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Short Paper

Preservation of Arctic landscapes overridden by cold-based ice sheets

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Abstract

For nearly 40 years, a massive, well-preserved glaciomarine delta more than 54,000 years old and ancillary landforms have formed the cornerstone of models positing limited ice-sheet extent in Arctic Canada during the late Wisconsinan. We present exposure ages for large boulders on the delta surface, which coupled with preservation of relict landforms demonstrate that the region was covered by minimally erosive, cold-based ice during the late Wisconsinan. Our data suggest that surficial features commonly used to define the pattern of late Wisconsinan ice movement cannot be used on their own to constrain late Wisconsinan ice-sheet margins in Arctic regions.

Keywords: Baffin Island; Glacial erosion; Quaternary chronology; Cosmogenic nuclide dating; Radiocarbon dating

Introduction

Identifying the extent of former ice sheets is critical to understanding their role in the global ocean–atmosphere–cryosphere system (Clark and Mix, 2002). The extent of the Laurentide Ice Sheet (LIS) in the Arctic during the late Wisconsinan has remained a subject of debate for more than a century (Daly, 1902). The Aston delta (Fig. 1), the largest (82 km^2) ice-proximal, raised, marine delta in the eastern Canadian Arctic, is intrinsically related to the LIS (Løken, 1966). The delta is graded to a sea level 80 m higher than present and contains in situ marine bivalves dated >54,000 ^{14}C yr B.P. The shoreline associated with the Aston delta extends continuously for more than 70 km along the Aston Lowland and is visible on satellite imagery. A complex assemblage of coeval landforms is linked to the shoreline, including numerous glacial meltwater channels that grade to the shoreline and to other smaller deltas at the same elevation.

Løken (1966) argued that the age and near-perfect preservation of the Aston delta and its associated landforms required that ice-free lowland refugia must have persisted through the late Wisconsinan in the eastern Canadian Arctic. This view countered the prevailing Flint (1943) paradigm that envisioned ice-sheet inception in high-relief terrain of the eastern Canadian Arctic, with subsequent expansion during the late Wisconsinan east to the shelf break along the Arctic coastline, and eventually south across the northern United States. The Løken (1966) hypothesis initiated a pendulum swing from the "maximum" LIS reconstruction to a model of a more restricted late Wisconsinan margin of the LIS (Dyke and Prest, 1987).

We tested the validity of the Løken (1966) hypothesis by dating large boulders resting on the Aston delta surface using cosmogenic radionuclides. We find that the boulders are much younger than the delta, and hypothesize that they were delivered by cold-based continental ice that withdrew from the area about 14,000 years ago, leaving behind a nearly undisturbed relict landscape.

The Aston Lowland

Løken's (1966) argument that the Aston Lowland could not have been glaciated during the late Wisconsinan rests on his interpretation of the surficial geology of the region. Although it has long been recognized that the modern surface commonly reflects the integrated effect of glaciation over several cycles (Miller et al., 1977), intact, large-scale landform assemblages are widely considered to be reliable indicators of the most recent episode of glacial activity. Where ice sheets are frozen to their beds and therefore produce little direct landform

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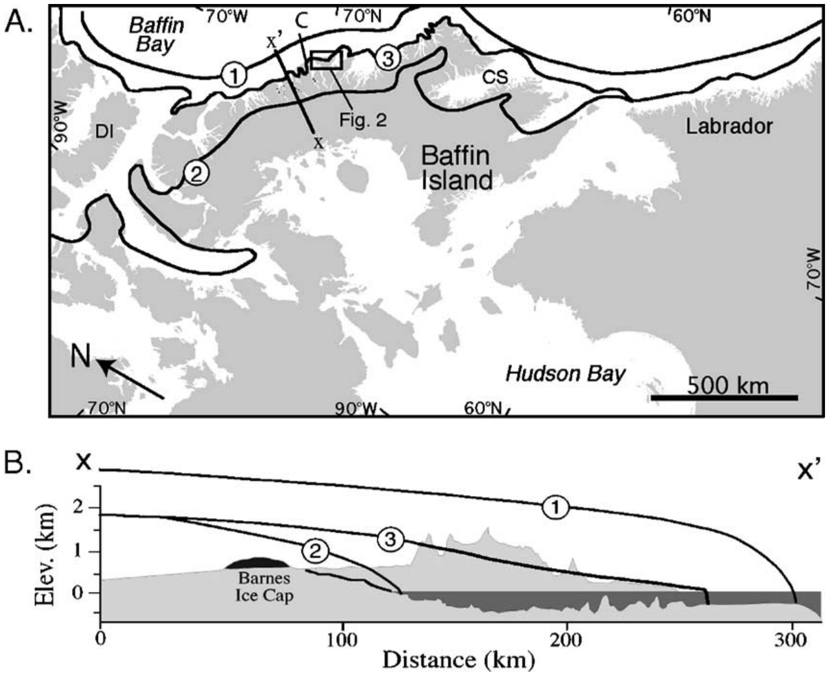

Figure 1. (A) Map of eastern Canadian Arctic showing Baffin Island and three late Wisconsinan reconstructions of the Laurentide Ice Sheet (LIS): (1) maximum extent representative of the Flint (1943) paradigm, (2) minimal extent representative of the Løken (1966) hypothesis and (3) extensive but thin ice sheet extent that accommodates new data presented here. Box shows location of Figure 2. CS = Cumberland Sound, DI = Devon Island, C = hamlet of Clyde River. B. Schematic cross section showing ice sheet profiles superposed on topographic profile for the landscape near x–x′ line on panel A and bathymetry of Clyde Inlet.

modification, meltwater channels that form along ice margins during deglaciation are the primary basis for defining the maximum ice extent and patterns of ice retreat (Dyke, 1993; Dyke et al., 1992). Meltwater channels typically drain to marine deposits, which commonly contain radiocarbon-datable organic materials that provide age constraints for ice margins. Thus, Løken (1966) concluded that the Aston delta, meltwater channels, and surrounding landscape pre-dated the late Wisconsinan. Implicit in this interpretation is that the meltwater channels were formed during the most recent glacial cycle, with evidence of earlier glaciations having been obliterated by later advances.

Radiocarbon dating

We reoccupied Løken's (1966) mollusk sampling site on the Aston delta (Figs. 2, 3A) where in situ, paired marine bivalves provided an age of >54,000 ^{14}C yr B.P. We confirmed Løken's (1966) result with new AMS ages of >48,800 ^{14}C yr B.P. on in situ paired valves of the mollusk *Mya truncata* (Fig. 3B) and >47,800 ^{14}C yr B.P. on adjacent woody plant remains (Table 1). These ages, taken together with four other new ^{14}C ages from the Aston Lowland (Table 1), confirm that most surficial deposits on the lowland pre-date the late Wisconsinan. From aerial photographs, Coulthard (2003) also mapped moraines, glacially fluted terrain, meltwater channels, the 80 m asl (above sea level) marine limit, and a younger marine shoreline at ~23 m asl on the Aston Lowland (Fig. 2). Ice-marginal meltwater channels converge at the Aston delta from ice sources in both Inugsuin and McBeth fiords. Many other smaller meltwater channels descend to the 80-m asl shoreline where they terminate, but subsets of independent meltwater channels cross the 80-m asl shoreline and terminate at the 23-m asl shoreline.

Cosmogenic exposure dating

The Aston delta is strewn with large boulders that rest on the delta surface. We sampled eight quartz-rich granitic to gneissic boulders (Fig. 3C; averaging 5 m on a side and 2.5 m high) and two quartz cobbles from the surface of the Aston delta for ^{10}Be and ^{26}Al cosmogenic exposure (CE) dating. Two additional boulders and one cobble were collected seaward of the delta. Cobble/boulder pairs were sampled to test for the possible shielding effects of seasonal snow cover, which rarely exceeds 1 m in the current regime. All cobbles were collected from wind-swept, snow-free surfaces in spring, when snow depths are greatest, minimizing snow-cover shielding. Comparing cobble and boulder ages also allows testing of landscape stability, as frost churning is more likely to affect cobbles than large boulders. We also collected beach cobbles from the 80-m asl shoreline along the Aston and adjacent lowlands, and three frost-riven bedrock samples from a low bedrock knoll (~124 m asl) protruding through the apex of the Aston delta (Fig. 2).

Methods, materials, and calculations

We visited the Aston Lowland in the summers of 2001 and 2002, and in May of 2002 and 2003, near the peak in snow depth. During summer fieldwork, we mapped details of the lowland, but foot travel limited collection for exposure dating. In the spring, we used snow machines to collect more samples for exposure dating. Samples were collected using sledge

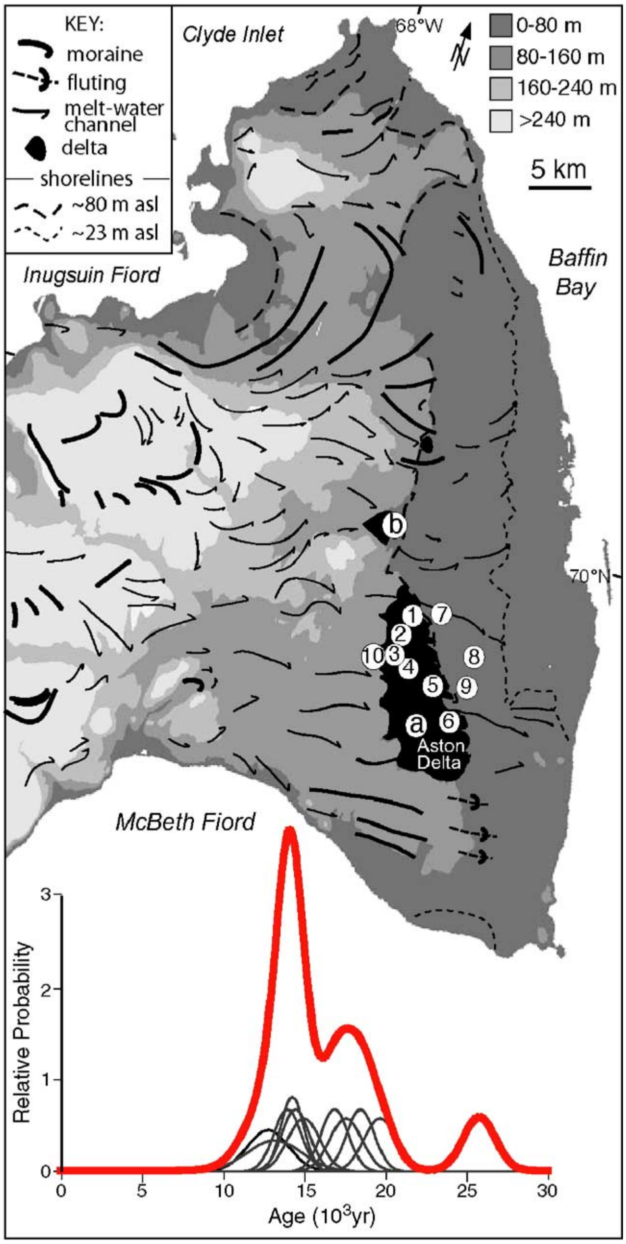

Figure 2. Map showing surficial geologic features of Aston Lowland and site locations for ^{14}C ages and thirteen cosmogenic exposure (CE) age samples. Raised glaciomarine deltas at ~80 m asl shown in black (see Table 1 for radiocarbon data on pre-Holocene buried organics). Løken's (1966) ^{14}C sampling site on Aston delta labeled 'a'. Rocky River delta labeled 'b'. Pre-LGM marine limit at 80 m asl shown by thick dashed line; post-glacial marine shoreline at ~23 m asl shown by thin dashed line. Probability distribution functions (PDFs) of nine ^{10}Be ages and three weighted pairs of ^{10}Be and ^{26}Al ages between 0 and 30,000 yr ago are shown as individual (where the area under each age distribution is one) and stacked (constructed by summing the individual PDFs) curves below map (for full CE dataset, see Table 2 and Briner (2003)).

hammers and chisels. Elevations were taken by combining GPS readings with information from 1:50,000-scale topographic maps with 10-m contour intervals; we consider sample elevation to be accurate to ±10 m. Where possible, we sampled quartz veins, but we commonly sampled quartz-rich granitic and gneissic surfaces. In all cases, efforts were made to sample the uppermost horizontal surface, considering surface geometry, sample height, potential surface erosion, and sample thickness. We targeted the centers of these surfaces to minimize edge effects (Masarik and Wieler, 2003).

Several factors make the Aston Lowland especially well suited for CE dating. Quartz, the target mineral for ^{26}Al and ^{10}Be exposure dating, is abundant in the Canadian Shield crystalline rocks of this region (Jackson et al., 1984). The Aston Lowland is a rocky landscape with hundreds of large erratic boulders (up to 10 m in exposed diameter), which are stable because they are large, commonly tabular, and lie on flat, well-drained rocky surfaces, with negligible periglacial activity. The hamlet of Clyde River reports a mean annual temperature of −12.4°C and a mean annual precipitation of 226 mm (http://www.climate.weatheroffice.ec.gc.ca). By observing and sampling erratics at the time of maximum snow depth, we have concluded that snow shielding, which would lead to erroneously young ages, is probably negligible; we avoided taking samples in gullies or small depressions where snowdrifts form. Bedrock erosion, which also leads to erroneously young ages, is slow in this region, $\leq$1.1 mm/1000 yr (Lal, 1991), so we treat boulder surface erosion as negligible. For erratics with a complex exposure and burial history, the calculated CE ages are technically *apparent* ages based on total cosmogenic nuclide concentrations.

Samples were prepared at the University of Colorado Cosmogenic Isotope Laboratory following procedures modified from Kohl and Nishiizumi (1992) and Bierman and Caffee (2001). A small subset of samples from the Clyde Foreland was prepared at the University of Vermont using the same procedures. Samples were crushed, and the 425–850 μm fractions were retained after sieving. Samples were then treated in acid solutions to remove clays and meteoric ^{10}Be. After heavy-liquid mineral separation, quartz was purified in a heated sonication bath with dilute HF-HNO_3. Typically 30–40 g of pure quartz were dissolved in batches of 10 or 11 samples, with one process blank per batch; known amounts of SPEX-brand Be and Al carrier were added to each sample and the blank. After complete dissolution, samples were treated with perchloric acid to remove fluoride and passed through an anion exchange column to separate Fe and Ti. Finally, Be and Al were separated using cation exchange. Al and Be hydroxides were precipitated, dried, heated to produce oxides, and packed into targets for accelerator mass spectrometric (AMS) measurement at Lawrence Livermore National Laboratory. The observed isotopic ratios were normalized to ICN ^{10}Be ($t_{1/2} = 1.5 \times 10^6$ yr) and NBS ^{26}Al ($t_{1/2} = 7.05 \times 10^5$ yr) standards that were diluted by K. Nishiizumi (personal communication, 1999). ^{10}Be/^{9}Be and ^{26}Al/^{27}Al ratios in our process blanks average $2.5 \pm 0.2 \times 10^{-14}$ and $1.3 \pm 0.5 \times 10^{-14}$, respectively.

CE ages were calculated using ^{10}Be and ^{26}Al production rates of 5.1 and 31.1 atoms g^{-1} yr^{-1}, respectively (Stone, 2000; Gosse and Stone, 2001). Site-specific production rates were corrected for elevation after Lal (1991), with consideration of both neutrons and muons according to Stone (2000), and for sample thickness. Because these samples are from

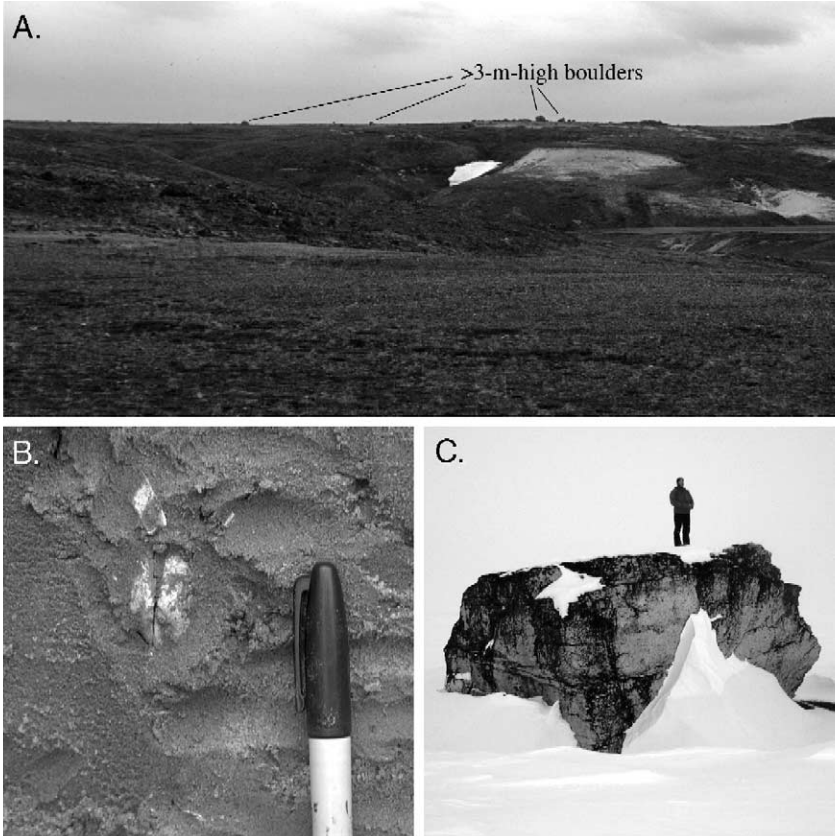

Figure 3. (A) Photograph of erosion gully (about 15 m vertical exposure) in 80-m asl glaciomarine delta on the Aston Lowland where Løken (1966) collected marine bivalves with ^{14}C ages >54,000 ^{14}C yr B.P.; arrows pointing at a boulders on delta surface. (B) Photograph of paired in situ marine bivalve that provided AMS ages of >48,000 and >54,000 ^{14}C yr B.P. (see Table 1), with marker for scale. (C) Photograph of large boulder on Aston delta sampled for CE dating, with person standing on top for scale.

high latitude (~70°N), nuclide production rates are not influenced by time-dependent changes in the geomagnetic field. The ages reported here are not corrected for atmospheric pressure anomalies, but if average low pressure over Baffin Bay that exists today has been a persistent feature, production rates may be underestimated by ~2% in the field area (Stone, 2000).

The CE age uncertainties reported here include only AMS measurement uncertainly at one standard deviation. Both ^{10}Be and ^{26}Al exposure ages were calculated for five samples. Three of these independent analyses exhibited good correlation (Table 2). An uncertainty-weighted average age was used for these three samples. Assigning fixed numbers to geological sources of uncertainty (e.g., post-depositional boulder stability,

Table 1
Pre-Holocene radiocarbon ages from Aston Lowland

Location	Material	Enclosing sediment	Sample elevation (m asl)	Relative sea level (m asl)	Conventional ^{14}C Age (^{14}C yr B.P.)	Lab number[a]	Lat. (°N)	Long. (°W)	Reference
Aston delta	*M. truncata*	Stratified sand	69	80	>48,800[b]	CURL-6843	69°52′	67°31′	Coulthard (2003)
Aston delta	*M. truncata*	Stratified sand	69	80	40,600 ± 2000[b,c]	AA-53298	69°52′	67°31′	Coulthard (2003)
Aston delta	*M. truncata, H. arctica*	Fine sand	61.3	80	>54,000	Y-1703	69°52′	67°31′	Løken (1966)
Aston delta	*M. truncata, H. arctica*	Fine sand	61.3	80	32,000 + 2000/ −1600[d]	I-1815	69°52′	67°31′	Andrews and Drapier (1967)
Aston delta	*H. arctica*	Clay	65	80	>39,000	I-1814	69°55′	67°34′	Andrews and Drapier (1967)
Aston delta	Wood	Stratified sand	75	80	>47,800[b]	CURL-6778	69°54′	67°33′	Coulthard (2003)
Rocky River delta	*M. truncata*	Bottomset mud	71	87	>54,700[b]	CURL-6957	69°59′	67°42′	Coulthard (2003)

[a] Laboratory designations: AA = University of Arizona NSF AMS Facility; CURL = University of Colorado Laboratory for Radiocarbon Preparation and Research; I = Teledyne Isotopes; Y = Yale University.

[b] Indicates an AMS determination, all other ages are conventional radiometric ages.

[c] Age is from same sample as CURL-6843; age is considered a minimum.

[d] Age is from same sample as Y-1703; age is considered a minimum.

Table 2
Sample site information and cosmogenic exposure age data for Aston Lowland

Sample ID	Sample type[a]	Site # (Fig. 2)	Lat. (N)	Long. (W)	Elevation (m asl)[b]	Sample height (m)[c]	^{10}Be (10^5 atoms g^{-1})	^{26}Al (10^5 atoms g^{-1})	^{10}Be age (×1000 yr)	^{26}Al age (×1000 yr)	Weighted mean age and 1 S.D. uncertainty (×1000 yr)
Aston delta											
PT01-04	Boulder	2	69° 53.642′	67° 35.100′	85	1.2	0.66 ± 0.03	4.41 ± 0.13	11.9 ± 0.5	13.2 ± 0.4	12.7 ± 0.9
CAD-COS-1	Cobble	3	69° 54.177′	67° 36.000′	87	0.0	0.71 ± 0.09	ND	13.1 ± 1.2	ND	ND
PT01–07	Boulder	1	69° 54.452′	67° 33.833′	80	1.2	0.74 ± 0.02	4.74 ± 0.14	13.5 ± 0.4	14.3 ± 0.4	13.9 ± 0.6
CAD02–8	Boulder	6	69° 52.079′	67° 27.388′	75	1.0	0.76 ± 0.03	ND	13.9 ± 0.6	ND	ND
CAF02–1[d]	Cobble	7	69° 55.210′	67° 33.066′	41	0.0	0.75 ± 0.03	ND	14.2 ± 0.5	ND	ND
CAD02–5	Boulder	4	69° 53.164	67° 29.801′	79	4.0	0.78 ± 0.03	ND	14.4 ± 0.6	ND	ND
CAD02–9[d]	Boulder	9	69° 53.086′	67° 27.357′	47	3.5	0.79 ± 0.04	ND	14.9 ± 0.7	ND	ND
CAD02–10[d]	Boulder	8	69° 53.751′	67° 26.581′	37	4.5	0.88 ± 0.03	ND	16.8 ± 0.6	ND	ND
PT01–06	Boulder	1	69° 54.627′	67° 33.888′	80	1.4	0.95 ± 0.03	5.76 ± 0.17	17.5 ± 0.5	17.4 ± 0.5	17.5 ± 0.7
CAD02–6	Boulder	2	69° 53.164′	67° 29.801′	73	1.5	0.99 ± 0.03	ND	18.4 ± 0.6	ND	ND
CAD02–7	Cobble	5	69° 53.164′	67° 29.801′	73	0.0	1.06 ± 0.04	ND	19.6 ± 0.7	ND	ND
CAD02–4	Boulder	4	69° 53.089′	67° 33.629′	78	4.0	1.42 ± 0.04	ND	25.8 ± 0.7	ND	ND
PT01–05	Boulder	2	69° 53.700′	67° 34.972′	85	1.5	5.13 ± 0.13	33.1 ± 0.98	95.4 ± 2.4	103.9 ± 3.1	98.5 ± 6.0
Bedrock knoll near Aston delta apex											
CAD02–2	Felsenmeer	10	69° 53.532′	67° 37.436′	124	<1.0	1.89 ± 0.05	ND	33.2 ± 0.9	ND	ND
CAD02–1	Felsenmeer	10	69° 53.532′	67° 37.435′	124	<1.0	4.56 ± 0.11	ND	81.1 ± 2.0	ND	ND
PT01–03	Felsenmeer	10	69° 53.164′	67° 37.465′	125	<1.0	7.77 ± 0.19	42.5 ± 1.2	139.5 ± 3.4	128.9 ± 3.7	134.6 ± 7.5
80 m asl marine limit cobbles											
CAF02–2	Cobble	–	70° 00.564′	67° 43.442′	83	0.0	1.10 ± 0.12	ND	20.7 ± 1.3	ND	ND
CF02–89	Cobble	–	70° 44.491′	69° 20.824′	82	0.0	1.57 ± 0.13	ND	29.5 ± 0.8	ND	ND
CF02–7	Cobble	–	70° 33.173′	68° 36.378′	85	0.0	1.91 ± 0.17	ND	34.7 ± 1.1	ND	ND
CF02–88	Cobble	–	70° 44.491′	69° 20.824′	82	0.0	2.16 ± 0.18	ND	40.7 ± 1.0	ND	ND
CF02–40	Cobble	–	70° 42.786′	69° 08.785′	85	0.0	2.22 ± 0.19	ND	40.9 ± 1.0	ND	ND
CF02–8	Cobble	–	70° 33.173′	68° 36.378′	85	0.0	2.35 ± 0.20	ND	42.6 ± 1.2	ND	ND
CAF02–3	Cobble	–	70° 00.564′	67° 43.44′3	83	0.0	4.05 ± 0.35	ND	76.7 ± 2.2	ND	ND

[a] Felsenmeer refers to frost-riven bedrock.

[b] Elevation determined by GPS.

[c] Sample height refers to height of sampled surface above surrounding landscape.

[d] Samples <1 km beyond delta lip.

isotopic inheritance, and snow cover) is difficult. However, quantifying methodological uncertainties is possible. Total Be and Al measurements are estimated to be accurate to 2% and 4%, respectively, and AMS uncertainties average ~4%. Thus, the propagated random error associated with analytic uncertainties is on the order of 4% to 5% for ^{10}Be and 5% to 6% for ^{26}Al. Additional uncertainty can be ascribed to knowledge of production rates: ~6% (Bierman and Caffee, 2001; Stone, 2000) and with estimation of elevational scaling: ~5% (Gosse and Phillips, 2001). We estimate the total uncertainty from all of these causes to be on the order of 2000 yr for late Wisconsinan samples.

Results

The thirteen boulder and cobble samples both distal to the delta and from its surface yield CE ages that range from about 12,000 to 100,000 yr (Table 2). However, seven of the boulder and cobble samples from the Aston delta cluster between 11,900 and 14,900 yr, with an average age of 13,900 ± 800 yr (Fig. 2). The remaining six samples from the Aston delta are older. Based on the CE age distribution of boulders in a nearby study area, Briner et al. (2005) concluded that the boulders must have contained variable amounts of inherited cosmogenic nuclide. In a similar fashion, we conclude that the six older samples from the Aston delta carry variable amounts of inherited cosmogenic nuclide. Paired ^{10}Be and ^{26}Al ages on four samples (Table 2) are statistically indistinguishable at $\pm 2\sigma$, bolstering the analytical accuracy of the ages. Two of the three cobble ages fall within the 13,900 ± 800 yr boulder cluster, indicating that the landscape surface has been stable and that snow shielding since deposition has had minimal influence.

The seven cobbles from the 80-m asl shoreline along the Aston and adjacent lowlands have CE ages that range from 21,000 to 77,000 yr; five of the cobbles date between 30,000 and 42,000 yr ago. (Table 2). Bedrock samples collected from the low knoll near the Aston delta apex have CE ages of 33,000, 81,000, and 135,000 yr (Table 2).

Discussion and conclusions

We conclude that only glacial ice could have delivered the boulders to the delta surface and the lowland beyond. There are few transport mechanisms that can deliver large boulders to a delta surface without disturbing it. Stream incision into the delta reveals some pebbles in a grain-supported sandy matrix, interbedded with finer quiet-water muds, but no cobbles or boulders. There is also no evidence for deflation, such as hollows in the delta surface, eliminating the possibility that the boulders are lag deposits from the delta. The low elevation of the ~23-m asl marine shoreline, of probable postglacial age, and the elevation of the independent meltwater channels draining to it preclude deposition of the boulders by iceberg rafting (Tarr, 1897) or surface reworking by sea-ice (Løken, 1966; Dionne, 1978). Mass wasting, such as ice-marginal debris flows or slush avalanches, could explain deposition of some of the boulders if the late Wisconsinan ice margin were near the delta apex, but it cannot explain the presence of boulders over 2.5 m in height near the delta lip. Fluvial systems across the lowland lack competence to move these boulders.

All seven beach cobbles collected along the 80-m asl shoreline pre-date the late Wisconsinan. Their exposure ages support our contention that the landform assemblage associated with a relative sea level ~80 m above present, including the Aston delta, was formed before the late Wisconsinan. That six of these cobbles have shorter exposure histories than the age of the 80-m asl shoreline and related features (>54,000 ^{14}C yr B.P.) requires that the cobbles have been shielded from cosmic radiation for a substantial portion of their post-depositional history (Table 2).

Our new CE ages for boulders and cobbles scattered across the Aston Lowland suggest that they have been exposed subaerially for only 14,000 yr. Basal ^{14}C ages of lake sediment on the Aston and adjacent lowlands indicate that open lake basins have been present since at least 12,000 yr ago (Briner, J.P., and Coulthard, R.D., unpublished data, 2003). The CE ages are most simply explained if the boulders experienced a single episode of exposure following their deposition by retreating late Wisconsinan ice.

Collectively, our evidence is only reconcilable with inundation of the lowlands during the late Wisconsinan by continental ice that was frozen to its bed, and therefore minimally erosive. This interpretation is strengthened by the three bedrock samples (Table 2) that have exposure histories longer than the postglacial period (14,000 yr), confirming that the bedrock was not covered or substantially eroded by late Wisconsinan ice.

Our data document exceptional preservation of an ancient landscape assemblage of surficial deposits extending over 100 km of coastline, despite inundation by a late Wisconsinan continental ice sheet. This observation challenges some of the fundamental interpretations of surficial geology in the Arctic, interpretations both of late Wisconsinan ice sheet extent in general and also of ice-marginal channels in specific (Dyke and Prest, 1987; Dyke, 1993). The dominant, large, ice-marginal meltwater channels that unambiguously terminate at the 80-m asl shoreline across much of the Aston Lowland reinforce the striking preservation of the Aston delta. These channels originate as point sources a few km inland of the shoreline and are unrelated to modern drainages. Some channels are associated with small deltas along the 80-m asl shoreline; others simply terminate in beach berms at the same elevation, but none exhibits subsequent equilibration to a lower base level. Most meltwater channels across the Aston Lowland must have formed during a deglaciation prior to the late Wisconsinan and were not substantially modified when overridden by cold-based late Wisconsinan ice. Nor was sufficient meltwater released as late Wisconsinan ice receded to incise these dominant meltwater channels to the lower (~23 m asl) base level. However, we associate the second independent set of delicate, lateral meltwater channels graded to the ~23 m asl shoreline with retreat of the late Wisconsinan ice sheet.

Our results challenge Løken's (1966) interpretation of ice-free refugia and, by extension, imply that many other lowlands in the eastern Canadian Arctic (Ives, 1978; Dyke, 1979; Andrews, 1987; England, 1976) also may have been glaciated by thin, minimally erosive cold-based ice during the late Wisconsinan. These conclusions are consistent with the concept of Arctic ice sheets having variable basal temperature regimes during the late Wisconsinan, including cold-based sectors (Sugden, 1977; Hughes et al., 1977). Our results are also compatible with other recent studies based on dated marine and terrestrial archives, many using CE dating, that have defined expanded margins of continental ice for northern Labrador (Clark and Josenhans, 1986; Marquette et al., 2004), southeastern Baffin Island (Bierman et al., 1999; Marsella et al., 2000; Kaplan et al., 2001, Miller et al., 2002), Devon Island (Dyke, 1999), Ellesmere Island (Zreda et al., 1999; England et al., 2004), and all of arctic Canada (Dyke et al., 2002).

Relict landscapes are known to occur across the core areas of the former Laurentide and Fennoscandian ice sheets (Dyke, 1993; Kleman and Hätterstrand, 1999), and extensive buried forests of last interglacial age occur around Hudson Bay (Terasmae and Hughes, 1960). Tors and other relict bedrock features have also been reported at high elevations within the boundaries of these ice sheets, where their preservation is ascribed to non-erosive, cold-based ice (Bierman et al., 1999; Fabel et al., 2002; Briner et al., 2003; Marquette et al., 2004). However, no demonstrably relict, large-scale, depositional-landform assemblages similar to those mapped on the Aston Lowland have been found preserved at the former margins of any large, Northern Hemisphere ice sheet. Our new data from the Aston Lowland demonstrate that entire landscape assemblages of surficial deposits and erosional features (including relatively delicate meltwater channels) found at the margins of former ice sheets may have been left essentially intact by overriding cold-based ice sheets. These findings provide an interpretative challenge to glacial geologists mapping former ice margins across the Arctic.

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