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1 **Evidence for an extensive ice shelf in northern Baffin Bay during the Last**
2 **Glacial Maximum**

3

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17 **Abstract**

18 The glaciological significance of ice shelves is relatively well established for the stability of
19 modern ice sheets of Antarctica. Past ice shelves of the Arctic, however, are poorly documented
20 while their role for the stability of former ice sheets remains mostly unknown. Here we present
21 swath bathymetry data and seismostratigraphic profiles that reveal a large moraine system
22 extending along the continental slope off Baffin Island, demonstrating that a 500-m thick ice
23 shelf covered northern Baffin Bay during the last glacial episode. We suggest that this ice shelf
24 had a profound impact on the stability of a series of major ice streams that drained the interior of
25 the Laurentide, Innuitian and Greenland ice sheets. Climate warming and global sea-level rise in
26 the early stage of deglaciation possibly contributed to a large-scale break-up of the ice shelf,
27 which led to the destabilisation and reorganisation of tributary ice streams from these three ice
28 sheets.

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30 **Introduction**

31 Ice shelves are critical components of marine-terminating ice sheets due to their buttressing effect
32 that controls mass balance by stabilizing the ice margins facing the ocean¹⁻⁷. Retreat and break-up
33 of ice shelves in Antarctica^{2,3,6,8-11} occur today at a time of important climate warming and may
34 lead to a drawdown of the West Antarctic Ice Sheet, resulting in a rapid transfer of ice to the ocean
35 and thereby contributing to global sea-level rise^{1,2,11,12}. Identifying former ice shelves and
36 reconstructing their evolution through time –particularly for past ice sheets of the Northern
37 Hemisphere where they remain poorly documented^{3,12,13}– will provide an essential analogue for
38 understanding the stability of modern ice sheets and their interplay with climate and global sea-
39 level change.

40 Baffin Bay forms a 450 km-wide and 2000 m-deep embayment between the Canadian Arctic
41 Archipelago and Greenland (Fig. 1). At the Last Glacial Maximum (LGM; locally ~25-16 ka BP),
42 Baffin Bay was located at the confluence of three ice sheets –the Laurentide (LIS), Innuitian (IIS)
43 and Greenland (GrIS) ice sheets¹⁴⁻¹⁷– forming a continuous belt of ice streams draining the interior
44 of Northern North America and Greenland and extending at or near the continental shelf break in
45 many sectors¹⁸⁻²⁶. However, the extension of these ice sheets beyond their grounding zones to form
46 floating ice shelves remains elusive. The scenario of ice shelves in the northern Hemisphere have
47 been hypothesized repeatedly since it was first introduced by Mercer²⁷ as a comparison between
48 the Arctic Ocean and West Antarctica. Hughes et al.²⁸ later expanded the idea to include floating
49 ice shelves in Baffin Bay and eastern North America. The scenario of an ice shelf extending in
50 Baffin Bay from a southern source of ice grounded in Davis Strait and associated with the Hudson
51 Strait Ice Stream was speculated by Hulbe²⁹ as a starting point to explain the mechanisms behind
52 Heinrich events. Although Hulbe et al.³⁰ modified their original stance to instead support fringing
53 ice shelves along the coasts of Eastern Canada, the idea of an extensive ice shelf sealing Baffin
54 Bay from the Labrador Sea was adopted in the following decades^{31,32} although still debated as a
55 trigger mechanism for Heinrich events³³. However, this scenario was recently refuted by Jennings
56 et al.³⁴ who argued that such an ice shelf would have impeded Labrador Sea water advection, a
57 key component for biological productivity observed at the LGM in cores off western Greenland.
58 They suggested instead that the GrIS margin was protected by either a belt of fringing ice shelves
59 and/or perennial sea-ice –a scenario in line with Hulbe et al.³⁰– that prevented deposition of ice-
60 rafted debris (IRD) and enabled marine advection and food supply during the LGM. Alternatively,
61 a scenario of an ice shelf from a northern source of ice grounded in northern Baffin Bay has been
62 so far unaddressed, in a context where the marine-terminating Lancaster Sound and Smith Sound
63 ice streams captured several major tributaries from the LIS, IIS and GrIS^{17,21}, creating ideal
64 conditions for the formation of an ice shelf that potentially controlled the stability of other ice
65 streams outflowing from the eastern Canadian Arctic Archipelago and western Greenland^{17,24,25}.

66 Solving the ice shelf issue in Baffin Bay is therefore necessary for evaluating the effects of
67 buttressing on ice flow, ice streams stability and ice sheet mass balance changes during a key stage
68 of deglaciation of the Arctic and a period of major meltwater flow into the ocean. Here we present

69 geophysical (swath bathymetry, acoustic profiles) datasets and a compilation of previously
 70 published sediment core data collected on the outer sector of the cross-shelf trough off Clyde Inlet
 71 (Baffin Island) and its adjacent continental slope of western Baffin Bay that together demonstrate
 72 the existence of an ice shelf in northern Baffin Bay –the Northern Baffin Bay Ice Shelf (NBBIS)–
 73 during the last glacial episode (Fig. 1). This geomorphological evidence and the re-interpretation
 74 of sediment cores allow defining the extent of the LIS on the continental shelf at the LGM and
 75 examining the potential impact of an ice shelf collapse on the evolution of ice streams of the three
 76 marine-terminating ice sheets in Baffin Bay.

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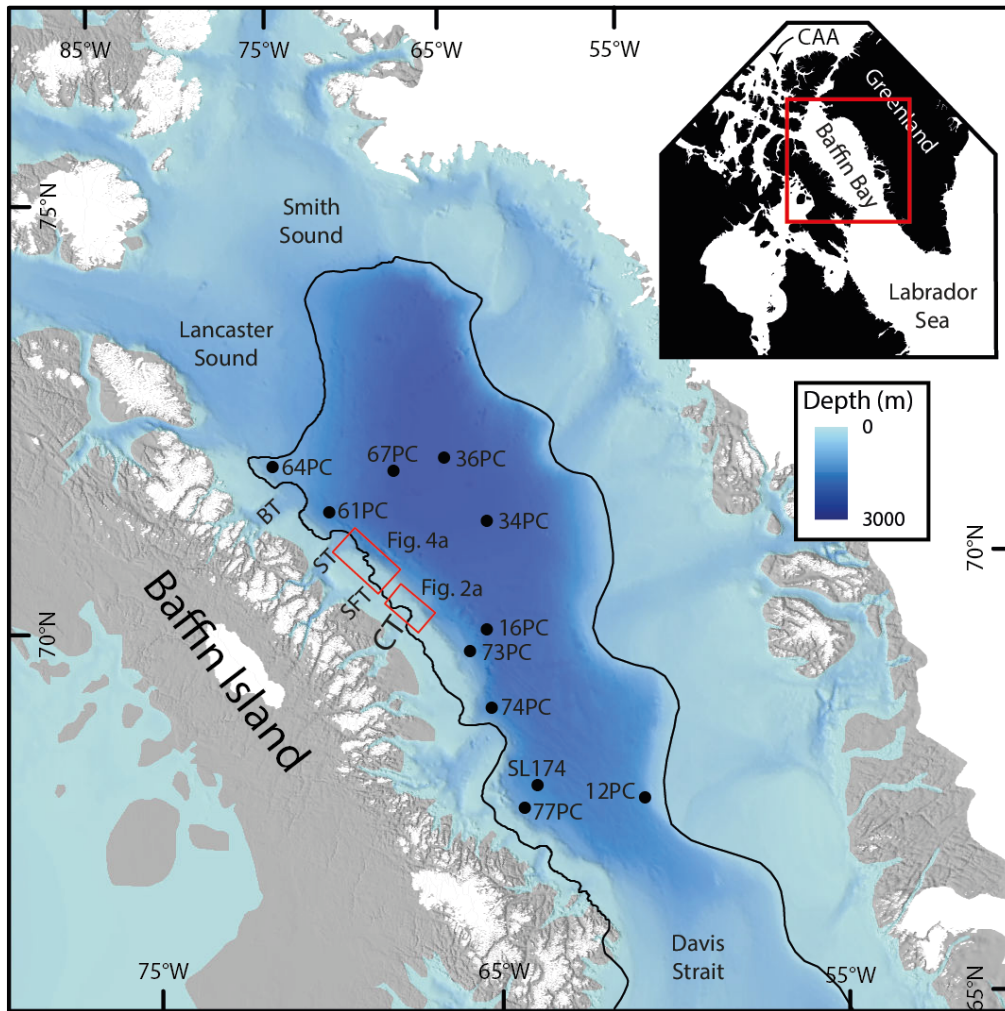
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Fig. 1: Location map of the investigated area. Location of Clyde Trough (CT), sediment cores and maximum extent of grounded ice on western Baffin Bay (thick line), compiled and modified from previous works^{21,25,26} and this paper. BT: Buchan Trough; ST: Scott Trough; SFT: Sam Ford Trough. Red rectangles represent study areas shown in greater details in Figs 2 and 5. (Inset) Location of Baffin Bay north of the Labrador Sea and between Greenland (GR) and the Canadian Arctic Archipelago (CAA).

100 **Results and discussion**

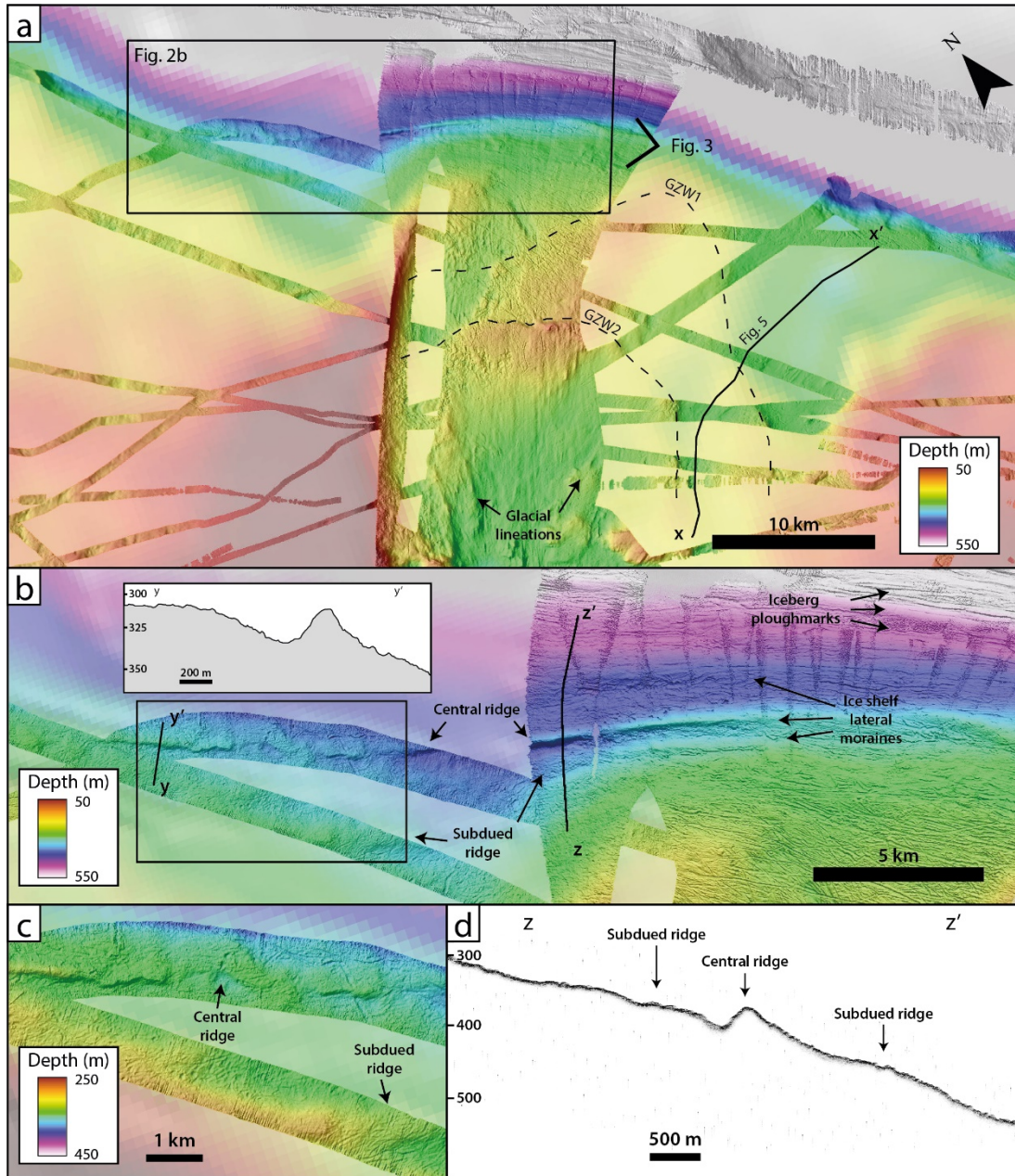
101 **The geomorphological signature of the NBBIS**

102 Three ridges running in parallel to the continental slope off Clyde Trough between 300 and 420
103 meters below sea-level (mbsl) are observed on the swath bathymetry imagery (Fig. 2a-b). These
104 ridges are independent from grounding zone wedges (GZWs) constructed by outlet glaciers and
105 ice streams emanating from Baffin Island. The central ridge is the largest; it is 30 m high, ~300-m
106 wide and extends almost continuously for >30 km along the slope off Clyde Trough (Fig. 2a and
107 3). It has an asymmetric profile showing a gentler ocean-facing slope and is observed at
108 progressively decreasing depths from north (330 mbsl) to south (300 mbsl). Although it appears
109 to be streamlined along the continental slope, one of the segments of the central ridge (Fig. 2b and
110 2c) shows evidence of sediment accretion by ice push in a NW-SE direction (i.e., towards Baffin
111 Island). Additionally, two 5-10 m-high subdued ridges occur on both sides of the main ridge at
112 420 and 310 mbsl, extending for <5 km in front of Clyde Trough and showing geomorphic
113 similarities to the neighbouring central ridge (Fig. 2b). Similar ridges are also observed at 350
114 mbsl off Sam Ford Trough and 410 mbsl south of Scott Trough, 40 and 100 km northwest of Clyde
115 Trough, respectively (Fig. 4). These ridges probably correspond to the central ridge observed on
116 the upper continental slope off Clyde Trough as they are also ~30 m high with a gentler ocean-
117 facing slope.

118 We rule out the possibility of these landforms being terminal moraines of the LIS on the upper
119 continental slope as its geometry does not appear to be influenced by the location of cross-shelf
120 troughs. If they indeed originated from flowing ice across the Baffin Island continental shelf, one
121 would expect some bulge in front of the trough. Instead, we observe a curvature in the orientation
122 of these ridges into Clyde Trough (Fig. 2a). These ridges are therefore interpreted as lateral
123 moraines of the NBBIS on the basis of (a) their geomorphology similar to previously reported ice-
124 shelf moraines in the Canadian Arctic Archipelago³⁵⁻⁴⁰, and (b) their location, depth and orientation
125 along the continental slope off Baffin Island. The progressively decreasing depths of these ice shelf
126 lateral moraines comply with a paleoglaciological reconstruction including a seaward thinning of
127 the ice shelf. The smaller subdued ridges could represent different phases and/or thickness changes
128 of the NBBIS during the LGM, although their relatively subdued appearance could also suggest
129 formation during prior glaciations (i.e., MIS-6).

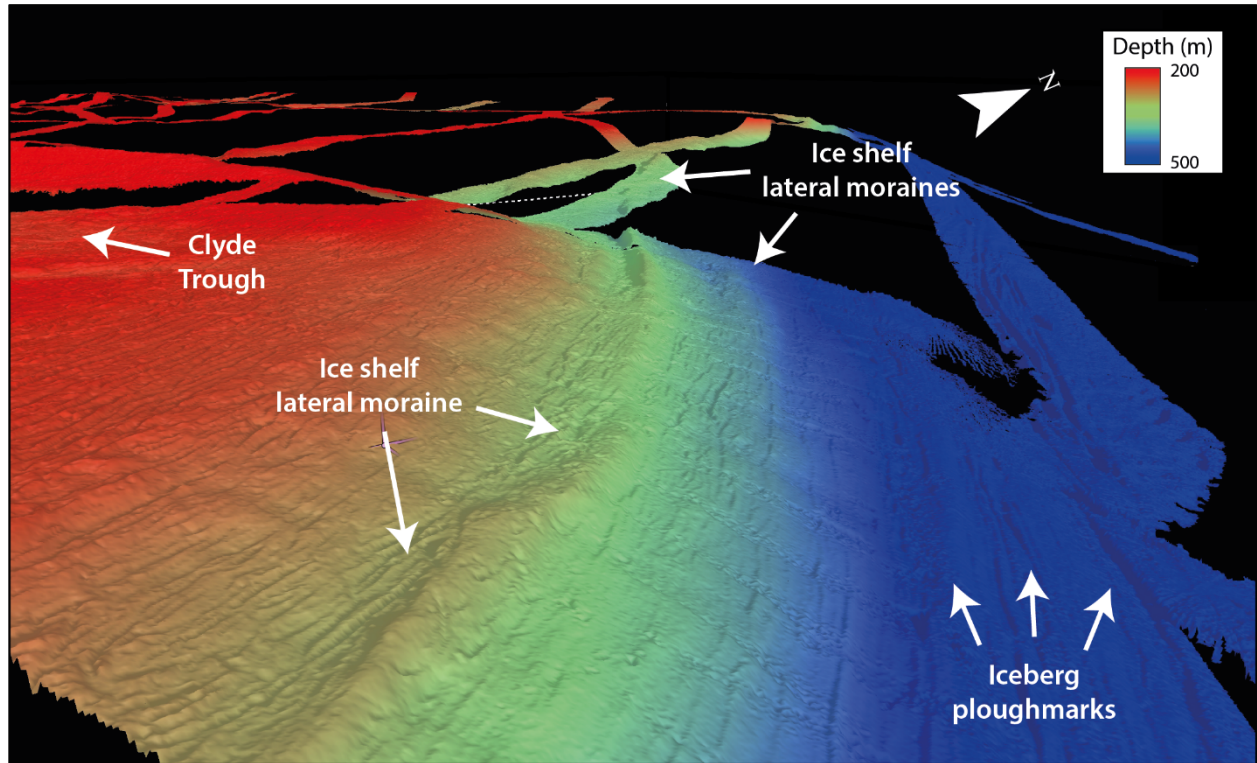
130 In outer Clyde Trough (Fig. 2a and 3), the absence of gullies on the trough-mouth fan and of
131 streamlined glacial bedforms at the continental shelf edge suggest that the Clyde Ice Stream (CIS)
132 did not reach the continental shelf break at the LGM –in contrast with other ice streams on
133 northeastern Baffin Island²⁵– and was probably not connected to the NBBIS. This disconnection
134 between the CIS and the NBBIS in outer Clyde Trough is supported by the presence of two GZWs
135 located ~10 km landward from the continental shelf edge and ~15 km west of the slope ridge
136 system (Fig. 5), leaving an open area between the CIS margin in the outer trough and the grounded
137 NBBIS on the slope.

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160 **Fig. 2: Geophysical data along the Baffin Shelf margin off Clyde Trough.** (a) Bathymetry of the
161 outer Clyde Trough and adjacent upper continental slope. Dashed lines represent GZW1 and
162 GZW2 positions. (b) Bathymetry along the continental slope of off Clyde Inlet showing the ice
163 shelf lateral moraines and the deep iceberg ploughmarks. (Inset in b) Bathymetric profile across
164 the ice shelf lateral moraine. (c) Zoom on the central ridge of the ice shelf lateral moraine. (d)
165 Parasound profile across the ice shelf lateral moraine.

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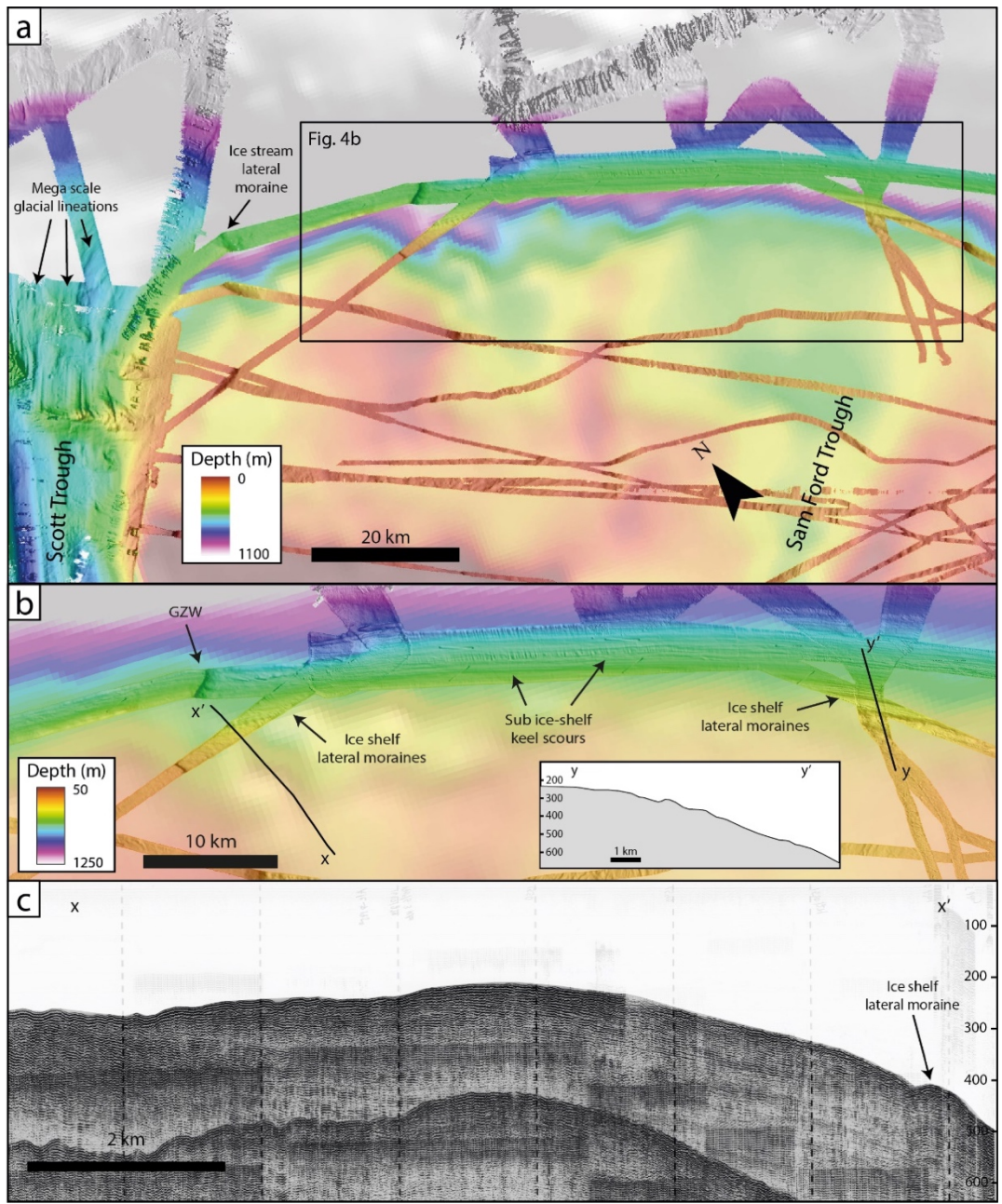
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Fig. 3: The ice shelf lateral moraines on the continental slope off Clyde Trough. 3D imagery generated using the QPS Fledermaus software showing the ice shelf lateral moraines and iceberg ploughmarks.

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More to the north, a GZW located ~20 km off Scott Trough at ~450 mbsl and associated with streamlined bedforms oriented parallel to the continental slope indicate grounded ice flowing southeastward along the shelf (Fig. 4a and 4b). The streamlined bedforms are similar to mega-scale glacial lineations⁴¹⁻⁴³ or sub-ice shelf keel scours^{6,44} and were recognized to be the product of ploughing across the seafloor by an ice shelf. This system therefore suggests that ice flowing out of the Scott Trough was either 1) deflected from its along-trough original flow by an obstacle (i.e., a floating ice shelf in Baffin Bay); or 2) a large independent ice body expanding all the way up to Clyde Trough (i.e., a fringing ice shelf). The first hypothesis is more probable as there is no explanation for the divergence of the Scott Ice Stream from an along-trough to along-slope orientation without a buttressing mechanism. These landforms, together with the ice shelf lateral moraines observed at shallower depths than the bottom of Scott Trough (>600 mbsl; Supplementary Fig. 1), suggest that, in contrast to Clyde Trough, the Scott Ice Stream –and probably other systems of northeastern Baffin Island– merged with the NBBIS. Mega-scale glacial lineations, ice stream lateral moraine and ‘lift-off’ moraines identified by Brouard and Lajeunesse²⁵ on the Scott trough-mouth fan in turn indicate an ice streaming phase extending to the shelf edge (Fig. 4a). Initially interpreted as features of LGM ages²⁵, they could instead correspond to a local subsequent readvance prior to 14.2 kyr BP⁴⁵.

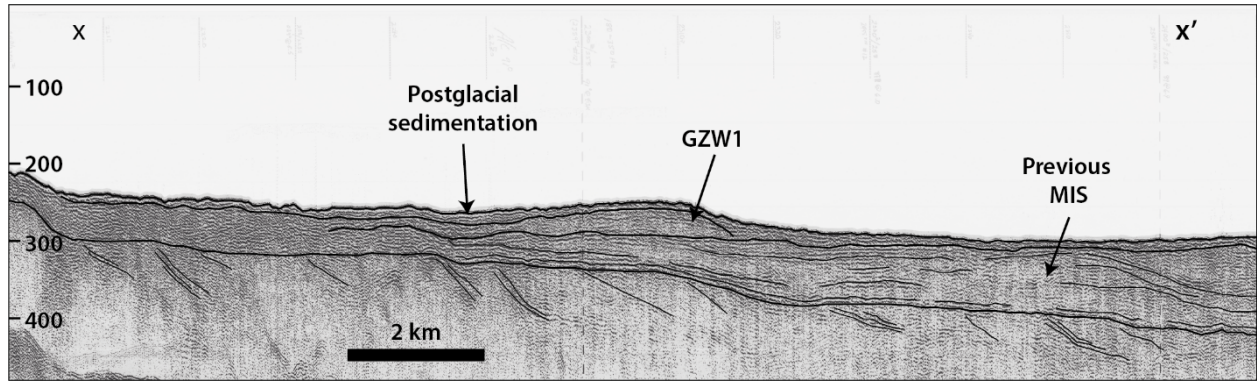
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222 **Fig. 4: Geophysical data along the northwestern Baffin Shelf margin.** (a) Bathymetry of the
223 upper continental slope between Scott Trough and Clyde Trough (see Fig. 1). (b) Bathymetry
224 along the continental slope of Baffin Island showing a GZW south of Scott Trough aligned with
225 the ice shelf lateral moraine and sub-ice shelf keel scours. (Inset in b) bathymetric profile of the
226 ice shelf lateral moraine near Sam Ford Trough. (c) Airgun profile 78029_AG_274_1516 showing
227 the ice shelf lateral moraine near Scott Trough.

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Fig. 5: Seismic evidence of ice extent in Clyde Trough. Airgun profile 80028_AG_RAYT_257_0200 showing GZW1 and deeply buried glacialic debris-flows in outer Clyde Trough (location in Fig. 2a).

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In addition, the continental slope along Baffin Island is heavily affected by curvilinear scours between 5-10 m deep and down to >750 mbsl (Figs. 2a, 3 and 4a). These scours, interpreted as iceberg ploughmarks, indicate extensive calving from a thicker body of ice in northern Baffin Bay probably after the LGM¹⁵.

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The available swath bathymetry and seismostratigraphic data do not allow identifying ice shelf lateral moraines south of Clyde Trough with confidence and, therefore, precisely addressing the NBBIS extent toward southern Baffin Bay. Faint bedforms similar to those presented above are observed on the bathymetry some 120 km to the south, but their association with those off Clyde Trough is ambiguous as they are located at greater depths (400 mbsl; Supplementary Fig. 2). The timing of formation of this lateral ice-shelf moraine is also unknown as no sediment core, thus no direct dating, were retrieved on this bedform. In this context, the presence of an extensive ice shelf on the Arctic ocean during MIS-6^{42,46} could suggest contemporaneity on Baffin Bay. Such an ice shelf is supported by a raised marine sediment sequence identified on Eastern Baffin Island^{47,48} that was dated at this period⁴⁹, suggesting a more extensive ice cover during the penultimate glaciation. Additionally, several studies provided evidence for the presence of the LIS along the eastern margin of Baffin Island throughout MIS-4 to MIS-2⁵⁰⁻⁵⁵. However, sediment records in Baffin Bay and along the Baffin Island continental shelf allow discussing the potential timing and extent of the NBBIS.

257 **The sedimentary signature of the NBBIS**

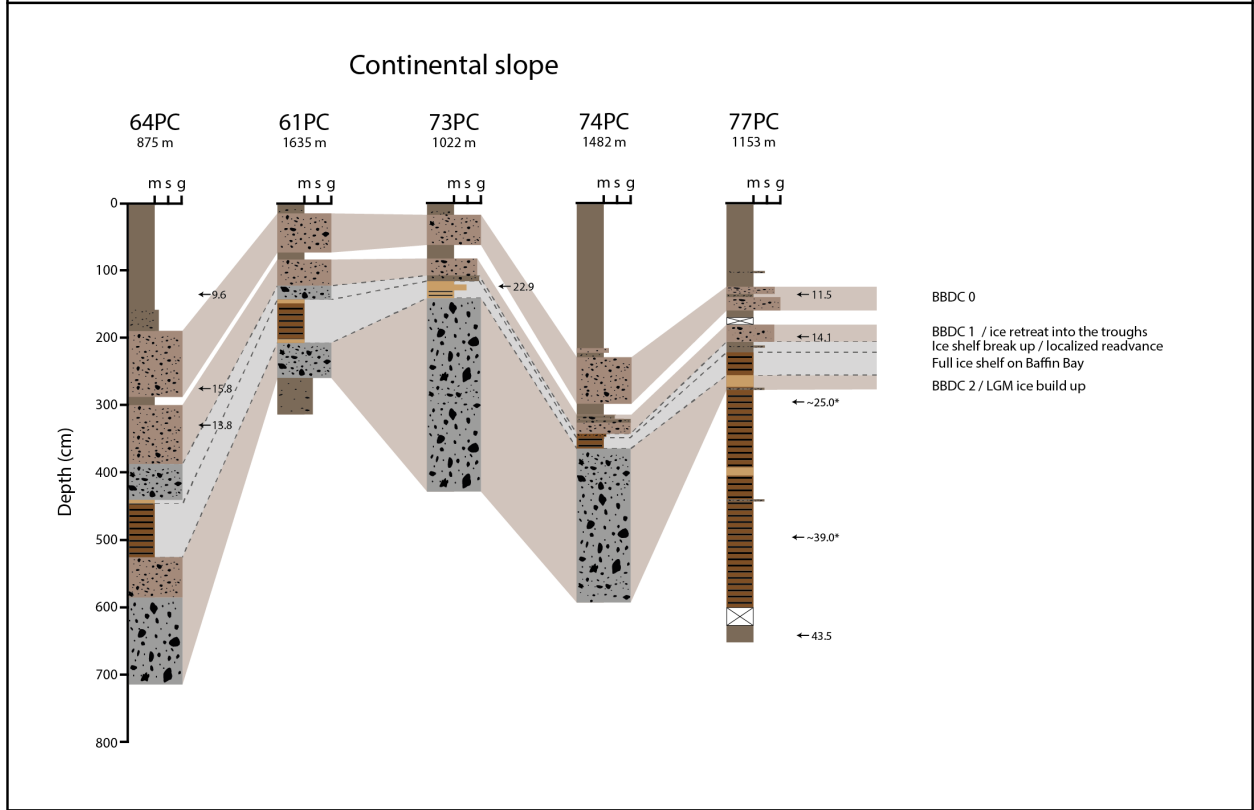
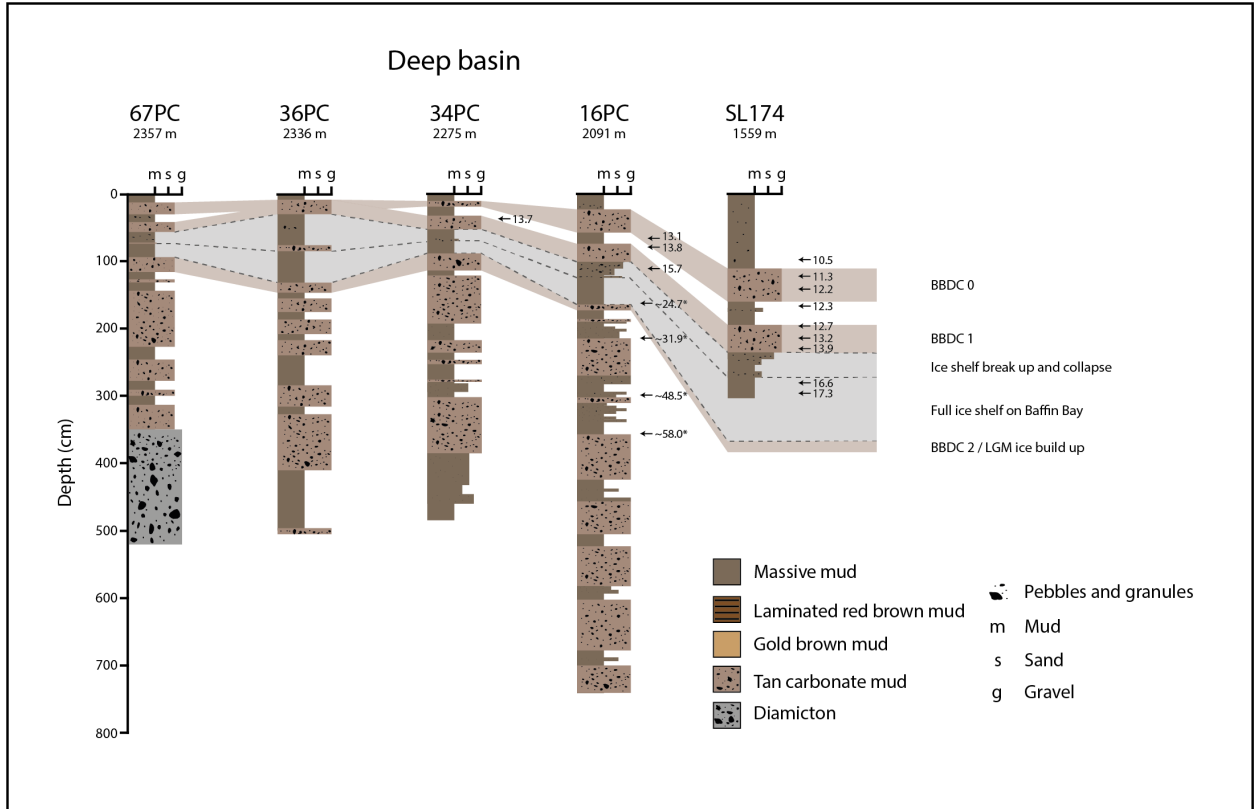
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The previously published sediment records from Baffin Bay (Fig. 6)^{14,21,45,56-60} are compatible with the presence of an ice shelf during the LGM. The buildup of ice sheet in northern Baffin Bay prior to the LGM is marked by a layer of IRD and carbonate-rich sediments originated from northern Baffin Bay termed Baffin Bay Detrital Carbonate (BBDC) layer, which is identified basin-wide and dated between 26-24.7 kyr BP (BBDC-2^{45,56,57,60}). The quasi-absence of IRD throughout the LGM (~24.7~16.5 kyr BP) in most cores of Baffin Bay suggests an extensive ice cover, either as perennial sea ice⁶¹ or an ice shelf^{6,34}. The occasional clasts observed in some cores of northern

265 Baffin Bay could be explained by their relatively short distance from the ice grounding line as it
266 is affected by mass flows and the rain out of ice shelf basal debris^{6,33,62,63,64}. Provenance study on
267 core 16PC, located 100 km east of Clyde Trough in central Baffin Bay (Fig. 1), shows uniform
268 mineralogic composition dominated by a Greenland-sourced sediment assemblage and a restricted
269 Baffin Island-sourced input during the LGM interval⁵⁷. Localized and uniform mineralogic
270 assemblages are typical of sub-ice shelf setting reflecting uniform conditions in which transport is
271 dominated by meltwater plumes^{6,65}. A coarsening-upward trend with frequent IRD in cores of
272 Baffin Bay starts at ~16.5 kyr BP^{57,58,60} and is followed by the deposition of carbonate-rich BBDC-
273 1 between ~14.5 and ~13.7 kyr BP^{57,60}. Such a coarsening-upward sequence typifies the
274 progressively more open water conditions that usually follow ice shelf collapse events^{6,64}. This
275 sedimentary record is therefore in support to the hypothesis of an ice shelf in Baffin Bay during
276 the LGM. In addition, it provides a time framework suggesting that break-up started at ~16.5 kyr
277 BP and ended with the onset of BBDC-1 at ~14.5 kyr BP^{15,57,60}.

278 Sediment cores collected on the Baffin Island continental slope (Fig. 6) allow defining the position
279 of the LIS margin on the continental shelf off Baffin Island during the LGM and early deglaciation.
280 The base of most cores is marked by ice-proximal dark grey-brown diamicton interpreted as
281 glacial debris-flows deposits and correlated to an ice advance at ~25 kyr BP⁴⁵. In 77PC, a gold
282 brown mud layer located halfway along the core was correlated to BBDC-2^{26,45} and therefore
283 correspond to the ice advance observed in the other cores along the continental slope. Provenance
284 study on this core indicates that a localized source of carbonate sediments, originating from a
285 Paleozoic outcrop east of the Home Bay^{66,67}, area also contributed to the composition of the gold
286 brown mud layer⁶⁸. Cores from the continental slope offshore Baffin Island (Fig. 1) typically
287 consist of laminated red brown mud with rare or absent IRD during the LGM interval. Jenner et
288 al.⁴⁵ noted, however, that coarse IRD-rich beds from the basal diamicton gradually decrease in
289 abundance upwards into laminated red brown mud and very fine sand with IRD in cores 61PC off
290 Scott Trough. These laminated red brown muds are interpreted as lateral sediment supply from NE
291 Baffin Island, as they thin in deeper water off the trough mouth fans^{14,45}, an interpretation
292 corroborated by their mineral composition⁶⁰. They are, however, absent in core 73PC (Fig. 1),
293 suggesting the absence of grounded ice at the shelf break in Clyde Trough during the LGM, in line
294 with the receded position of GZWs and the presence of predominantly Greenland-sourced
295 sediments in core 16PC⁵⁸. Except for 77PC, located off Home Bay in southern Baffin Bay, the
296 laminated red brown muds are characterized by an absence of bioturbation and microfossils⁴⁵.
297 According to the ice-shelf sedimentary model of Smith et al.⁶, this sequence might represent an
298 ice advance to the continental shelf edge at the LGM (stratified diamicton), followed by ice shelf
299 buildup with frequent iceberg calving (turbidites interbedded with IRD layers) and, ultimately, a
300 full ice shelf cover (laminated red brown mud). A second diamicton overlying the red brown
301 laminated muds is observed immediately below BBDC-1 in cores north of Clyde Trough^{45,69},
302 representing glacial debris-flows deposits correlated to a smaller localized advance from
303 northeastern Baffin Island ice streams to the shelf break prior to 14.2 kyr BP⁴⁵.

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331 **Fig. 6: Sediment assemblages in Baffin Bay and along the Baffin Shelf.** Lithology of piston cores
332 from Baffin Bay modified from various published datasets (see methods). Radiocarbon ages are
333 reinterpreted in calendar years using the online software Calib 8.2 with the Marine20
334 radiocarbon age calibration curve⁸⁷ and a local reservoir correction (ΔR) of 87 ± 20 ⁸⁸. Additionally,
335 relative paleointensity (*) chronology is also presented for core 16PC⁵⁹ and 77PC²⁶. Correlations
336 are based on Baffin Bay detrital carbonate (BBDC) beds and are compiled from original
337 publications. BBDC events are represented by the brown shaded areas – ages are from Simon et
338 al.⁵⁷ and Jackson et al.⁶⁰: BBDC-2: ~25-24.7 kyr BP; BBDC-1: ~14.2-13.7 kyr BP; BBDC-0: ~12.7-11
339 kyr BP. The grey shaded horizon represents ice shelf setting on Baffin Bay; note the quasi-absence
340 of IRD during that interval.
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343 To our knowledge, no sediment core has been collected or published from the Greenland side of
344 northern Baffin Bay to allow direct comparison with Baffin Island continental slope assemblages.
345 In southern Baffin Bay, sediment core data show similar sequence as those from the Baffin Island
346 continental slope^{34,70,71}. However, widespread foraminifera assemblages and bioturbation during
347 the LGM interval suggest the presence of perennial sea-ice⁶¹ and/or a nearby ice shelf
348 margin^{62,72,73}. A thorough discussion on sediment assemblages and their relation to ice shelf and/or
349 perennial sea-ice on the continental slope of western Greenland was provided by Jennings et al.³⁴.

350 **Evidence of ice shelf inception in northern Baffin Bay**

351 The presence of an ice shelf in northern Baffin Bay at the LGM and during the early stage of
352 deglaciation is supported by invoking the Marine Ice Cliff Instability (MICI) theory, which
353 stipulates that fracturing due to longitudinal stresses exceeding the yield strength initiate ice cliff
354 failures when a marine-based ice-margin reaches ~1 km in thickness⁷⁴⁻⁷⁶. Till wedges, GZWs and
355 mega-scale glacial lineations identified on the upper continental slope off Lancaster Sound^{21,25} and
356 Smith Sound (Supplementary Fig. 2) indicate grounded ice as deep as 1350 mbsl. Accounting for
357 a coeval higher relative sea-level (RSL) of ~75 m based on the modeled RSL values from a nearby
358 Baffin Island site⁷⁷, ice thickness can be estimated using:

$$359 \quad H_{LGM} = (\rho_w / \rho_i) \cdot (D + \Delta D_{LGM}) \quad (1)$$

360 where H_{LGM} is the minimum ice thickness during the LGM, $\rho_w = 1028 \text{ kg m}^{-3}$ and $\rho_i = 910 \text{ kg m}^{-3}$
361 are the mean densities of sea water and ice, respectively, D is the water depth and ΔD_{LGM} is the
362 correction for water depth at the LGM⁷⁴. In the case of the Lancaster Sound and Smith Sound
363 trough-mouth fans, grounded ice had to be >1550 m-thick. The Lancaster Sound till wedges and
364 the Smith Sound GZW could not have been deposited without an ice shelf buttressing –and
365 temporarily stabilising– the front of these ice streams^{4,76,78}. In order to maintain a stable position
366 without an ice shelf in northern Baffin Bay, the ice margin would have needed to retreat until it
367 reached the theoretical depth of ~800 m, hence continually calving icebergs throughout the LGM⁷⁶.
368 Such a constant calving in northern Baffin Bay is, however, not compatible with the sedimentary
369 record from the slope and deep basin off Baffin Island (Fig. 6) where a quasi-absence of IRD was

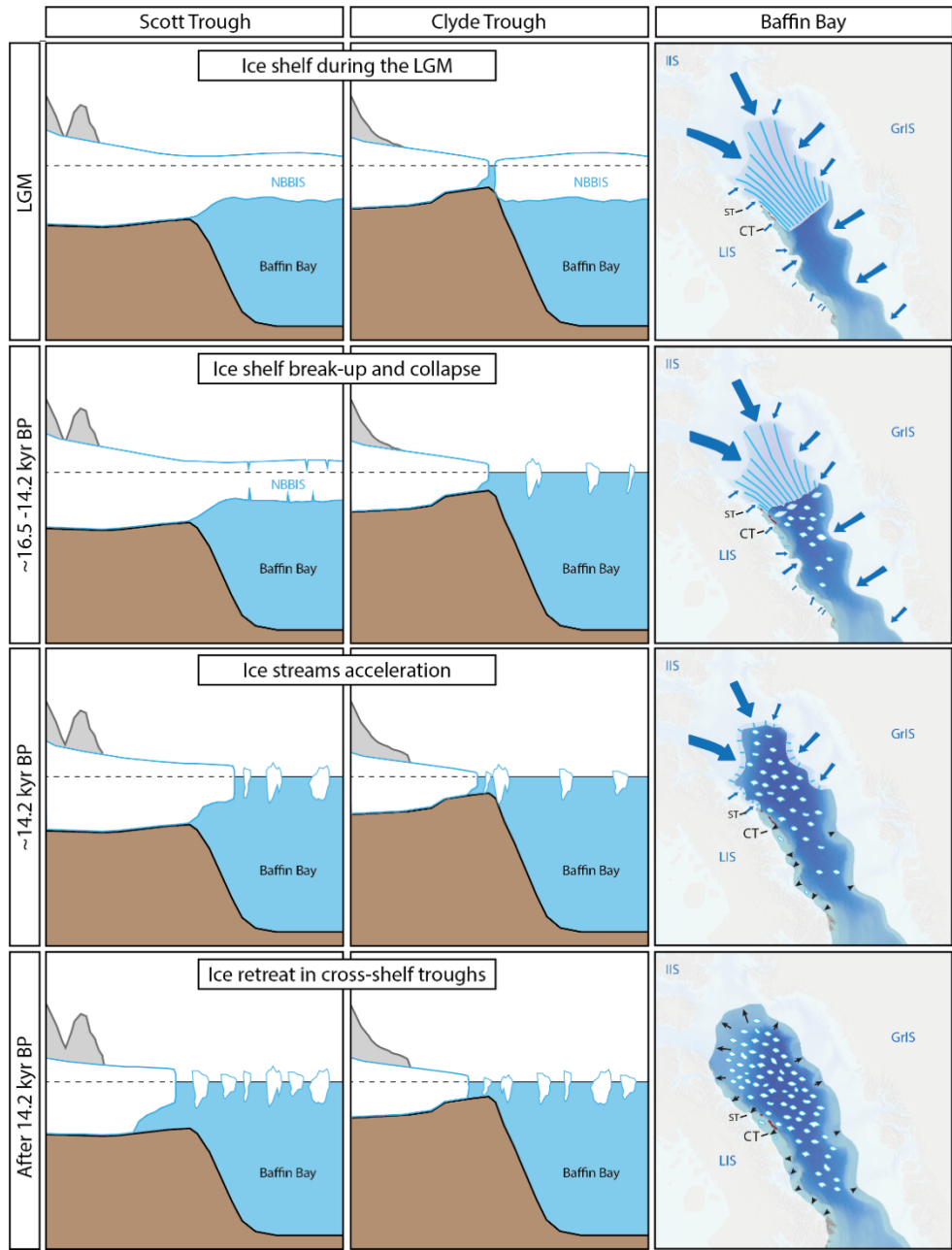
370 observed during this interval. Moreover, numerical models indicate that ice grounded at 1500 mbsl
371 is expected to form a ~500 m-thick ice shelf⁷⁹; a thickness consistent with observations off Clyde
372 Trough where ice shelf lateral moraines are observed at ~400 mbsl (i.e., ~475 m at the LGM).

373 **Implications of a NBBIS**

374 Glacial landforms and deposits off Baffin Island continental shelf combined with the Baffin Bay
375 sedimentary record provide definitive evidence for the presence of a 500 m-thick ice shelf in
376 northern Baffin Bay at and shortly after the LGM. The scenario of an ice shelf fed by ice streams
377 located in northern Baffin Bay does not require grounded ice in Davis Strait sealing inflow of food
378 supply from Labrador Sea waters, therefore reconciling with biological productivity observations
379 on the continental slopes of southern Baffin Bay during the LGM^{34,45}. This scenario provides a
380 framework for revising the glaciation development around Baffin Bay and reassessing the potential
381 impacts of the ice shelf collapse on the reorganisation of major ice streams draining the LIS, IIS
382 and GrIS during the last glacial cycle (Fig. 7).

383 *Ice shelf inception at the LGM:* Based on the presence of BBDC-2 and diamicton along the margin
384 of eastern Baffin Island, the NBBIS probably started building up with an advancing ice shelf
385 margin across Baffin Bay between ~26 and ~24.7 kyr BP. The presence of the short-lived BBDC-
386 3 event⁴⁴ suggests an earlier buildup with frequent break-up of the NBBIS margin. This earlier
387 buildup would be in line with the presence of the LIS on the Baffin Island continental shelf –and
388 possibly Lancaster Sound– during MIS-3⁵⁰⁻⁵⁵. An extensive LIS during MIS-3 would likely have
389 facilitated an earlier advance of the ice margin across the other shelves surrounding Baffin Bay.
390 Regardless of the exact timing of ice shelf inception in northern Baffin Bay, grounded ice flowing
391 from Lancaster Sound and Smith Sound fed the NBBIS between at least ~24.7 and ~16.5 kyr BP,
392 which in turn buttressed peripheral glaciers and ice streams of the eastern Canadian Arctic
393 Archipelago and possibly Western Greenland. The available geological record allows identifying
394 the southward extent of the NBBIS at least down to the latitudes of Clyde Trough. The relatively
395 shallow depths of the ice shelf lateral moraine in front of Clyde Inlet (<350m) suggests that the ice
396 shelf was thinning and its margin was possibly located nearby, therefore making it difficult to
397 extend farther south to Home Bay and preserve a constant thickness of ~500m for >100km.
398 Although geophysical data from the Greenland continental shelf do not allow confirmation, it is
399 probable that the ice shelf had a similar extent across the entire Baffin Bay. The relatively deep
400 troughs (<500 mbsl) on the Greenland side of northern Baffin Bay possibly prevented the
401 formation of ice shelf lateral moraines. Similarly to northeastern Baffin Island, ice streams located
402 off the GrIS may have merged with the NBBIS. The exact extent of the NBBIS in southern Baffin
403 Bay remains unknown; sediment assemblages^{45,60} show similarities to those of northern Baffin
404 Bay, while the record of marine productivity during the LGM suggests openings in sea-ice as
405 polynias and/or advection under a proximal ice-shelf margin³⁴. It is therefore possible that, while
406 northern Baffin Bay was covered by a basin-wide ice shelf system, southern Baffin Bay was
407 characterized by fringing ice shelf and/or perennial sea-ice along both continental shelves, which
408 could explain the presence of ice shelf lateral moraines off Home Bay.

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430 **Fig. 7: Conceptual model for early deglaciation including the NBBIS and the LIS outlets in Baffin**
 431 **Bay.** Reconstruction of ice sheets in Baffin Bay during the LGM and subsequent deglaciation. LIS:
 432 Laurentide Ice Sheet; IIS: Inuitian Ice Sheet; and GrIS: Greenland Ice Sheet. CT: Clyde Trough;
 433 ST: Scott Trough. Blue arrows indicate an advancing or stable ice margin and black triangles
 434 indicate a retreating ice margin. Brown lines represent ice shelf lateral moraines along Baffin
 435 Island continental shelf.

436 *Ice shelf break-up and collapse:* Rising sea level and/or enhanced incursion of relatively warm
437 Atlantic waters via the Western Greenland Current^{34,80} may have provoked a destabilization and
438 collapse of the NBBIS front between ~16.5 and ~14.2 kyr BP (Supplementary Fig. 3). The
439 initiation of this break-up is recorded by an increase in IRD and coarse-grained sediments in cores
440 from Baffin Bay^{57,60}. Such a break-up would have been accelerated by warming summer
441 temperatures⁸¹ providing the necessary heat to produce sufficient meltwater to fill crevasses and
442 induce hydrofracturing^{10,11}, in turn favouring the production of small icebergs rather than large
443 tabular icebergs^{1,4,30}. The final collapse of the NBBIS corresponds to the onset of widespread
444 delivery of northern Baffin Bay-sourced detrital carbonates in Baffin Bay – BBDC-1^{15,58,60}.

445 *Ice streams acceleration:* As the NBBIS rapidly collapsed by ~14.2 kyr BP, ice streams of
446 northeastern Baffin Island became unbuttressed, thereby thinning due to their acceleration,
447 similarly to observations made on present-day ice shelves in Antarctica^{1,5,7,8}. The accelerated
448 discharge from northeastern Baffin Island ice streams probably led to the deposition of the younger
449 diamicton identified on the continental slope north of Clyde Trough⁴⁵. The MSGs and ice stream
450 lateral moraine at the shelf edge in Buchan and Scott troughs²⁵ further supports this acceleration
451 of ice streams. The presence of ‘lift-off’ moraines at the shelf break²⁵ suggests tidally related
452 buoyancy at the grounded ice sheet margin⁸², which could potentially be a sign of ice stream
453 thinning. The absence of the second diamicton south of Clyde Trough suggests that no readvance
454 nor glacier acceleration occurred in Clyde Trough, probably because the CIS was not initially
455 buttressed by the NBBIS. The occurrence of ridges similar to ‘lift-off’ moraines on Melville Bay
456 trough-mouth fans²⁴ could hint to a similar history as northeastern Baffin Island ice streams. Ice
457 streams acceleration around northern Baffin Bay are coeval to a period marked by exceptionally
458 high rates of global sea-level rise (Meltwater Pulse 1A^{12,83,84}) suggesting contribution of the North
459 America high-arctic ice sheets to this event.

460 *Ice retreat in cross-shelf troughs:* Ice stream fronts retreated landward within their troughs at ~14.2
461 kyr BP⁴⁵, consistent with previous age constraints of ice retreat from the Baffin Island continental
462 shelf^{19,20,45}. The previous event of ice purge may have resulted in their episodic retreat in
463 northeastern Baffin Island due to their destabilisation²⁵, whereas the initially unbuttressed CIS
464 margin underwent a slower retreat. Furthermore, ice retreat in Lancaster Sound and Smith Sound
465 led to the increased delivery of IRD-rich carbonates and deposition of BBDC-1 in Baffin
466 Bay^{15,45,56-58,60}.

467 **Conclusion**

468 Identifying landforms associated with modern ice shelves remains a challenge due to their scarcity,
469 the difficulty to access sub-ice-shelf environments and technological limitations of sonar imaging
470 systems. However, the last decades witnessed improvements in ship-bound technologies (i.e.,
471 high-resolution multibeam echosounder, autonomous underwater vehicle and 2D/3D seismic
472 imagery) allowing the identification of submarine bedforms diagnostic of past ice shelves, such as
473 sub-ice-shelf keel scours/mega scale glacial lineations⁴¹⁻⁴³, GZWs⁴² and corrugation ridges⁴⁴. A

474 more comprehensive understanding of such landforms is of particular interest as they provide
475 direct and key evidence for past ice shelves in the Arctic, which may have considerable
476 implications on glacial dynamics at the margin of continental ice sheets that was so far little
477 studied.

478 The ice shelf scenario in northern Baffin Bay provides a satisfactory explanation for the landforms
479 observed along the continental slope between Scott and Clyde troughs, as well as in Lancaster and
480 Smith sounds. It is also in agreement with sediment assemblages identified on the continental
481 slopes off Baffin Island and Greenland, as well as in Baffin Bay itself during the LGM. With a
482 surface of at least 150 000 km² –an area comparable to some of the largest ice shelves of present-
483 day Antarctica– the NBBIS constitutes an analogue from the past for understanding future changes
484 to the cryosphere in a warming world in a context of disintegration of buttressing ice shelves. The
485 demise of the NBBIS would have provided an ideal setting for triggering the acceleration of ice
486 streams and the rapid loss of glacial ice to the ocean, thereby influencing drastically the ice flow
487 regimes of the LIS, IIS and GrIS. These findings could further support the hypothesis that the
488 North America High Arctic ice sheets did not have considerable contribution to rising sea level
489 before Meltwater Pulse 1A^{83,84}. Defining the extent of the NBBIS and the chronology of its history
490 is, however, necessary for assessing a scenario that should include the acceleration of major Arctic
491 ice streams following ice shelf collapse when identifying sources for Meltwater Pulse 1a. This
492 paper provides the basis for further investigations aiming at documenting –both offshore and
493 onshore– lateral ice shelf moraines of past ice shelves of the Arctic seas.

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503 **Author contributions**

504 POC conceived the study and initiated this project in cooperation with PL and JFG. POC
505 interpreted the geophysical data sets, wrote the paper and prepared the figures. POC, PL, JFG, BD,
506 CG, DH, and EB were involved in the discussion of the data and contributed to the final version
507 of this paper.

508 **Competing interests**

509 The authors declare no competing interests.

510 **Methods**

511 **Geophysical data along the Baffin Island continental slope**

512 Swath bathymetric data was collected in 2017 during expedition MSM66 of the RV Maria S.
513 Merian⁸⁵ using a Kongsberg Simrad EM122 (12 kHz) system, which allowed the coverage of
514 Clyde Trough. This dataset is complemented by swath bathymetric data from ArcticNet cruises
515 collected during transits from 2003 to 2016 onboard the CCGS Amundsen, equipped with a
516 Kongsberg Simrad EM302 (30 kHz). These datasets were processed for anomalous data points
517 and artefacts removal using Caris Hips and Sips software and gridded at a 10 m cell-size resolution.
518 They were then imported into ESRI ArcGIS software for geomorphological mapping and
519 landforms identification. The International Bathymetric Chart of the Arctic Ocean (IBCAO) data⁸⁶,
520 gridded at a 500 m cell-size resolution, was also used to show overall bathymetry of Baffin Bay
521 and its adjacent shelves. Parasound profiles were acquired onboard the RV Maria S. Merian using
522 a Teledyne-Reson Parasound DS P-70 (secondary low frequency ca. 4 kHz). The raw data were
523 recorded into ASD and PS3 format and then converted into SEGY using ps32segy software of Dr.
524 Hanno Keil (University of Bremen). The shallow-acoustic profiles were then imported into the
525 IHS Markit Kingdom software for processing and interpretation. Seismic lines
526 78029_AG_274_1516 and 80028_AG_RAYT_257_0200 were acquired by the Geological Survey
527 of Canada during airgun surveys in 1978 and 1980, respectively. Extraction and interpretation
528 were done using the LizardTech GeoViewer® software. Both acoustic and seismic data were then
529 transferred into Adobe Illustrator® for figure production. Thicknesses and water depth were
530 calculated using a velocity of 1500 m/s.

531 **Sediment cores and chronology**

532 Sediment cores were compiled from previous studies to describe the lithostratigraphy along the
533 Baffin Island continental slope and in Baffin Bay. Jenner et al.⁴⁵ noted that cores 64PC, 61PC,
534 74PC and 77PC (all included in this study) typify the regional lithostratigraphy along the northeast
535 Baffin margin from north to south. Additionally, core 73PC⁴⁵ was included in the compilation as
536 it was located nearby Clyde Trough. Cores located directly in front of the Baffin Island troughs in
537 which the LGM assemblages were mostly dominated by glacial debris-flows and turbidites we not
538 included. Cores from Baffin Bay were selected to allow a north to south representativity and to
539 avoid redundant information. In general, the lithofacies provided a good correlation between them
540 on the basis of radiocarbon dating. For full description of the cores, readers are referred to the
541 original publications - 16PC⁵⁷; 34PC and 36PC⁵⁶; 61PC, 64PC, 73PC, 74PC and 77PC⁴⁵; 67PC²¹;
542 SL174⁶⁰.

543 Radiocarbon ages were calibrated within the age-depth modelling process using the online
544 software Calib 8.2 with the Marine20 radiocarbon age calibration curve⁸⁷ and a local reservoir
545 correction (ΔR) of 87 ± 20 ⁸⁸ commonly used on northeastern Baffin Island^{26,45,57,60} (Supplementary
546 Table 1). This reservoir correction is in line with the one currently used for radiocarbon date
547 calibrations of central West Greenland^{34,71}, that indicate a reservoir correction (ΔR) of 140 ± 35

548 years⁸⁹. We recognize that an offset caused by a well-mixed ocean was most likely variable through
549 time and the appropriate ΔR reservoir correction for the region might have been larger than the
550 one used and provide younger ages. However, this would not considerably change the
551 interpretation of the ice shelf scenario.

552 **Data availability**

553 The swath bathymetric data collected in 2017 during expedition MSM66⁸⁵ have been deposited in
554 the PANGAEA repository, available under <https://doi.org/10.1594/PANGAEA.902341>. The
555 swath bathymetric data from ArcticNet cruises can be visualized on the Université Laval Géoindex
556 + website (<http://geoindex-plus.bibl.ulaval.ca>). The Parasound profiles collected in 2017 during
557 expedition MSM66⁸⁵ have been deposited in the PANGAEA repository, available under
558 <https://doi.pangaea.de/10.1594/PANGAEA.944843>. The seismic reflection data along with the
559 acquisition specifics are available on the Marine Data Holding public repository of National
560 Resources Canada (<http://geogratis.gc.ca/>).

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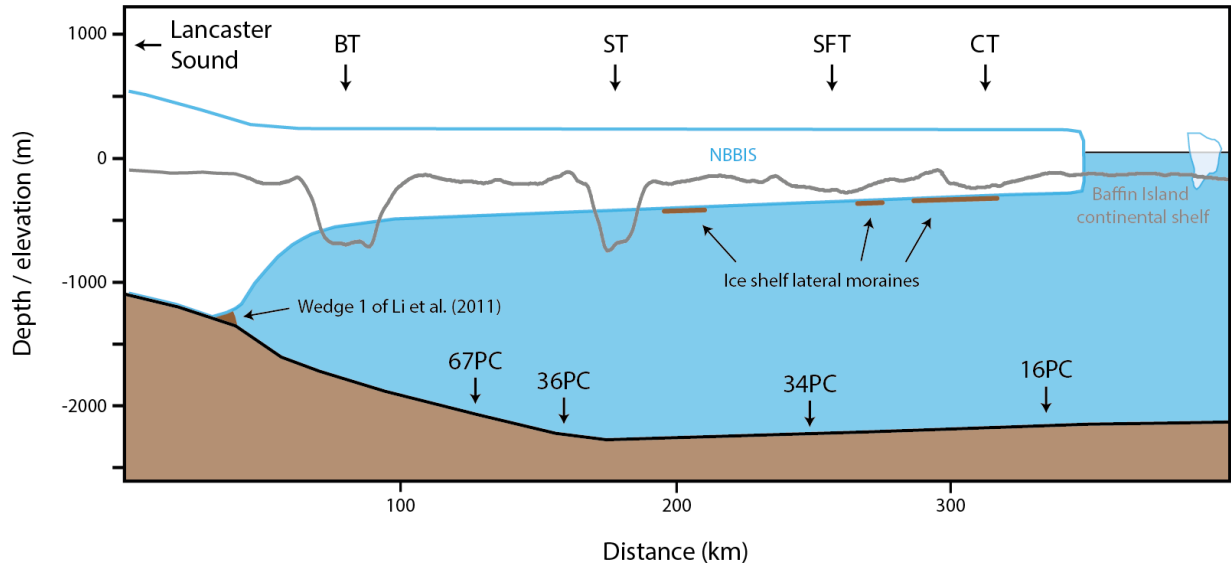
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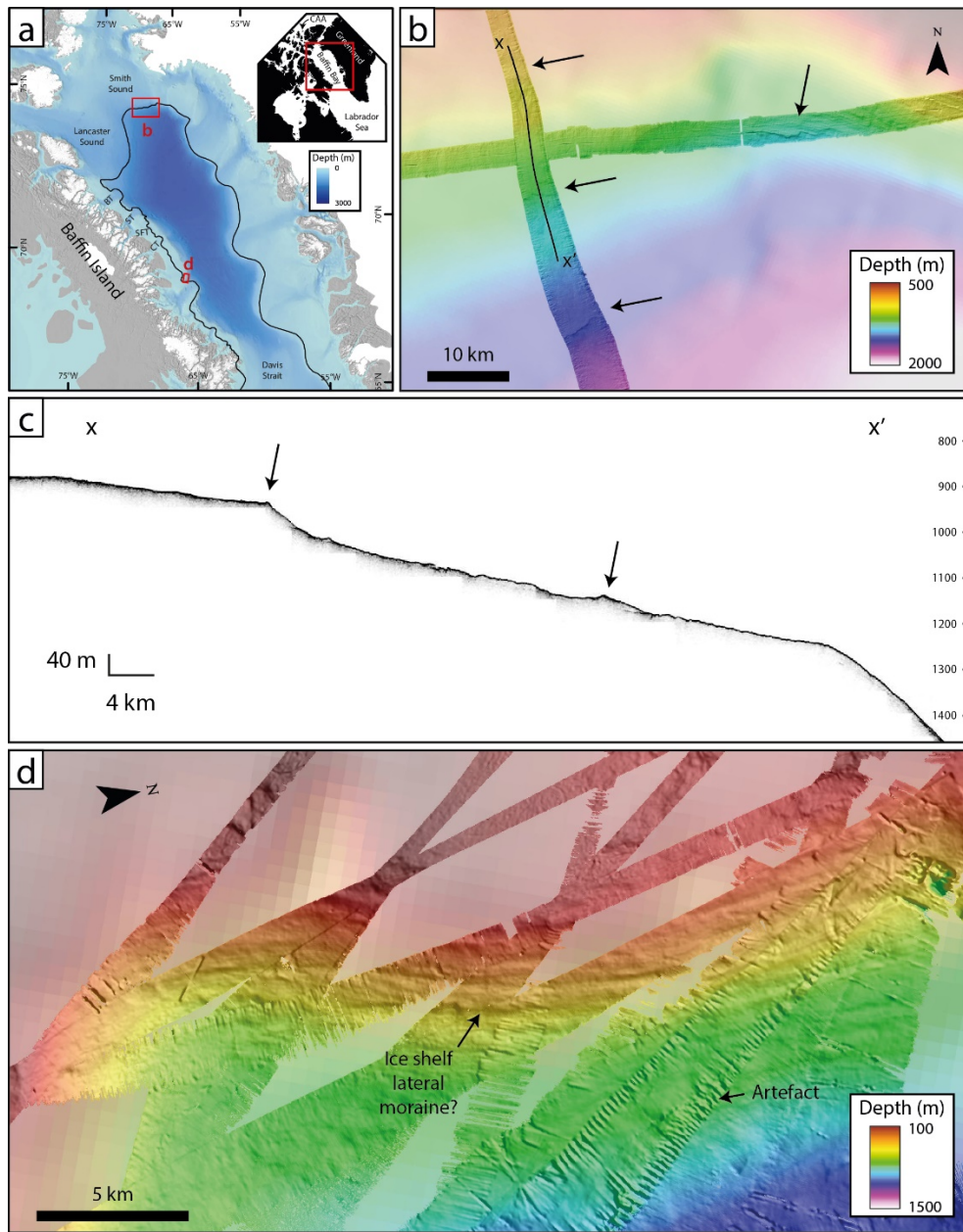
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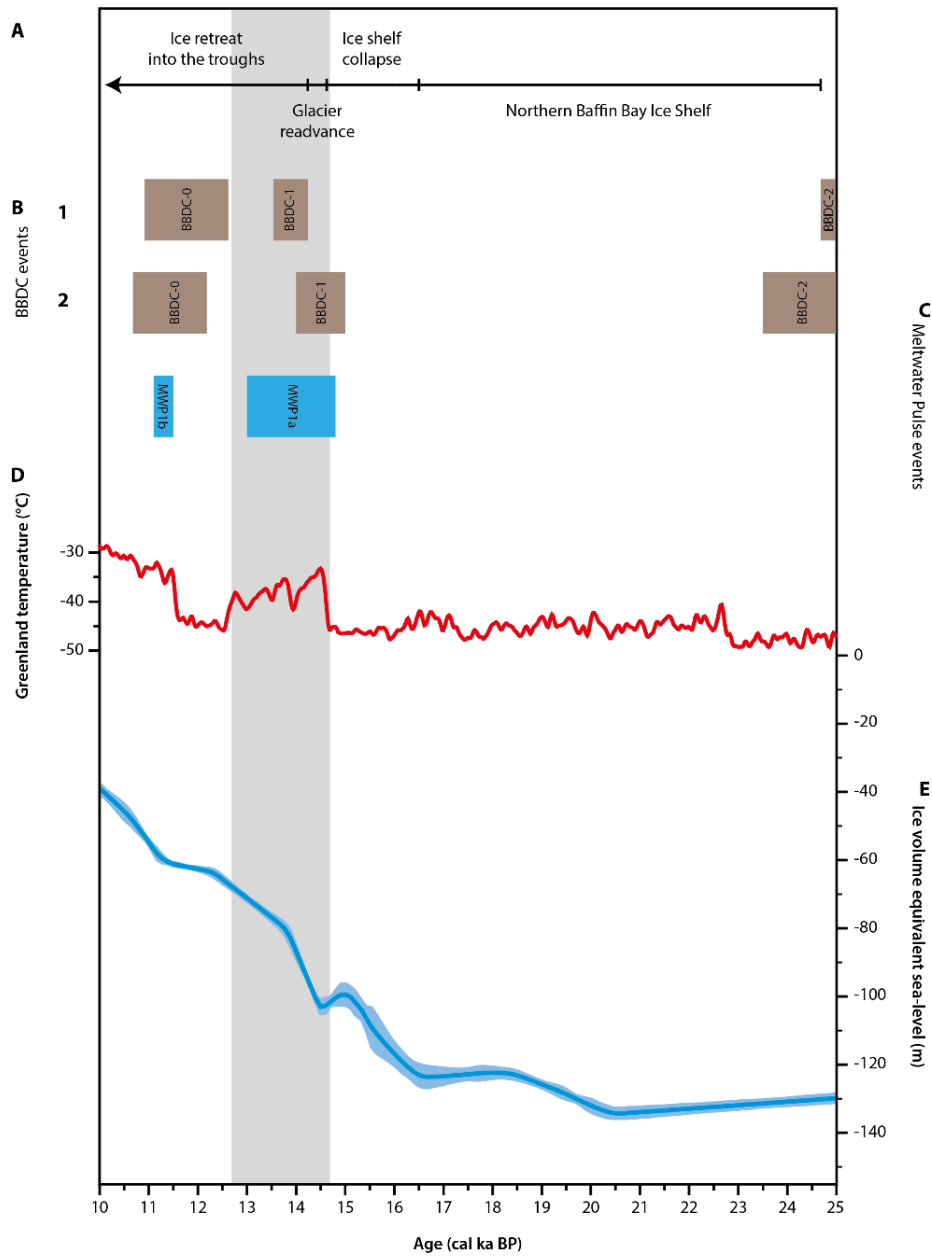
774 **Supplementary Fig. 1: Longitudinal transect of the NBBIS in northern and central Baffin Bay.**
775 Location of the ice shelf lateral moraines discussed in this paper are in dark gray. Core locations
776 in Baffin Bay are tentatively given. BT: Buchan Trough; ST: Scott Trough; SFT: Sam Ford Trough;
777 CT: Clyde Trough.

778



779

780 **Supplementary Fig. 2: Geomorphological evidence of the presence of an ice shelf in northern**
 781 **Baffin Bay.** Arrows indicate GZWs and moraines. (a) Location of figure S2b cores and maximum
 782 extent of grounded ice on western Baffin Bay (thick line). (b) Bathymetry off Smith Sound showing
 783 GZWs between ~900 and ~1200 mbsl, and possibly a moraine at ~1700 mbsl. (c) Chirp profile in
 784 Smith Sound showing the two GZWs at ~900 and ~1200 mbsl. (d) Bathymetry off Home Bay
 785 showing a potential ice shelf lateral moraine at ~400 mbsl.



786

787 **Supplementary Fig. 3: Chronology of the last deglaciation in Baffin Bay and regional climatic**
 788 **events.** (a) Baffin Bay Ice Shelf history. (b) Baffin Bay Detrital Carbonate layers based on
 789 radiocarbon dating^{57,60} (1) and relative paleointensity (RPI) chronology⁵⁹ (2). (c) Meltwater Pulse
 790 events⁸⁴. (d) Greenland mean-annual temperatures reconstructed using $\delta^{15}\text{N}$ gas-phase⁸¹ (red
 791 line). (e) Ice volume equivalent sea-level⁸⁰ (blue line) presented with one standard-deviation. The
 792 grey shaded area represents the Bølling–Allerød warm interval.

Supplementary Table 1: Radiocarbon ages for cores used in this study.

| Sample information | | Conventional radiocarbon age | | | Calibrated radiocarbon ages yrs BP (2σ) | | | Reference |
|--------------------|---------------|------------------------------|-------|---------|--|--------|-----------------------------|-----------|
| Core | Depth in core | ^{14}C age years BP | \pm | Minimum | Maximum | Median | | |
| 16PC | 66 | 11 905 | 40 | 12980 | 13302 | 13141 | <i>Simon et al., 2012</i> | |
| | 79 | 12 470 | 40 | 13573 | 13980 | 13752 | | |
| | 111 | 13 820 | 130 | 15324 | 16134 | 15737 | | |
| 34PC | 37 | 12 380 | 105 | 13374 | 13976 | 13650 | <i>Andrews et al., 1998</i> | |
| 64PC | 135 | 9200 | 35 | 9484 | 9852 | 9639 | <i>Jenner et al., 2018</i> | |
| | 275 | 13 850 | 95 | 15443 | 16111 | 15777 | | |
| | 330 | 12 500 | 45 | 13596 | 14002 | 13796 | | |
| 73PC | 123 | 19 900 | 80 | 22621 | 23192 | 22921 | <i>Jenner et al., 2018</i> | |
| 77PC | 137 | 10 550 | 40 | 11 270 | 11 736 | 11 504 | <i>Jenner et al., 2018</i> | |
| | 200 | 12 750 | 55 | 13 867 | 14 442 | 14 137 | | |
| | 638 | 37 900 | 1 600 | 38 410 | 41 213 | 43 542 | | |
| SL174 | 97 | 9793 | 120 | 10 122 | 10 859 | 10 456 | <i>Jackson et al., 2017</i> | |
| | 122 | 10 390 | 40 | 11 104 | 11 495 | 11 276 | | |
| | 142 | 10 997 | 110 | 11 831 | 12 553 | 12 202 | | |
| | 169 | 11 010 | 85 | 11 888 | 12 515 | 12 226 | | |
| | 196 | 11 410 | 50 | 12 506 | 12 817 | 12 673 | | |
| | 215 | 12 000 | 80 | 13 038 | 13 455 | 13 234 | | |
| | 233 | 12 580 | 60 | 13 656 | 14 111 | 13 895 | | |
| | 278 | 14 510 | 120 | 16 256 | 16 990 | 16 629 | | |
| | 294 | 15 060 | 110 | 16 963 | 17 698 | 17 294 | | |

Ages were calibrated within the age-depth modelling process, using the online software Calib 8.2 with the Marine20 radiocarbon age calibration curve⁸⁷. A local reservoir correction (ΔR) of 87 ± 20 was used to account for the regional offset of the world ocean ^{14}C age⁸⁸.