infinite-age TOC dates from glaciomarine sediments in Lake 3 suggest that the coastal zone may have remained ice-free during the last glacial maximum, but the validity of these dates remains questionable.

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