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^{10}Be ages from central east Greenland constrain the extent of the Greenland ice sheet during the Last Glacial Maximum

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Abstract

Traditional ice sheet reconstructions have suggested two distinctly different ice sheet regimes along the East Greenland continental margin during the Last Glacial Maximum (LGM): ice to the shelf break south of Scoresby Sund and ice extending no further than to the inner shelf at and north of Scoresby Sund. We report new ^{10}Be ages from erratic boulders perched at 250 m a.s.l. on the Kap Brewster peninsula at the mouth of Scoresby Sund. The average ^{10}Be ages, calculated with an assumed maximum erosion rate of 1 cm/ka and no erosion (respectively, 17.3 ± 2.3 ka and 15.1 ± 1.7 ka) overlap with a period of increased sediment input to the Scoresby Sund fan (19–15 ka). The results presented here suggest that ice reached at least 250 m a.s.l. at the mouth of Scoresby Sund during the LGM and add to a growing body of evidence indicating that LGM ice extended onto the outer shelf in northeast Greenland.

1. Introduction

The role that ice sheets play in the global climate system depends largely on their connection to adjacent ocean basins. Pleistocene ice sheets rimming the North Atlantic Ocean heavily influenced global oceanic circulation and abrupt climate change (Bond et al., 1993; Broecker, 1997; Clark et al., 1999; Jennings et al., 2006). Recent studies, many taking advantage of new marine coring and imaging techniques and dating methods (e.g., Zreda et al., 1999; Landvik et al., 2005; Ottesen et al., 2005), have led to a new understanding of the extent and dynamics of ice sheet margins during the Last Glacial Maximum (LGM). For example, recent cosmogenic exposure dating studies from Arctic Canada depict ice that terminated on the continental shelf during the LGM (Briner et al., 2005), in some places overriding weathered, non-glacial landscapes (e.g., Briner et al., 2003; Davis et al., 2006).

Terrestrial-based studies in northeast Greenland depict LGM ice terminating at the mouth of fjords or on the inner shelf (e.g., Funder et al., 1998), whereas recent studies on the northeast Greenland continental shelf suggest that the Greenland Ice Sheet reached the shelf break during the LGM (e.g., O'Cofaigh et al., 2004). Here, we apply cosmogenic ^{10}Be dating to erratics perched on a peninsula adjacent to the open ocean as an attempt to reconcile the marine studies with a terrestrial dataset.

2. Background and setting

The eastern margin of Greenland (spanning 60–81°N, Fig. 1) consists of two contrasting landscape types. South of Scoresby Sund (70°N), coastal areas consist of presently glaciated alpine topography, whereas north thereof a 100–200-km-wide unglaciated margin is composed of intensely weathered uplands dissected by deep fjords. Glacial troughs cross-cut the continental shelf outboard

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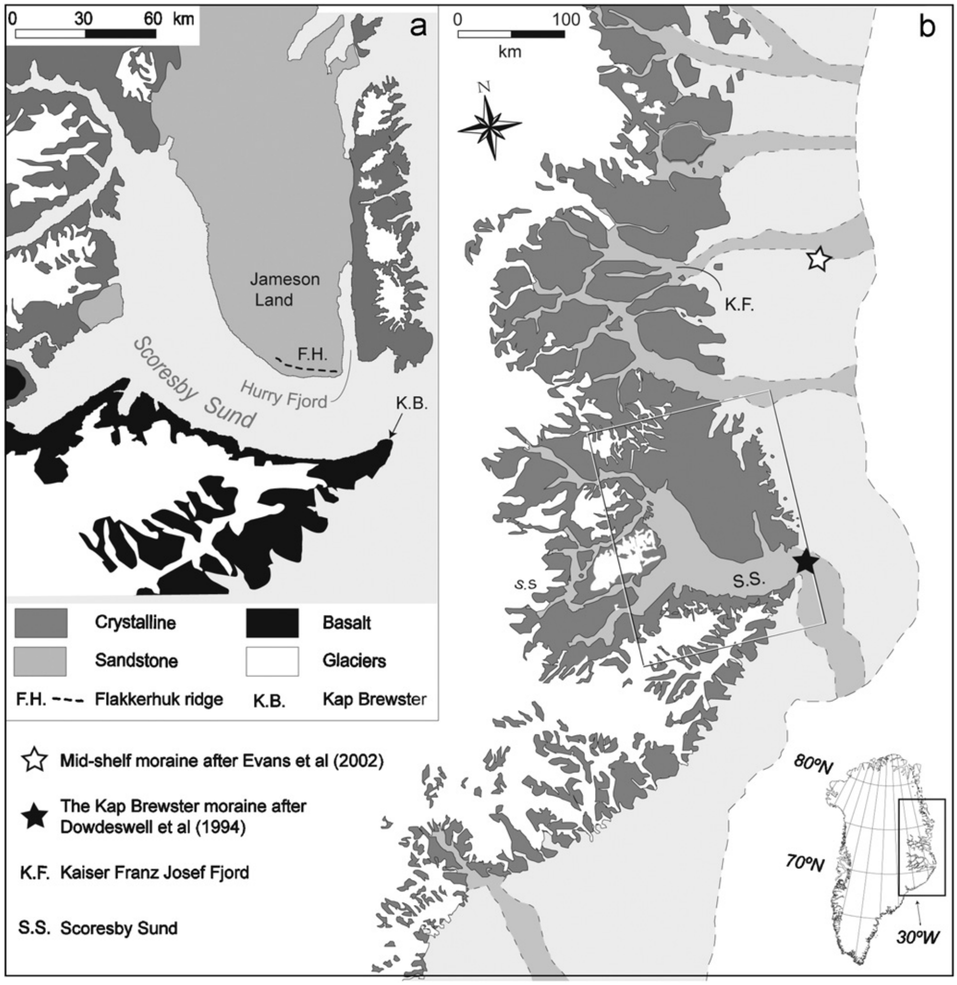

Fig. 1. (a) Bedrock map of the Scoresby Sund showing the source of sandstone erratics after Henriksen (1989). (b) Map of northeast Greenland. The dashed line marks the continental shelf break. Shaded areas bounded by dashed lines show cross-shelf troughs.

of major fjords both south and north of Scoresby Sund (Fig. 1).

Current reconstructions of the Greenland Ice Sheet south of Scoresby Sund, based on marine studies, depict an LGM margin at the edge of the continental shelf (Mienert et al., 1992; Andrews et al., 1996; Bennike and Björck, 2002). The glacial history of Scoresby Sund and northward is derived from both terrestrial and marine studies. Based on intense bedrock weathering and the lack of deposits from the last glaciation, interfjord uplands north of and at Scoresby Sund have long been thought to be ice-free throughout the LGM (Funder and Hjort, 1973; Hjort, 1981; Landvik, 1994). During recent decades, considerable effort has been put into both on- and offshore investigations of the Late Quaternary glacial history of this area. One large step was taken through the "Polar North Atlantic Margins" (PONAM) program, in which most investigations focused on the Scoresby Sund area (Fig. 1). This work led to the reconstruction of a large outlet glacier restricted to Scoresby Sund during the LGM, terminating at the Kap Brewster subaqueous moraine (Fig. 1; Dowdeswell et al., 1994) leaving Jameson Land and the adjacent continental shelf free from ice (e.g., Möller et al. 1994; Funder et al., 1998). The northern margin of the Scoresby Sund outlet glacier during the LGM is thought to relate to the Flakkerhuk ridge on southern Jameson Land (Fig. 1), which is an erosional landform composed of pre-LGM sediments (Tveranger et al., 1994). This implies an ice elevation near Hurry Fjord (Fig. 1a) of <70 m a.s.l. (Fig. 1; Funder et al., 1998). Inland of the Flakkerhuk ridge the sandstone bedrock is exposed and intensely weathered.

Kap Brewster, a peninsula composed of Tertiary basalt bordering the southern mouth of Scoresby Sund, lies ~25 km down fjord from the eastern end of the Flakkerhuk ridge (Fig. 1). Sandstone erratics are perched above 230 m a.s.l. on Kap Brewster. The only sources for lithology of these erratics are either from Jameson Land or from the floor of Scoresby Sund (Fig. 1; Henriksen, 1989). Mangerud and Funder (1994) hypothesized that these erratics were deposited by Scoresby Sund ice during the LGM, because the erratics are near relatively fresh E–W oriented glacial striae, covered by a thin mantle of drift.

3. Methods and results

Samples for ^{10}Be dating were collected from four erratic sandstone boulders, 40–70 cm high, from Kap Brewster (Fig. 2) during the summer of 2005. All samples were taken from flat upper boulder surfaces except for KB-4, which was taken from a sloping edge ~20 cm above ground (Table 1). The erratics are resting on a flat, well-drained ~5 cm thick drift unit draped over basaltic bedrock and are situated on elevations between 230 and 251 m a.s.l. Samples were processed for ^{10}Be analysis at the University at Buffalo following procedures in Briner (2003). ^{10}Be measurements were made at the Tandem Laboratory, Uppsala University and ages were calculated using a ^{10}Be production rate of 5.1 ± 0.3 atoms g^{-1} yr^{-1} (Stone, 2000). Site-specific production rates were corrected for altitude (Lal, 1991; Stone, 2000) and ^{10}Be concentrations were adjusted for sample thickness and shielding (Table 1). Because these samples are from high latitude (~70 °N), radionuclide production rates are not influenced by changes in the geomagnetic field (Gosse and Phillips, 2001). Bedrock weathering rates in arid arctic regions are relatively low (e.g., 1 mm ka^{-1}; Bierman et al., 1999). However, because the Kap Brewster erratics are composed of sandstone, we may expect higher erosion rates. The exact bedrock weathering rate is not known; therefore, we calculate ^{10}Be ages for a range of values between 0 and 10 mm ka^{-1}.

The four different sandstone erratics have ^{10}Be ages that range between 9.1 ± 1.6 and 16.6 ± 3.2 ka under 0 mm ka^{-1} erosion conditions (Fig. 2), and between 9.8 ± 1.7 and 19.3 ± 3.8 ka under 10 mm ka^{-1} erosion conditions (Table 1). The ^{10}Be age of the youngest sample (KB-4) falls outside of the two-sigma range of the mean of the oldest three erratics. Since this sample was collected only 20 cm above the ground, compared to the other samples which were collected from 40- to 70-cm-high boulders, the anomalously younger age is likely due to shielding by

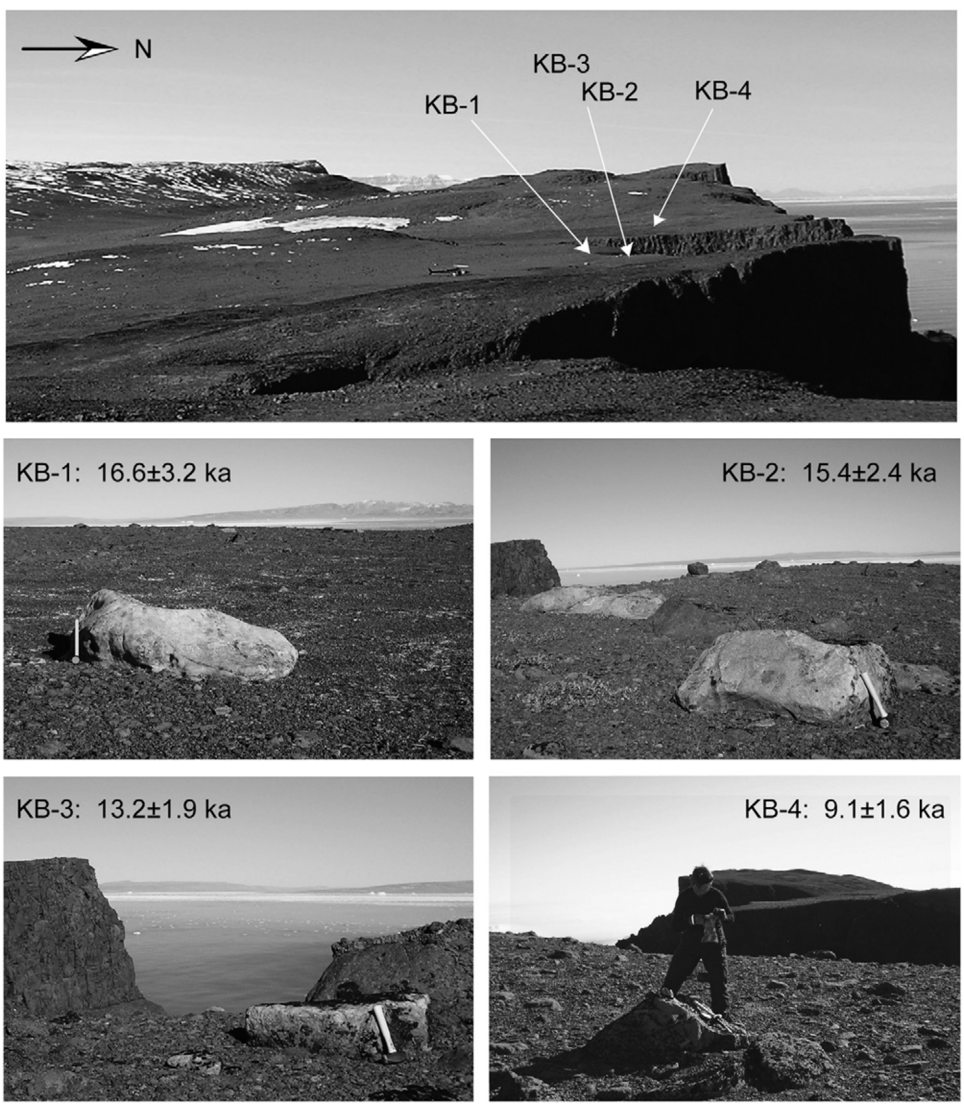

Fig. 2. Sampling area and sampled erratic boulders. The sledge hammer for scale is 30 cm long. ^{10}Be ages shown in figure are calculated with no erosion and are corrected for shielding and sample thickness.

Table 1
^{10}Be results from Kap Brewster

Sample	Latitude (N)	Longitude (W)	Altitude (m)	Sample position[a]	Thickness correction[b]	Shielding correction[c]	Scaling factor[d]	^{10}Be ($\times 10^5$ atoms/g[e])	^{10}Be age (ka), no correction	^{10}Be age (ka)[f], $e = 0$ mm/ka	^{10}Be age (ka)[f], $e = 5$ mm/ka	^{10}Be age (ka)[f], $e = 1$ cm/ka
KB-1	70°09′03.4″	23°04′31.5″	230	Top surface, 70 cm	0.984	1	1.277	1.06±0.17	16.3±3.2	16.6±3.2	17.8±3.5	19.3±3.8
KB-2	70°09′03.8″	23°04′33.7″	230	Top surface, 40 cm	0.984	1	1.277	0.99±0.13	15.2±2.4	15.4±2.4	16.5±2.6	17.8±2.8
KB-3	70°09′03.2″	23°04′39.4″	251	Top surface, 40 cm	0.976	0.996	1.304	0.85±0.10	12.8±1.8	13.2±1.9	14.0±2.0	14.9±2.1
KB-4	70°09′03.6″	23°04′49.8″	239	Sloping edge, 20 cm	0.976	0.884	1.288	0.51±0.08	7.8±1.4	9.1±1.6	9.4±1.6	9.8±1.7

[a] Description of where on the boulder and from which height above ground the sample is taken.
[b] Thickness correction using exponential decrease in nuclide production and bulk density of 2.32 g/cm.
[c] Correction for shielding by distant objects (and shielding by sample geometry for KB-4). Shielding $<5°$ is neglected.
[d] Scaling factor after Stone (2000).
[e] Correction for blank ($3.0195 \pm 0.8235 \times 10^{-14}$).
[f] Ages calculated with erosion rates of 0 mm/ka, 5 mm/ka and 1 cm/ka.

either sediment or seasonal snow. Thus, we choose to discard the youngest age and base further discussions on the average age of the three oldest ages which ranges between 15.1±2.5 ka for minimum (0 mm ka^{-1}) and 17.3±2.9 ka for maximum erosion (10 mm ka^{-1}).

4. Implications for the LGM ice configuration

Our ^{10}Be ages are consistent with exposure of Kap Brewster soon after the LGM, thus suggesting that the peninsula was covered by ice during the LGM as has been hypothesized by Mangerud and Funder (1994). The elevation of the erratics indicates a minimum thickness of c. 250 m a.s.l. for this ice. To reconcile ice being >250 m thick on Kap Brewster, yet <70 m thick on the opposite side of Scoresby Sund, earlier reconstructions (Mangerud and Funder, 1994) have suggested that the southern side of the Scoresby Sund glacier was higher because it was fed by local tributary glaciers from the south (Fig. 3a). This ice configuration implies that ice-flow over Kap Brewster was directed from the basalt plateaus south of Scoresby Sund, where there is no source for the sandstone erratics (Fig. 1a). Thus, it would require that erratics were deposited by an earlier extensive advance of the Greenland Ice Sheet and later re-deposited on Kap Brewster by a local ice merging with the outlet glacier in Scoresby Sund during the LGM. In this scenario we would expect to have inherited ^{10}Be in the samples, since they would have been exposed before the LGM and we would expect our samples to be older (have higher ^{10}Be concentrations). Rather we suggest that the young erratics on Kap Brewster require LGM ice with flow lines parallel to the fjord trough, reaching at least 250 m a.s.l. at the mouth of Scoresby Sund.

If the glacial striae on Kap Brewster indeed are from the LGM as suggested by Mangerud and Funder (1994) this indicates that the ice was sliding at its bed at 250 m a.s.l. during this time. However, at the same elevation on the north side of Scoresby Sund the terrain is intensely weathered. It is possible that active ice within the previously depicted LGM limit on Jameson Land was buttressed by cold-based ice preserving the old landscapes beyond this limit (Fig. 3b). In other settings it has been found that cold-based ice can override and preserve weathered non-glacial landscapes (Kleman, 1994; Fabel et al., 2002; Briner et al., 2003, 2006; Sugden et al., 2005; Davis et al., 2006). The Scoresby Sund trough is deepest in the southern part, whereas the northern side gently rises towards Jameson Land (Fig. 3; Dowdeswell et al., 1993). Ice filling Scoresby Sund would be channelized in the southern part bounded by the southern steep slope of the trough, thus facilitating fast ice flow in this part of the trough. Thus, the asymmetric trough morphology could explain why ice was eroding its bed on Kap Brewster, yet was cold-based at the same elevation on Jameson Land.

Sediment cores from the northern part of the Scoresby Sund fan document an increased sediment flux to this part of the fan between 19 and 15 ka, interpreted as ice rafted

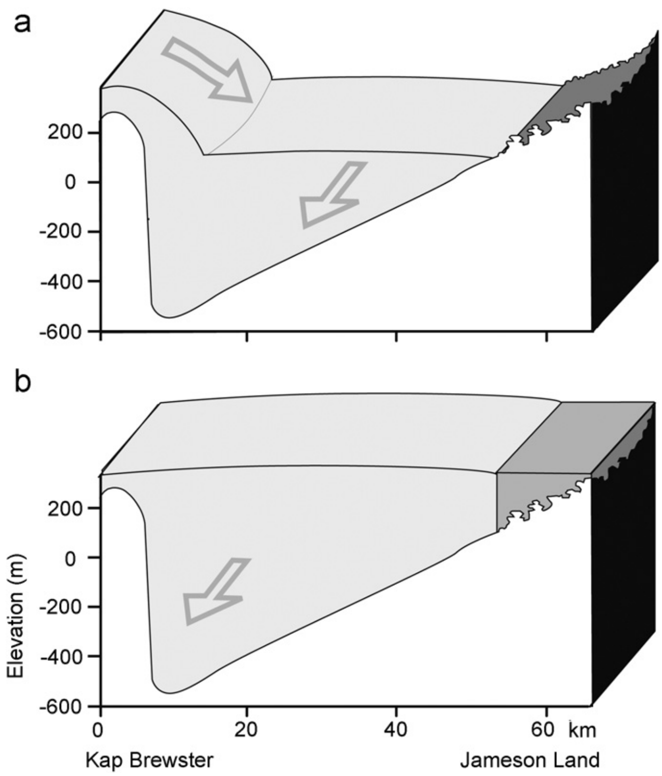

Fig. 3. Simplified illustration of two alternative LGM ice configurations in Scoresby Sund: (a) as suggested by Mangerud and Funder (1994) and (b) as suggested by this study. The bathymetric information is after Dowdeswell et al. (1993).

debris from ice situated at the Kap Brewster moraine more than 100 km away (Stein et al., 1993; Nam et al., 1995). Further south, at the mouth of the cross-shelf trough, Dowdeswell et al. (1997) show debris flow activity during the LGM. In line with traditional LGM ice reconstructions (e.g., Funder et al., 1998), they suggest that the debris flow lobes might derive either from strong cross-shelf transport from an ice front located at the mouth of Scoresby Sund during the LGM or from direct sediment delivery from extensive ice earlier during the last glacial cycle. Other studies of similar glacier-fed subaqueous fans have shown that the large number of debris flows making up these fan systems is a result of ice at the continental shelf break (King et al., 1996; Vorren and Laberg, 1997; Vorren et al., 1998; Dowdeswell and Elverhøi, 2002; Sejrup et al., 2004).

Based on a regional synthesis of the Greenland margin, Bennike and Björck (2002) suggested that LGM ice covered at least parts of the broad and shallow northeast Greenland shelf. Seismic data off Kaiser Franz Josef Fjord show a prominent moraine ca 50 km from the shelf break interpreted to be a LGM terminal or recessional moraine (Fig. 1b; Evans et al., 2002). Furthermore, O'Cofaigh et al. (2004) suggest that submarine channels on the continental shelf slope emanating from the lip of shelf troughs are generated by glacier ice on the outer shelf or at the shelf break. Radiocarbon dates show that mass wasting in these channels ceased around 13 ka, indicating that the last time these channels were active was during the LGM.

The traditional LGM reconstructions have suggested two distinctly different ice sheet regimes along the coast of East Greenland; ice to the shelf break south of Scoresby Sund and ice extending no further than to the inner shelf north thereof. The present study challenges these reconstructions by adding to a growing body of evidence indicating LGM ice extending onto the outer shelf also at and north of Scoresby Sund.

5. Conclusion

Previous LGM reconstructions of the northeastern sector of the Greenland Ice Sheet are based mainly on terrestrial studies and depict ice terminating at the mouth of fjords and sounds. In contrast, recent marine data from the northeast Greenland continental shelf suggest that the ice extended onto the outer shelf or even as far as the continental shelf break during the this time. Our average ^{10}Be ages, calculated with an assumed maximum erosion rate of 1 cm/ka and no erosion (respectively 17.3 ± 2.9 and 15.1 ± 2.5 ka) overlap with a period of increased sediment input on the northern part of the Scoresby Sund fan (19–15 ka), indicating the timing of the LGM ice sheet advance in East Greenland. The results presented here suggest that ice reached at least 250 m a.s.l. at the mouth of Scoresby Sund during the LGM, implying that ice reached the outer shelf at this time and that sliding ice in the fjord trough may have been buttressed by cold-based ice on Jameson Land.

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References

Andrews, J.T., Jennings, A.E., Cooper, T., Williams, K.M., Mienert, J., 1996. Late Quaternary sedimentation along fjord to shelf (trough) transect, East Greenland (ca. 68°N). In: Andrews, J.T., Austin, W.E.N., Bergsten, H., Jennings, A.E. (Eds.), Late Quaternary Paleoceonagraphy of the North Atlantic Margins, vol. 111. Geological Society Special Publication, pp. 153–167.

Bennike, O., Björck, S., 2002. Chronology of the last recession of the Greenland Ice Sheet. Journal of Quaternary Science 17, 211–219.

Bierman, P.R., Marsella, K.A., Patterson, C., Davis, P.T., Caffee, M., 1999. Mid-Pleistocene cosmogenic minimum-age limits for pre-Wisconsinan glacial surfaces in southwestern Minnesota and southern Baffin Island: a multiple nuclide approach. Geomorphology 27, 25–39.

Bond, G., Broecker, W., Johnsen, S., McManus, J., Labeyrie, L., Jouzel, J., Bonani, G., 1993. Correlations between climate records from North Atlantic sediment and Greenland ice. Nature 365, 143–147.

Briner, J.P., 2003. The last glaciation of the Clyde Region, Northeastern Baffin Island, Arctic Canada. Boulder. Ph.D. Thesis, University of Colorado, Boulder, USA, 282pp.

Briner, J.P., Miller, G.H., Davies, P.T., Bierman, P.R., Caffee, M., 2003. Last Glacial Maximum ice sheet dynamics in the Canadian Arctic inferred from young erratics perched on ancient tors. Quaternary Science Reviews 22, 437–444.

Briner, J.P., Miller, G.H., Davis, T.R., Finkel, R., 2005. Cosmogenic exposure dating in arctic glacial landscapes: implications for the glacial history of northeastern Baffin Island, Arctic Canada. Canadian Journal of Earth Sciences 42, 67–84.

Briner, J.P., Miller, G.H., Davies, P.T., Finkel, R., 2006. Cosmogenic radionuclides from fiord landscapes support differential erosion by overriding ice sheets. GSA Bulletin 118, 406–430.

Broecker, W.S., 1997. Thermohaline circulation, the Achilles heel of our climate system: will man-made CO_2 upset the current balance? Science 278, 1582–1588.

Clark, P.U., Alley, R.B., Pollard, D., 1999. Northern hemisphere ice-sheet influences on global climate change. Science 286, 1104–1111.

Davis, P.T., Briner, J.P., Coulthard, R.P., Finkel, R.W., Miller, G.H., 2006. Preservation of Arctic landscapes overridden by cold-based ice sheets. Quaternary Research 65, 156–163.

Dowdeswell, J.A., Elverhøi, A., 2002. The timing of initiation of fast-flowing ice streams during a glacial cycle inferred from glacimarine sedimentation. Marine Geology 188, 3–14.

Dowdeswell, J.A., Villinger, H., Whittington, R.J., Marienfeld, P., 1993. Iceberg scouring in the Scoresby Sund and on the East Greenland continental shelf. Marine Geology 111, 37–53.

Dowdeswell, J.A., Uenzelmann-Neben, G., Whittington, R.J., Marienfeld, P., 1994. The Late Quaternary sedimentary record in Scoresby Sund, East Greenland. Boreas 23, 294–310.

Dowdeswell, J.A., Kenyon, N.H., Laberg, J.S., 1997. The glacier-influenced Scoresby Sund Fan: evidence from GLORIA and 3.5 kHz records. Marine Geology 143, 207–221.

Evans, J., Dowdeswell, J.A., Grobe, H., Niessen, F., Stein, R., Hubberten, H.W., Whittington, R.J., 2002. Late Quaternary sedimentation in Kejsar Franz Joseph Fjord and the continental margin of East Greenland. In: Dowdeswell, J.A., O'Cofaigh, C. (Eds.), Glacier Influenced Sedimentation on High Latitude Continental Margins. Geological Society, London, UK, Special Publications, vol. 203, London, pp. 149–179.

Fabel, D., Stroeven, A.P., Harbour, J., Kleman, J., Elmore, D., Fink, D., 2002. Landscape preservation under Fennoscandian ice sheets determined from in situ produced ^{10}Be and ^{26}Al. Earth and Planetary Science Letters 201, 397–406.

Funder, S., Hjort, C., 1973. Aspects of the Weichselian chronology in central East Greenland. Boreas 2, 69–84.

Funder, S., Hjort, C., Landvik, J.Y., Nam, S.-I., Reeh, N., Stein, R., 1998. History of a stable ice margin—East Greenland during the middle and upper Pleistocene. Quaternary Science Reviews 17, 77–123.

Gosse, J.C., Phillips, F.M., 2001. Terrestrial in-situ cosmogenic nuclides; theory and application. Quaternary Science Reviews 20, 1275–1560.

Henriksen, N., 1989. Scoresby Sund omradets geologi. Geologisk beskrivelse og kort 1:500,000, map sheet 12, Scoresby Sund. Danmarks og Grønlands Geologiske Undersøgelse, Copenhagen, Denmark.

Hjort, C., 1981. A glacial chronology for northern East Greenland. Boreas 10, 259–274.

Jennings, A.E., Hald, M., Smith, M., Andrews, J.T., 2006. Freshwater forcing from the Greenland Ice Sheet during the Younger Dryas: evidence from southeastern Greenland shelf cores. Quaternary Science Reviews 25, 282–298.

King, E.L., Sejrup, H.P., Haflidason, H., Elverhøi, A., Aarseth, I., 1996. Quaternary seismic stratigraphy of the North Sea Fan: glacially-fed gravity flow aprons, hemipelagic sediments and large submarine slides. Marine Geology 130, 293–316.

Kleman, J., 1994. Preservation of landforms under ice sheets and ice caps. Geomorphology 9, 19–32.

Lal, D., 1991. Cosmic ray labeling of erosion surfaces: in-situ nuclide production rates and erosion models. Earth and Planetary Science Letters 104, 424–439.

Landvik, J.Y., 1994. The last glaciation of Germania Land and adjacent areas, northeast Greenland. Journal of Quaternary Science 9, 81–92.

Landvik, J.Y., Ingólfsson, O., Mienert, J., Lehman, S.J., Solheim, A., Elverhöi, A., Otesen, D., 2005. Rethinking Late Weichselian ice sheet dynamics in coastal NW Svalbard. Boreas 34, 7–24.

Mangerud, J., Funder, S., 1994. The interglacial–glacial record at the mouth of Scoresby Sund, East Greenland. Boreas 23, 349–358.

Mienert, J., Andrews, J.T., Milliman, J.D., 1992. The East Greenland continental margin (65°N) since the last deglaciation: changes in sea floor properties and ocean circulation. Marine Geology 106, 217–238.

Möller, P., Hjort, C., Adrielsson, L., Salvigsen, O., 1994. Glacial history of interior Jameson Land, East Greenland. Boreas 23, 320–348.

Nam, S.I., Stein, R., Grobe, H., Hubberten, H., 1995. Late Quaternary glacial-interglacial changes in sediment composition at the East Greenland continental margin and their paleoceanographic implications. Marine Geology 122, 243–262.

O'Cofaigh, C., Dowdeswell, J.A., Evans, J., Kenyon, N.H., Taylor, J., Mienert, J., Wilken, M., 2004. Timing and significance of glacially influenced mass-wasting in the submarine channels of the Greenland Basin. Marine Geology 207, 39–54.

Ottesen, D., Rise, L., Knies, J., Olsen, L., Henriksen, S., 2005. The Vestfjorden-Trænadjupet paleo-ice stream drainage system, mid Norwegian continental shelf. Marine Geology 218, 175–189.

Sejrup, H.P., Haflidason, H., Hjelstuen, B.O., Nygård, A., Bryn, P., Lien, R., 2004. Plestocene development of the SE Nordic Seas margin. Marine Geology 213, 169–200.

Stein, R., Grobe, H., Hubberten, H., Marienfeld, P., Nam, S., 1993. Latest Pleistocene to Holocene changes in glaciomarine sedimentatioin in Scoresby Sund and along the adjacent East Greenland continental margin: preliminary results. Geo-Marine Letters 13, 9–16.

Stone, J.O., 2000. Air pressure and cosmogenic isotope production. Journal of Geophysical Research 105, 23753–23759.

Sugden, D.E., Balco, G., Cowdery, S.G., Stone, J.O., Sass, III, 2005. Selective glacial erosion and weathering zones in the coastal mountains of Mary Bird Land, Antarctica. Geomorphology 67, 317–334.

Tveranger, T., Houmark-Nielsen, M., Løvberg, K., Mangerud, J., 1994. Eemian-Weichselian stratigraphy of the Flakkerhuk ridge, southern Jameson land, East Greenland. Boreas 23, 359–384.

Vorren, T.O., Laberg, J.S., 1997. Trough mouth fans—paleoclimate and ice-sheet monitors. Quaternary Science Reviews 16, 865–881.

Vorren, T.O., Laberg, J.S., Blaume, F., Dowdeswell, J.A., Kenyon, N.H., Mienert, J., Rumohr, F., 1998. The Norwegian-Greenland continental margins: morphology and late Quaternary sedimentary processes and environment. Quaternary Science Reviews 17, 273–302.

Zreda, M., England, J., Phillips, F., Elmore, D., Sharma, P., 1999. Unblocking of the Nares Strait by Greenland and Ellesmere ice-sheet retreat 10,000 years ago. Nature 398, 139–142.