Postglacial sea-level lowstand on Cumberland Peninsula, Baffin Island, Nunavut¹

B. Cowan, J. Carter, D.L. Forbes, and T. Bell

Abstract: This study investigates the postglacial sea-level history of eastern Cumberland Peninsula, a region of Baffin Island, Nunavut, where submerged terraces were documented in the 1970s. The elevation gradient of emerged postglacial marine-limit deltas and fiord-head moraines led Arthur Dyke to propose a conceptual model for continuous postglacial submergence of the eastern peninsula. Multibeam mapping over the past decade has revealed eight unequivocal submerged deltas at 19–45 m below present sea level (b.s.l.) and other relict shore-zone landforms (boulder barricade, spits, and sill platform) at 16–51 m b.s.l. Over a distance of 115 km from Qikiqtarjuaq to Cape Dyer, the submerged coastal features increase in depth toward the east, with a slope (0.36 m/km) less than that of the marine-limit shoreline previously documented (0.58–0.62 m/km). The submerged ice-proximal deltas, deglacial ice limits, and radiocarbon ages constrain the postglacial lowstand between 9.9 and 1.4 ka cal BP. The glacial-isostatic model ICE-7G_NA (VM7) computes a lowstand relative sea level at 8.0 ka, the depth of which increases eastward at 0.28 m/km. The difference between observed and model-derived lowstand depths ranges from 1 m in the west to 10 m in the east and the predicted tilt is significantly less than observed ($p = 0.0008$). The model results, emerging data on Holocene glacial readvances on eastern Baffin Island, and evidence for proglacial delta formation point to a Cockburn (9.5–8.2 ka) age for the lowstand, most likely later in this range. This study confirms the 1970s conceptual model of postglacial submergence in outer Cumberland Peninsula and provides field evidence for further refinement of glacial-isostatic adjustment models.

Key words: submerged deltas, Cockburn Substage, Holocene lowstand, glacial-isostatic adjustment model, multibeam bathymetry, Arctic.

Résumé : L'étude se penche sur l'histoire postglaciaire du niveau de la mer de l'est de la péninsule de Cumberland, une région de l'île de Baffin (Nunavut), où des terrasses immergées ont été documentées dans les années 1970. Le gradient d'élévation de deltas postglaciaires émergés à la limite marine et de moraines d'amont de fjord ont mené Arthur Dyke à proposer un modèle conceptuel pour l'immersion postglaciaire continue de la partie est de la péninsule. La cartographie bathymétrique multifaisceaux réalisée au cours de la dernière décennie a révélé huit deltas immergés non équivoques à 19–45 m sous le niveau de la mer (snm) actuel et d'autres reliques de formes de relief littorales (barricade de bloc, flèches et plateforme de seuil) à 16–51 m snm. Sur une distance de 115 km de Qikiqtarjuaq à Cape Dyer, la profondeur des éléments littoraux immergés augmente vers l'est, suivant une pente (0,36 m/km) inférieure à celle du littoral de la limite marine documentée précédemment (0,58–0,62 m/km). Les deltas juxtaposés immergés, les limites de déglaciation et des âges au carbone radioactif situent le bas niveau postglaciaire entre 9,9 ka cal BP et 1,4 ka cal BP. Le modèle glacio-isostatique ICE-7G_NA (VM7) donne un bas niveau par rapport au niveau de la mer à 8,0 ka, dont la profondeur augmente vers l'est à raison de 0,28 m/km. L'écart entre les profondeurs du bas niveau observée et modélisée va de 1 m à l'ouest à 10 m à l'est et l'inclinaison prédite est significativement moindre que l'inclinaison observée ($p = 0,0008$). Les résultats de modélisation, de nouvelles données sur des réavancées glaciaires dans l'est de l'île de Baffin à l'Holocène et des preuves de la formation de deltas proglaciaires indiqueraient que le bas niveau s'est produit à la phase Cockburn (9,5–8,2 ka), vraisemblablement vers la fin de cette fourchette. L'étude confirme le modèle conceptuel des années 1970 d'immersion postglaciaire de la partie externe de la péninsule de Cumberland et fournit des observations de terrain permettant de peaufiner les modèles d'ajustement glacio-isostatiques. [Traduit par la Rédaction]

Mots-clés : deltas immergés, sous-phase Cockburn, bas niveau Holocène, modèle d'ajustement glacio-isostatique, bathymétrie multifaisceaux, Arctique.

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Introduction

Submerged postglacial coastal landforms are predicted by glacial-isostatic adjustment (GIA) models (Quinlan and Beaumont 1981; Tarasov and Peltier 2004) and documented around the margins of late Quaternary ice sheets (e.g., Hill et al. 1985; Shaw and Forbes 1995). Andrews (1980) identified easternmost Baffin Island as a region with potential for a preserved Holocene submerged sea-level record.

At the northeastern limit of the Laurentide Ice Sheet (LIS) in the Canadian Arctic, Baffin Island (Fig. 1) has a postglacial history of punctuated ice recession, isostatic adjustment, and relative sea level (RSL) change. Cumberland Peninsula has experienced both emergence and submergence of its coastline, as revealed by extrapolated marine limit shorelines along the southwestern coast (Dyke 1979). In that region, synchronous early Holocene raised deltas at the postglacial marine limit indicate an eastward-dipping shoreline with a gradient of 0.58–0.62 m/km, hypothesized to continue below sea level in eastern Cumberland Peninsula (Fig. 2; Dyke 1979; Andrews 1980, 1989; Clark 1980).

The absence of documented raised early Holocene marine features, a few depth soundings of submarine terraces in fiords, and output from GIA models all support the hypothesis of postglacial submergence in eastern Cumberland Peninsula (Miller and Dyke 1974; Miller 1975; Peltier 2020). The terraces were tentatively interpreted as deltas and correlated with moraines of the last major glaciation in the region (Miller 1975). Considerable additional information on the distribution of raised marine shorelines and late glacial ice margins in southern and eastern Cumberland Peninsula has been published since (e.g., Locke 1987; Kaplan et al. 1999; Kaplan and Miller 2003; Briner et al. 2009; Dyke 2013a, 2013b; Margreth et al. 2017), including work in Sunneshine Fiord, just south of Cape Dyer (e.g., Andrews et al. 1996; Miller et al. 2005). Yet, without further information on the spatial distribution of submerged shorelines, the postglacial crustal tilt and sea-level trends of eastern Cumberland Peninsula remained poorly constrained.

This study presents the discovery, verification, and documentation of eight submerged deltas identified during targeted coastal surveys between Pangnirtung and Qikiqtarjuaq on the Cumberland Peninsula (Fig. 1A) and radiocarbon ages on molluscs in sediment cores from submerged deltaic sediments. These data provide geological evidence of a Holocene lowstand and an opportunity to test the local validity of the most recent published GIA model (Peltier 2020).

Study area

Deglacial history

Cumberland Peninsula is the easternmost landmass in the Canadian Arctic Archipelago (Fig. 1C). Its high-relief physiography both influenced and was modified by the growth and recession of ice sheets and local alpine glaciers throughout the Quaternary. At present, the Penny Ice Cap (PIC; Fig. 1A) and numerous local cirque and valley glaciers are located on Cumberland Peninsula. During the Last Glacial Maximum (LGM) — locally known as the late Foxe Glaciation — the LIS, PIC, and alpine glaciers reached their outermost limit along the eastern coast of Baffin Island and adjacent continental shelf (Kaplan and Miller 2003; Miller et al. 2005; Briner et al. 2009; Margreth 2015; Corbett et al. 2016; Margreth et al. 2017; Dalton et al. 2020). At the LGM, low-gradient warm-based alpine outlet glaciers occupied most of the fiords and valleys of eastern Cumberland Peninsula, while much of the inter-fiord uplands remained ice-free or covered by cold-based alpine glaciers (e.g., Margreth 2015; Margreth et al. 2017; Pendleton et al. 2019; Crump et al. 2020).

Initial retreat from the LGM began by 14.6 ka cal BP, leaving the coastal fringe of eastern Cumberland Peninsula partially ice-free by 14.0 ka cal BP (Briner et al. 2009). Several short reversals

occurred throughout the overall glacial recession, during which the LIS, PIC, and alpine glaciers readvanced. Readvances occurred during the Younger Dryas (YD) cold interval (12.8–11.7 ka cal BP) and the Cockburn Substage (9.5–8.2 ka cal BP), including the 8.2 ka cold event (Briner et al. 2009; Young et al. 2012, 2020; Margreth et al. 2017; Crump et al. 2020).

By the end of the YD, the southeastern coast of the peninsula was ice-free. Deglaciation was asymmetrical: the south coast experienced extensive deglaciation before the north (Margreth 2015). At the YD, glaciers filled the northern fiords (e.g., Merchants Bay; Fig. 1A), occupied the heads of fiords in the east (e.g., Mermaid Fiord; Fig. 1A), and remained inland of the fiord heads in the southwest (Margreth 2015). Northern fiords experienced rapid deglaciation after the YD cold event (Dyke et al. 2003; Miller et al. 2005; Margreth 2015).

The Cockburn Substage was a major readvance of alpine glaciers to the fiord heads and coast during the overall deglaciation (Andrews and Ives 1978). It deposited extensive lateral and end moraines associated with local readvances at many sites, particularly circa 9.3 ka and 8.2 ka (Young et al. 2012, 2020; Margreth et al. 2017; Crump et al. 2020). On Cumberland Peninsula, the innermost pre-Neoglacial moraines are interpreted as Cockburn-equivalent moraines (Fig. 1A), correlated to the dated Cockburn moraines along the northeast and northern margins of the LIS (Miller and Dyke 1974; Andrews and Ives 1978; Margreth 2015; Crump et al. 2020). Recent ^{10}Be cosmogenic exposure dating has identified a number of readvances in eastern Baffin Island (~11.8 ka, 10.3 ka, 9.2 ka) in addition to the prominent 9.3 ka and 8.2 ka events associated with cooling episodes recorded in Greenland Ice Sheet cores (Rasmussen et al. 2006), circulation in Baffin Bay, varying insolation intensity, and deglacial ice dynamics (Young et al. 2012, 2020; Pendleton et al. 2019; Crump et al. 2020). The residual Foxe Dome of the LIS then progressively receded throughout the Holocene, with minor readvances, culminating in its present limit at the Barnes Ice Cap (6000 km²; Fig. 1C), the last remnant of the LIS (Miller et al. 2005; Briner et al. 2009).

GIA models

RSL records from formerly glaciated regions reflect the complex history and interaction of GIA and eustasy in the postglacial period. Walcott (1970) interpreted the free air gravity anomaly over North America in relation to elastic crustal bending and viscous displacement of the underlying mantle, computing the shape and amplitude of subglacial downwarping and forebulge uplift around the margins of the former LIS. Over the subsequent half century, there has been great progress in the theory and development of GIA models (e.g., Peltier 1982; Andrews and Peltier 1989). The implications of postglacial forebulge relaxation and inward migration for patterns of RSL change were recognized by Clark et al. (1978) and Quinlan and Beaumont (1981), who identified concentric zones of continuously falling RSL, falling then rising RSL (with a Holocene lowstand), and continuously rising RSL, with increasing distance from the former ice load, in a manner consistent with the conceptual model for Cumberland Peninsula proposed by Dyke (1979).

Similar RSL patterns associated with postglacial isostatic adjustment have been reproduced in a succession of models incorporating the distribution of former ice loads, the rheology of the crust and mantle, and other gravitational and rotational effects (e.g., ICE-3G; Tushingham and Peltier 1991; ICE-5G (VM2); Peltier 2004). The most recent version of the ICE-nG model, incorporating a revised and extensively validated ice thickness history (ICE-7G) and a radial mantle viscosity profile (VM7) is available for testing against field observations (Peltier 2020). The evolution of this model from earlier versions was achieved in part through comparison of model output with geological evidence, geodetic constraints, and water-level records (Roy and Peltier 2015, 2017, 2018).

Fig. 1. (A) Locations of submerged coastal features mapped in eastern Cumberland Peninsula, Margreth's (2015) early Holocene ice margins for end of Younger Dryas (11.7 ka) and Cockburn-Substage (9.5 ka), with the present zero isobase from Kaplan and Miller (2003). Numbers denote submerged deltas (Table 1). AF, Akpait Fiord; BC, Broughton Channel; BF, Boas Fiord; CB, Clephane Bay; CD, Cape Dyer; CM, Cape Mercy; DH, Durban Harbour; KF, Kangert Fiord; KiF, Kingnait Fiord; MB, Merchants Bay; MF, Mermaid Fiord; PF, Pangnirtung Fiord; PaF, Padle Fiord; PI, Padloping Island; SF, Sunneshine Fiord; TF, Touak Fiord. Modified from Margreth (2015). (B) Locations of raised marine limits with radiocarbon dates (Table 2) that made up the sea-level conceptual model (Fig. 2; Andrews 1975; Lowdon and Blake 1975; Andrews 1976; Dyke 1979). CF, Clearwater Fiord; KaF, Kangerk Fiord; KiF, Kingnait Fiord; PF, Pangnirtung Fiord; SB, Shilmilik Bay; UF, Usualuk Fiord. (C) Location of Cumberland Peninsula in the eastern Canadian Arctic. BIC, Barnes Ice Cap. Base map coastlines and present-day permanent snow and ice from Natural Earth (2017).

Shoreline record

There is little information in the literature on the character of submerged relict shorelines in Arctic regions (see, however, Rasch 2000; Sparrenbom et al. 2006). This is in part because many Arctic coasts are emergent, with relict shorelines raised above present sea level, and in part because the technology to map submerged coastal geomorphic features has not been widely deployed until recently (Hughes Clarke et al. 2015). Some evidence of lower postglacial RSL has been observed along the eastern, southeastern, and northwestern fringes of the former LIS, within the glacial-isostatic zones of submergence (e.g., Nixon et al. 2014). These include submerged wave-cut terraces, deltas, beach ridges, incised bedrock, barrier platforms, flooded estuaries and salt marshes, and flooded isolated basins (e.g., England and Andrews 1973; Shaw and Forbes 1995; Forbes et al. 1995, 2014; Bell et al. 2003; Shaw 2005; Billy et al. 2018). Relict shoreline features combined with Global Navigation Satellite System monitoring stations co-located with tide gauges are important for constraining regional GIA and RSL models and provide the data required to construct RSL curves for the Canadian Arctic (Forbes et al. 2004; Simon et al. 2014; Robin et al. 2020; James et al. 2021). As there has been limited validation of the most recent GIA model in the eastern Arctic, the submerged shoreline data set presented in this paper offers an opportunity for comparison and possible refinement of the model in a region dominated locally at the LGM by alpine ice, between the Laurentide and Greenland ice sheets.

Raised shorelines have been used to define the broad patterns of LGM ice loading and postglacial adjustment across much of Baffin Island (e.g., Andrews 1989). On Cumberland Peninsula, evidence of postglacial uplift and emergence has been reported for the western, northern, and southeastern coasts (e.g., Pheasant and Andrews 1973; Dyke 1979; Kaplan and Miller 2003; Miller et al. 2005).

Dyke (1979) used the elevations of raised sea-level indicators to extrapolate a series of postglacial sea-level curves along the western coast of Cumberland Peninsula (Fig. 2). The resulting conceptual model suggests a postglacial RSL record continuously below present sea level on the eastern peninsula (e.g., curve H, Fig. 2). The marine limits at sites E–G in Fig. 2 form a reasonably synchronous early Holocene strandline (9.9–9.0 ka cal BP²; Dyke 1979) with an eastward gradient of 0.58–0.62 m/km. Extrapolation of this gradient suggests that marine limits intersect present sea level east of a line running roughly north–south from Qikiqtarjuaq to Cape Mercy (zero isobase, Fig. 1A). Curve H, characteristic of continuous submergence, was extrapolated from a depth sounding of a submerged terrace in a northeastern Cumberland Peninsula fiord (Miller and Dyke 1974). No further field evidence of the submerged postglacial setting has been acquired prior to this study, leaving a large gap in our understanding of the crustal adjustment and RSL trends of easternmost Baffin Island.

Observations of transgression over at least the past 1200 years, consistent with the conceptual model, include submerged shingle

ridges (9 m below present sea level (b.s.l.)) and deeply incised bedrock channels blocked by modern shingle barrier ridges near Qikiqtarjuaq (England and Andrews 1973; Pheasant and Andrews 1973). The present sea level is therefore thought to mark the postglacial marine limit on the outermost coast of Cumberland Peninsula (Dyke 1979; Andrews and Miller 1985; Andrews 1989), east of the zero isobase (Fig. 1A).

Approach and methods

Our approach to the exploration of submerged shoreline features, primarily deltas, over the course of three field seasons (2012–2014) was to target both small side-entry valleys and fiord heads in drainage basins that hosted Holocene glaciers from expanded ice fields and cirques.

The fiords and coastal inlets of eastern Cumberland Peninsula are largely uncharted, so the application of our exploration strategy needed careful execution, given the common occurrence of shallow fiord sills and moraine systems. The preferred survey vessel was the 19 m, shallow-draft (2.75 m), Government of Nunavut fisheries research vessel *MV Nuliajuk* (minimum safe operating depth of 10 m) equipped with forward-looking and downward multibeam sonar that generated sufficient bathymetric survey data to provide safe access for the much larger *CCGS Amundsen*, with a draft of 7.2 m (Hughes Clarke et al. 2015) and piston-coring capability.

MV Nuliajuk was equipped with a Kongsberg EM3002 multibeam echosounder and a 3.5 kHz Knudsen chirp 3200 sub-bottom sonar. Brucker et al. (2013) detail the multibeam system and processing methodology used during these surveys. The multibeam depths were adjusted to mean sea level and corrected for tidal variations using WebTide Arctic version 9 for Baffin Island. The 3.5 kHz profiles were acquired simultaneously with the multibeam surveys (depths assume an acoustic velocity of 1500 m/s in water).

Sediment cores were collected in 2014 and 2015 to validate the acoustic stratigraphy and provide chronological control on facies deposition and associated submerged shoreline features. Gravity cores (<2.6 m) were recovered using *MV Nuliajuk*, from sediments draping the submerged fiord-head delta in Boas Fiord, while paired piston (<9 m) and trigger-weight gravity cores were acquired using *CCGS Amundsen* from prodeltaic sediments in inner Durban Harbour and basin deposits in Akpait Fiord. Shell samples from cores were extracted at the Geological Survey of Canada Marine Core Laboratory, at the Bedford Institute of Oceanography. They were cleaned, prepared, identified, and submitted by the late Alice Telka (Paleotec Services). Accelerator mass spectrometry (AMS) radiocarbon analysis was completed under the direction of John Southon at the W.M. Keck Carbon Cycle AMS Facility, University of California, Irvine (lab code: UCIAMS). The reported radiocarbon dates were calibrated using CALIB 8.2 (Stuiver et al. 2021) and the MARINE20 data curve (Heaton et al. 2020). The regional ΔR corrections used were 82 ± 18 years for northeast Baffin Island and 14 ± 58 years for southeast Baffin Island; these are updates of the original

²Radiocarbon dates have been (re)calibrated using CALIB 8.2 (Stuiver et al. 2021) and the MARINE20 database (Heaton et al. 2020) for comparison of chronologies. Calibration details are described in Table 2.

Fig. 2. Marine limit elevations plotted against known or extrapolated ages and schematic relative sea level curves for southwestern Cumberland Peninsula and the submerged delta in Padle Fiord. Modified after Dyke (1979), with newly calibrated radiocarbon ages for marine limits (Table 2). See Fig. 1B for locations of sites: A, Clearwater Fiord; B, Middle Clearwater Fiord; C, Shilmilik Bay; D, Kangerk Fiord; E, Usualuk Fiord; F, Pangnirtung Fiord; G, Kingnait Fiord; H, Padle Fiord.

Coulthard et al. (2010) ΔR corrections. For Boas Fiord and Durban Harbour, the ΔR correction used was 48 ± 38 years, the mean of the two ΔR values above, reflecting their locations near the interface of the northeast and southeast Baffin Island regions.

For the GIA model output, postglacial RSL elevations were obtained from topographic difference data arrays on a one-degree grid, available at 500-year intervals (Peltier 2020). The net-CDF format data were accessed using Panoply version 4.12.7 (NASA Goddard Institute for Space Studies) with netCDF Java version 5.4.2. Time series used in this paper were obtained from ICE-7G_NA (WM7) output for nodes along the 66.5°N parallel in the study region (Fig. 1A). Low-stand elevations determined by the model at 8.0 ka were related to observed submerged shoreline indicators using bilinear interpolation between adjacent model nodes.

Results

Four types of submerged coastal landforms were mapped during the coastal seabed surveys, including deltas, a boulder barricade, spits, and a sill platform (Cowan 2015). Eight submerged deltas, ranging in depth from 19 to 45 m b.s.l., were identified between Kangerk Fiord and inner Durban Harbour, east of Merchants Bay (55 km distance), and as far south as Clephane Bay along the southeast coast (88 km; Fig. 1A; Table 1). Three of these delta sites are described and illustrated below using shaded-relief multibeam seabed imagery (Figs. 3A, 3B, and 3C). These examples highlight the main geomorphic features that confirm their identification as relict submerged deltas, their ice-proximal formation, and the relationship between delta lip morphology and the corresponding RSL. Bathymetric profiles of all eight submerged deltas surveyed are presented in Fig. 3D. This shows that the side-entry deltas (Profiles 2, 3, 5, and 7) have steep and usually deep

delta fronts, in contrast to the gentler slopes of the fiord-head delta fronts (Profiles 1, 4, 6, and 8).

Kangerk Fiord

Two submerged deltas were mapped in Kangerk Fiord, one at the fiord head (#1, Fig. 3A) and the other at the mouth of the only side-entry valley (#2, delta profile, Fig. 3D). Due to equipment failure, sub-bottom profiles were not acquired in this fiord.

The submerged fiord-head delta terrace in Kangerk Fiord is flat (0.8°) with a moderately gentle foreslope (12° ; Table 1, Fig. 3A). The terrace lip occurs at a mean depth of 19 m b.s.l. (Table 1). The terrace extends down-fiord 4 km from the modern river mouth, covering an area of about 1.6 km^2 . The terrace surface is marked by prominent depressions, typically bowl shaped with gentle slopes. The deepest is 250 m across and steep sided, with relief of 20 m. The depressions are partially filled with fine-grained sediment; otherwise, the terrace surface consists of a gravel lag (sub-rounded cobbles to boulders) covered by a thin silt veneer. The terrace depressions are interpreted to be kettle holes formed by melting of residual ice blocks around which the delta prograded. These indicate that the delta was formed in close proximity to the receding glacier front.

Boas Fiord

Boas Fiord is aligned north-south, opening to Baffin Bay through a trough on the east side of Padloping Island. Glaciers (or permanent snow and ice) cover 22% of the 1140 km^2 drainage basin and provide meltwater and sediment for an extensive braided sandur (Fig. 3B).

The submerged fiord-head delta in Boas Fiord is the largest of all the deltas surveyed, extending down-fiord for 4 km and covering an area of 9.5 km^2 (#4, Figs. 1A, 3B). Its surface is more or

Table 1. Locations and dimensions of submerged deltas and shorelines mapped during this study.

Site	Fiord	Latitude (°N)	Longitude (°W)	Delta lip depth ^a (m)	Terrace slope (°)	Front slope ^b (°)	Interpreted RSL ^c (m)	ICE-7G RSL ^d (m)	Width (m)	Length (m)	Terrace area ^e (km ²)
1	Kangert	66.923	63.783	19	0.8	12	−20	−16	575	4000	1.6
2	Kangert	66.996	63.816	19	0.5	19	−20	−16	720	710	0.4
3	Padle	66.900	63.220	29	1.6	16	−30	−25	1300	700	1.2
4	Boas	66.673	62.848	33	0.3	7	−34	−29	2050	7500	9.5
5	Boas	66.776	62.749	37	1.3	16	−38	−31	1800	1000	1.7
6	Durban	66.946	62.272	44	0.5	12	−45	−36	900	>1600	1.4
7	Mermaid	66.226	62.766	36	0.5	23	−37	−31	1000	>800	0.8
8	Clephane	65.911	62.429	45	1.1	5	−46	−37	915	>1200	1.1
BC	Broughton	67.533	64.035				−16	−15			
AF	Akpait	66.883	61.744				−51	−41			

Note: AF, Akpait Fiord; BC, Broughton Channel; RSL, relative sea level.

^aDelta terrace depth is calculated as the average terrace lip depth ($n = 20$).

^bDelta front slopes were calculated for the upper slope only, over a depth range of 20 m starting at the delta lip.

^cPaleo-sea levels are interpreted as 1 m below the average delta terrace (lip) depth. See text for discussion.

^dModelled 8 ka lowstand RSL generated by the ICE-7G_NA (VM7) model (Peltier 2020).

^eDelta terrace area is measured from the river mouth to the terrace lip.

less flat (0.3°) with a low-angle front slope (7°) and a delta lip depth of 33 m (Table 1). This is the only site where substantial sub-bottom penetration was achieved for interpretation of the internal structure of submerged deltas (Fig. 4). A 3.5 kHz acoustic survey line crosses a side terrace of the main fiord-head delta ($x-x'$ in Fig. 3B). Gravity core BF4 successfully recovered 135 cm of sediment and dateable shell material in 31 m water depth on the delta terrace (Figs. 3B, 4; Carter 2021).

The sub-bottom acoustic stratigraphy comprised ice-contact deposits (unit A) overlain by draped, acoustically stratified sediments interpreted as glaciomarine (unit B), in turn overlain by deltaic facies (unit C) and thin, acoustically transparent deposits interpreted as post-transgressive marine mud (unit D). Unit C exhibited the characteristic tripartite structure of a “Gilbert-type” delta (Gilbert 1885, p. 107), with horizontally stratified topsets (C3) truncating steeply dipping foresets (C2) that grade downslope into prodelta bottomsets (e.g., Cameron et al. 1993; Lønne 1995; Masselink and Hughes 2003). The topsets exhibit remnant cut-and-fill channels. The erosional unconformity between the foresets and topsets, or the transgressive surface, is situated approximately 2 m below the depth of the delta terrace lip at 33 m b.s.l.

Sample BF4 (103–104 cm) from the gravity core BF4 was a single fragment of the bivalve *Hiatella arctica* that provided a calibrated radiocarbon age of 1060–740 cal BP (2 σ age range; UCIAMS-155824; Table 2), giving a mean sedimentation rate of 0.98–1.39 mm/year for the top 103.5 cm in the core. The sample is interpreted to be from post-submergence mud (unit D). Extrapolating the mean sedimentation rate downward to the acoustic unit C contact at 2.0 m b.s.l., the minimum age constraint for the onset of transgression (and thus the minimum age constraint for the postglacial lowstand) is estimated at 2050–1440 cal BP.

Inner Durban Harbour

Inner Durban Harbour is the informal name for the cove at the southern extremity of Durban Harbour, where a submerged delta is located (site #6, Figs. 1A, 3C). The apex of the delta is located at the confluence of several small drainage systems sourced from high-elevation lakes and small remnant cirque and valley glaciers. The submerged delta is contained within a narrow embayment (about 900 m wide) that opens into a wider outer basin (Fig. 3C). Moraine deposits line the inner slope at the head of the inlet, while till veneer covers the western valley walls (Dyke 2013b). Miller (1975) interpreted the moraine at the head of the inlet as late Foxe in age.

The almost flat (0.5°) submerged delta terrace exhibits a straight, progradational, delta front, the mean lip depth of which is at 44 m b.s.l., with a 12° slope down to >110 m b.s.l., giving the delta a submarine relief of about 66 m (Table 1; Fig. 1A, #6; Fig. 3D). The delta foresets (acoustic unit C2) transition downslope to bottomsets (C1), which overlie deposits interpreted as ice-contact (unit A; Fig. 5). The thin marine cover at the seabed — post-submergence unit D — is not well resolved in the acoustic records. Iceberg scours are evident on the now-inactive delta front.

Sample DH6 (210–212 cm) from piston core DH6 is a single valve of *Bathyrca glacialis* that gave a calibrated radiocarbon age of 9870–9490 cal BP (2 σ age range; UCIAMS-169710; Fig. 6; Table 2). The sample is interpreted to be from acoustic unit C1 (delta bottomsets). The basal unit in the core, lithofacies 1 (LF1), is a coarse matrix-supported gravel interpreted as an ice-contact or proximal deposit. Lithofacies 2 (LF2) and 3 (LF3), overlying the contact with LF1, show a coarsening upward pattern consistent with prodelta sedimentation and delta progradation, together representing acoustic unit C1. Lithofacies 4 (LF4) is interpreted as post-submergence sediment (equivalent to acoustic unit D). All marine units (LF2 to LF4) contain ice-raftered granules and pebbles (see Carter 2021 for further details on lithofacies and physical properties). Based on this interpretation, the sample date range provides a maximum age constraint for the postglacial lowstand and an age for initiation of prodelta sedimentation at this site.

Other submerged coastal landforms

In addition to submerged deltas, supporting evidence for a RSL lowstand comes from the submerged boulder barricade in Broughton Channel near Qikiqtarjuaq, which was mapped in a water depth of 16 to 18 m b.s.l., thus constraining the average high-tide level to 16 m b.s.l. (Fig. 1; Cowan 2015). In Akpait Fiord, a wave trimmed sill platform at 51 m b.s.l. and a gravel spit at 50 m b.s.l. that extends southwestward from a sill platform, with a relief of 1–2 m above the platform, provide the deepest RSL evidence in the region (Fig. 1; Cowan 2015).

GIA model output

Isobases determined from the ICE-7G_NA (VM7) model (Peltier 2020) are broadly curved and aligned approximately north–south in the vicinity of the submerged deltas described in this paper. Time series of postglacial RSLs were extracted for nodes at 66.5°N from 65.5°W to 61.5°W (Fig. 1A). The resulting RSL histories (Fig. 7) display the range of patterns suggested by Clark et al. (1978), and by Dyke (1979) for this region (Fig. 2). They range from continuous emergence (uplift) west of ~65°W, to initial rebound (causing

Fig. 3. (A) Multibeam bathymetry of submerged fiord-head delta in Kangert Fiord at 19 m below sea level (b.s.l.) (site #1, Fig. 1A). (B) Multibeam bathymetry of submerged delta at the head of Boas Fiord at 33 m b.s.l. (Site #4, Fig. 1A). Also shown are the acoustic profile $x-x'$ (Fig. 4) and location of gravity core (BF4) on the submerged delta. (C) Multibeam bathymetry of inner Durban Harbour (Site #6, Fig. 1A) with acoustic profile $y-y'$ (Fig. 5) and location of piston core (DH6) featured in Fig. 6. (D) Submerged delta profiles reconstructed from the multibeam bathymetric data, with a vertical exaggeration of 6.7 $\times$. Locations and names are identified by number in Fig. 1A and Table 1. Topography from Natural Resources Canada (2013).

emergence after 10 ka) followed by a lowstand and subsequent submergence further east. An intermediate pattern with slight emergence above present sea level after 4.5 ka is evident at 64.5°W. Within the region covered in this figure, the outer zone of continuous submergence is not observed, but the extent of

rebound diminishes progressively eastward to <10 m from 10 ka to 8 ka at 61.5°W (in the mouth of Sunneshine Fiord). Note that the more westerly node has no values prior to 8 ka due to late ice.

An early Holocene lowstand is indicated by the model output, ranging from <5 m b.s.l. at 7.5–7.0 ka (64.5°W, in the vicinity of

Fig. 4. Acoustic record (3.5 kHz) from the head of Boas Fiord (Fig. 3B). Unit contacts (heavy lines) and internal stratification (finer solid and broken lines). Delta front profile $x-x'$ (Fig. 3B) extends across the prodelta slope of the submerged fiord-head delta and shows the foreset beds of the eastern side terrace (depths assume an acoustic velocity of 1500 m/s in water).

the head of Kingnait Fiord, to 20–44 m b.s.l. at 8.0 ka in the region of 63.5–61.5°W. The shape of the eastern curve (61.5°W) suggests that the 500-year interval aliases a slightly earlier lowstand, as might be expected due to forebulge migration.

Table 1 shows the lowstand sea levels determined from the marine bathymetric surveys reported in this paper for each of eight submerged deltas and two other sea-level indicators. The geological evidence shows lowstand levels ranging from 16 m b.s.l. in Broughton Channel at Qikiqtarjuaq in the west (Fig. 1) to 51 m b.s.l. in Akpait Fiord, near Cape Dyer in the east, and 46 m b.s.l. at Clephane Bay in the southeast. The corresponding range of model-derived levels is from 15 m b.s.l. to 41 m b.s.l. and 37 m b.s.l., respectively. The difference between the observed lowstand depths and the model depths increases toward the east and southeast.

Discussion

Paleo-sea levels

Submerged deltas on Cumberland Peninsula were mapped at water depths between 19 and 45 m b.s.l. Contemporaneous sea levels during deposition of these Gilbert-type deltas can be estimated from the depth of the transgressive surface. The submerged delta at the head of Boas Fiord, the only site with well-imaged sub-bottom stratigraphy (Fig. 4), was used as an analogue for estimating the RSL depths for deltas without sub-bottom profiles.

The transgressive surface was identified ~2 m below the average delta terrace lip. This marks the erosional base of former braided channels on the sandur surface during deposition of the delta foresets (Church 1972), thereby delimiting the lowest possible water level at the time of deposition. Considering the small tidal range, averaging 1 m for northeast Cumberland Peninsula (1.9 m Cape Dyer, 0.9 m Qikiqtarjuaq; Canadian Hydrographic Service 2021), the high-tide limit of former sea level would be about 1 m below the average terrace lip depth for all the mapped delta landforms.

Spatial distribution of submergence and crustal tilting

Because of the spatially variable timing of deglaciation, it is evident that any submerged shorelines delimited by deltas formed at initial deglaciation on eastern Cumberland Peninsula would be diachronous. In contrast, Dyke (1979) showed that the marine limit deposits (sites E, F, and G), the highest postglacial preserved shorelines in the western part of Cumberland Peninsula, formed roughly synchronously at 9.9–9.0 ka cal BP (median ages 9.6–9.4 ka cal BP, Table 2; Fig. 2) and through differential uplift away from the LIS margin, are now tilted eastward at 0.58–0.62 m/km (Fig. 8).

Of the 10 submerged coastal landforms reported in this study (Fig. 1), the shallowest (16 m b.s.l.) is found in the west and the deepest (51 m b.s.l.) in the east, indicating an eastward linear paleo-shoreline tilt. The tightly fitted linear gradient for the submerged deltas (Fig. 8) suggests synchronous deposition at a shoreline-building episode during the overall deglaciation, after which they all underwent comparable GIA. In the band roughly between 66.5°N and 67.0°N, the eight deltas and two additional shoreline indicators in Broughton Channel and Akpait Fiord show an eastward tilt of 16.14 ± 0.69 m°longitude = 0.36 ± 0.02 m/km, with $R^2 = 0.981$. These deltas are interpreted to have formed from a pulse of sediment and meltwater coeval with a climatically controlled glacial recession following an early Holocene readvance. We note, in passing, that the delta in Clephane Bay (site 8, Table 1) is the only point falling outside the 95% confidence interval for the linear relation shown in Fig. 8. This may reflect its more southerly location and likely some curvature in the isobases.

The lower slope of the submerged lowstand shoreline relative to the marine limit shoreline of Dyke (1979) may reflect in part a regional difference east of the zero isobase, and more likely a later date (Fig. 8).

Depositional history and chronology

The discovery and bathymetric mapping of submerged shore features confirms the Holocene submergence and transgression of eastern Cumberland Peninsula; however, these landforms cannot provide sea-level index points for the RSL history of the region without depositional ages. Delta formation is related to sediment supply and meltwater discharge from valley glaciers and therefore can be related to the deglacial chronology. To better constrain the age of the lowstand, we consider the two radiocarbon ages for the submerged deltas in Boas Fiord and Durban Harbour in the context of their evidence of deltaic deposition and what is known of the deglacial chronology of eastern Cumberland Peninsula.

The submerged deltas are related to one of the following: (1) the regressive limb of the Holocene sea-level record, possibly the initial 'marine limit' upon deglaciation of the site; (2) the postglacial lowstand; or (3) the transgressive limb of the Holocene sea-level record. Marine-limit deltas are typically incised, with evidence of terraces that formed as sea level fell below the prograded delta surface to form lower deltas. Lowstand deltas are deposited at stable sea level during the postglacial RSL inflection from regression (falling RSL) to transgression (rising RSL), which provides more time for delta formation. No incision or lower terraces were observed on the submerged deltas mapped in this

Table 2. Summary table of calibrated radiocarbon dates, rounded to the nearest decade, used in this study.

Location (Fig. 1)	Sediment core	Sample No.	Laboratory No. ^a	¹⁴ C date (±1σ, BP)	ΔR ^b (averaged)	cal BP 2σ age range (median)	Species ^c	Reference ^d	Marine limit (Figs. 1B and 2)
Boas Fiord	BF4 ^e	BF4 (103–104)	UCIAMS-155824	1570 ± 20	48 ± 38	1060 (910) 740	<i>H.a.</i>	This study	
Durban Harbour	DH6 ^f	DH6 (210–212)	UCIAMS-169710	9165 ± 25	48 ± 38	9870 (9650) 9490	<i>B.g.</i>	This study	
Pangnirtung Fiord	n/a	n/a	GSC-2001	9090 ± 45	14 ± 58	9880 (9610) 9410	<i>M.t.</i>	1	F
Kingnait Fiord	n/a	n/a	GSC-2083	8880 ± 135	14 ± 58	9760 (9360) 8980	<i>M.t.</i>	2	G
Usualuk Valley	n/a	n/a	GSC-2183	9060 ± 55	14 ± 58	9870 (9580) 9360	<i>P.a.</i>	3	E
Middle Clearwater Fiord	n/a	n/a	GSC-2211	6520 ± 45	14 ± 58	7010 (6780) 6550	<i>M.t.</i>	4	B
Clearwater Fiord	n/a	n/a	DIC-335	6110 ± 80	14 ± 58	6600 (6330) 6070	n/a	4	A

Note: All radiocarbon dates were (re)calibrated using CALIB 8.2 (Stuiver et al. 2021) and the MARINE20 data set (Heaton et al. 2020).
^aLaboratory abbreviations: UCIAMS, Keck Carbon Cycle AMS Lab, University of California, Irvine; GSC, Geological Survey of Canada; DIC, Dicar Corp and Dicarb Radioisotope Company.
^bΔR values represent averages from nearby data (Calib 8.2, Stuiver et al. 2021).
^cSpecies (this study: Telka (2015, 2016) or from published source): *H.a.*, *Hiattella arctica*; *B.g.*, *Bathyrca glacialis*; *M.t.*, *Mya truncata*; *P.a.*, *Portlandia arctica*.
^d1, Andrews 1975; 2, Lowdon and Blake 1975; 3, Andrews 1976; 4, Dyke 1979.
^eBH4 core collected from station 2014Nulijuk-0004.
^fDH6 core collected from station 2015805-0006.

Fig. 5. Acoustic profile y–y' is a composite of two separate acoustic profiles from inner Durban Harbour, covering the prodelta and submerged fiord-head delta (site #6, Table 1, Fig. 3C). See text for description of acoustic units. Location of piston core DH6 is shown (Fig. 6).

study; thus, it is unlikely that they were deposited on the regressive limb of their local sea-level curve. Instead, these deltas are more likely to have been deposited during the lowstand or on the early transgressive limb of the local sea-level curve. If the latter is correct, the deltas may represent a pulse of sediment delivered from the recession of ice cover landward of the fiord-heads under a rising RSL.

The termination of delta growth may have resulted from two independent factors: (1) the flooding of the delta terrace during transgression, or (2) a rapid decline in paraglacial sediment supply as ice retreated inland (Forbes and Syvitski 1994). Preservation of eight deltas 19–45 m b.s.l. attests to a postglacial decrease in sediment supply on Cumberland Peninsula during the following transgression. Even in Boas Fiord, with the largest drainage basin in this study, still partially glaciated, sediment supply has

not kept pace with rising sea level, as the modern sandur front is 4 km up-fiord from the lowstand delta lip.

The depressions found on the surface of the submerged fiord-head delta plain of Kangert Fiord (site 1; Fig. 3A) are interpreted as glacial kettle holes. These demonstrate that this delta was deposited in contact with valley glaciers at a lower RSL. Kangert Fiord is the westernmost fiord where submerged deltas were documented. To the east of Kangert Fiord, the submerged deltas lack kettles and therefore were deposited as ice-proximal to ice-distal deltas when glaciers had receded up-valley.

Based on deglacial ice limits (Fig. 1A; Margreth 2015), the maximum age of deposition is determined by the age of the closest ice limit up-valley from the submerged ice-contact and ice-proximal deltas. The rapid deglaciation of the LIS and peripheral local glaciers was time-transgressive around the perimeter of Cumberland

Fig. 6. X-radiographs of split core halves and lithological log for core DH6, collected from the prodelta area of Durban Harbour (Fig. 3C). LF1 is interpreted as an ice-contact or proximal deposit; LF2 and LF3 coarsen upward in a pattern consistent with prodelta sedimentation and delta progradation, represented by acoustic unit C1 (Fig. 5). LF4 is interpreted as post-submergence sediment.

Peninsula, beginning earlier in the south (Miller 1975; Margreth 2015). All of the submerged deltas reported here were ice covered at 14.6 ka (Margreth 2015). Rapid recession from the fiord mouths proceeded until the readvance to YD ice limits at circa 11.7 ka cal BP. At this time, the two submerged deltas in the southeast were ice-free (sites 7 and 8, Fig. 1A). This interpretation makes assumptions for site 8, as the glacial limits for the YD are interpolated and have not been mapped. The deglaciation of the easternmost coast was more extensive than in the northeast, where alpine glaciers remained in the fiords at the YD readvance and the submerged delta sites in Boas Fiord were still covered by ice (sites 4 and 5, Fig. 1A). Foraminifera in glaciomarine sediments in Sunneshine Fiord have been dated as early as 13.66–13.15 ka cal BP (AA-13052; Andrews et al. 1996; recalibrated by Carter 2021 following the method in this paper). A marked reduction in sedimentation rate circa 10 ka cal BP (Carter 2021) supports the view that the fiord did not see substantial ice readvance in the Cockburn Substage, which has been interpreted as being very limited in scope on the peninsula (Fig. 1; Margreth 2015). The mollusc (*Bathyrca glacialis*) valve recovered from the sparsely colonized prodeltaic unit in Durban Harbour returned a calibrated age range (median) of 9870 (9650) 9490 cal BP (Table 2), which falls between pre-Cockburn and Cockburn ages reported for glacial readvances on eastern Baffin Island. It is possible that this unit, interpreted as basal prodeltaic, may in fact predate the beginning of deltaic sedimentation. It is

Fig. 7. Simulated relative sea level (RSL) histories for Cumberland Peninsula at 66.5°N from Pangnirtung Fiord (65.5°W) to the mouth of Sunneshine Fiord (61.5°W) as output from the ICE-7G_NA (VM7) model (Peltier 2020). Nodes located in Fig. 1A.

taken to constrain the maximum age of the submerged delta shoreline.

The Boas Fiord topset beds are draped by post-submergence marine muds, from which a valve of *Hiattella arctica* was extracted and dated at 1060 (910) 740 cal BP (Table 2). With average sedimentation rates of 0.98–1.39 mm/year calculated from the radiocarbon age, extrapolation downward to the unit C contact, ~2 m below sea-floor, provides a minimum age of 2.05–1.44 ka cal BP for the post-glacial lowstand. Local delta progradation at the lowstand was therefore occurring at some time between 9.9 and 1.4 ka cal BP, corresponding to the transition between the post-YD (Preboreal) recession and the Cockburn Substage readvance at 9.5–9.3 ka cal BP, and the latter half of the Neoglacial readvances (5700–500 cal BP), respectively. This is consistent with our interpretation of a synchronous deltaic deposition equivalent to or younger than the 9.9–9.0 ka cal BP marine limits recorded by Dyke (1979) and aligned with the equivalent isobases of Kaplan and Miller (2003).

It is noteworthy that many of the fiord-head moraines in the study region (Dyke 2013a, 2013b), including those in Kangert, Boas, and Mermaid fiords, and in Durban Harbour, remain undated, and thus a possible readvance and delta-building phase as late as the widespread glacial response to the 8.2 ka event (Young et al. 2012, 2020; Crump et al. 2020) cannot be ruled out. The lowstand date of circa 8.0 ka produced by the ICE-7G_NA (VM7) model (Fig. 7) strongly suggests that a lowstand occurred at that time, when outwash from glacial readvances in response to 8.2 ka regional cooling may have provided the pulse of sediment for delta building. This interpretation points to the need for more detailed work on the ages of post-Cockburn and supposed Neoglacial moraines in these fiord systems of eastern Cumberland Peninsula.

Refining the GIA model

Our documentation of a lower RSL on eastern Cumberland Peninsula conforms with the conceptual model proposed by Dyke (1979) and with the topographic difference results of the ICE-7G_NA (VM7) model (Peltier 2020). Dyke (1979) proposed that the 0.58–0.62 m/km eastward gradient of the raised early Holocene marine limits (E–G in Fig. 8) on the southwest coast of Cumberland Peninsula continues below sea level to the east. In this paper, we report a tightly fitting submerged linear gradient (Fig. 8) consistent with this eastward dipping plane, but at a shallower gradient and offset at a greater depth than Dyke's marine limit shoreline, as might be expected for a lowstand shoreline.

Fig. 8. Least-squares slopes (with 95% confidence limits) for the submerged shoreline depths and the model-derived 8 ka lowstand depths (at the same locations) as a function of longitude (from west to east) across Cumberland Peninsula (Table 1), with the maximum (solid line) and minimum (broken line) trend of raised marine limits (circa 9.5 ka; Dyke 1979). Numbers denote submerged delta locations in Fig. 1A and Table 1; letters correspond to sea-level curves in Fig. 2 (Table 2; Dyke 1979), boulder barricade in Broughton Channel (BC), and sill platform with spits in Akpait Fiord (AF; Cowan 2015), all located in Fig. 1. The 8.0 ka lowstand depths interpolated to the submerged shoreline locations are generated from the ICE-7G_NA (VM7) model (Peltier 2020).

The 8.0 ka lowstand RSL values generated by the model for the surveyed delta locations are remarkably consistent with the observed paleo-shorelines, but with an offset ranging from 1 m in the west to 10 m in the east. The resulting linear slope of the lowstand shoreline derived from the model is $12.48 \pm 0.57 \text{ m}/^\circ\text{longitude} = 0.28 \pm 0.01 \text{ m/km}$ to the east, significantly lower than the observed slope, $0.36 \pm 0.02 \text{ m/km}$, of the submerged deltas ($t = 4.11$ with 16 degrees of freedom, significant at $p = 0.0008$). This suggests that the relict delta depths reported in this study may have value for refining model performance in the study area. It is possible that the offset between the observed and model slopes in Fig. 8 is due to an imperfect fit in timing. However, as noted earlier, there is no evidence of incision, as would be expected if RSL dropped lower after initial deposition of the deltas, and further we might expect a less linear slope if the delta formation were asynchronous. We conclude that the paleo-shoreline was formed very close to the lowstand and likely dates from the same period.

Returning to the offset between the observed and model tilts, alpine glaciation of Cumberland Peninsula exhibited high spatial complexity on a small scale and may not be adequately captured in the ICE-7G model. There is a growing body of evidence on which to base a more refined ice loading model (Corbett et al. 2016; Margreth et al. 2017; Pendleton et al. 2019; Young et al. 2020; Crump et al. 2020). If the hypothesis of a late-Cockburn or 8.2 ka ice readvance to account for delta building close to 8 ka is correct, this points to the need for still further improvement of the Holocene glacial record in the region. It is also possible that some tectonic complexity related to the Baffin Bay rift margin, or other crustal processes, may play a part in the discrepancy between the model and field data sets (Fig. 8).

Conclusion

Over the past several years, the value of high-resolution mapping of the shallow shelf and submerged shorelines in eastern Baffin Island has been increasingly evident (Hughes Clarke et al. 2015; Normandeau et al. 2020; Deering et al. 2021). With the use of multibeam echosounder technology, the first high-resolution maps of these uncharted waters in eastern Cumberland Peninsula were surveyed aboard *MV Nuliajuk* (2012–2014). The results of these surveys were the discovery and documentation of eight submerged ice-proximal deltas (19–45 m b.s.l.) and other submerged coastal landforms. Each of these represents a depth of formation at a lowstand in the sea-level history and can therefore be used to constrain the shoreline gradient resulting from GIA across northern and eastern Cumberland Peninsula. The submerged shorelines exhibit a 0.36 m/km gradient toward the east, confirming the crustal warping hypothesized from marine limits in the southwest (Dyke 1979) and southeast (Kaplan and Miller 2003) and approximating the gradient of the 8.0 ka lowstand RSLs generated by the ICE-7G_NA (VM7) model for these surveyed delta locations (Peltier 2020).

From the deglacial chronology of Cumberland Peninsula and two radiocarbon ages from sparsely colonized early Holocene sediments associated with the Boas Fiord and Durban Harbour submerged deltas, the age of the deltas is constrained between 9.9 and 1.4 ka cal BP, encompassing the age of the 8 ka lowstand identified in the model output. Because a Neoglacial age is implausible for a shoreline as deep as we observe, we conclude that the cause of delta formation close to the Holocene lowstand may have been synchronous readvances between 9.3 and 8.2 ka BP of alpine glaciers into Kangert Fiord and the basins of Boas Fiord, Durban Harbour, Mermaid Fiord, and other systems. This points

to the need for a re-evaluation and testing of the ages of moraines mapped in the heads and tributary valleys of these fiords. This study provides the first detailed imaging and documentation of submerged shorelines in the eastern Canadian Arctic. It demonstrates that former proglacial deltas and a variety of other shoreline landforms with modern analogues can be observed on the seafloor where the relict shorelines have been tilted by postglacial isostatic adjustment of the crust. These submerged RSL indicators can contribute to a better understanding of the crustal response around the LIS and of Holocene and present sea-level change in the Arctic.

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