8-1-2008

The Most Extensive Holocene Advance in the Stauning Alper, East Greenland, Occurred in the Little Ice Age

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The most extensive Holocene advance in the Stauning Alper, East Greenland, occurred in the Little Ice Age

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Keywords
Glaciation; Greenland; Holocene; Little Ice Age.

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doi:10.1111/j.1751-8369.2008.00058.x

Abstract

We present glacial geologic and chronologic data concerning the Holocene ice extent in the Stauning Alper of East Greenland. The retreat of ice from the late-glacial position back into the mountains was accomplished by at least 11 000 cal years B.P. The only recorded advance after this time occurred during the past few centuries (the Little Ice Age). Therefore, we postulate that the Little Ice Age event represents the maximum Holocene ice extent in this part of East Greenland.

The character and origin of Holocene climate changes remain poorly constrained. Possible explanations for climate fluctuations over the past 10 000 years range from solar variability to changes in the strength of ocean circulation (Denton & Karlén 1973; Broecker et al. 1999; Bond et al. 2001; Broecker & Denton unpubl. ms). Tests of hypotheses of Holocene climate change require a variety of high-quality geologic and biologic proxy records. Here, we present data concerning the late Holocene glacier extent in the Stauning Alper, which is adjacent to Scoresby Sund, the largest fjord system in East Greenland (Fig. 1). These data bear on the nature and possible cause of Holocene climate change.

Today, small alpine glaciers extend eastward from the Stauning Alper, terminating close to Schuchert Dal, which is a broad, north–south-trending valley. During the Last Glacial Maximum, these local alpine glaciers merged with inland (Greenland ice sheet) ice draining through the fjords. This combined ice mass filled Scoresby Sund and extended at least to the Kap Brewster moraine at the fjord mouth (Mangerud & Funder 1994; Håkansson et al. 2007), if not to the shelf edge. The exact timing of ice recession from the fjord mouth is unknown, but the oldest sediments in Scoresby Sund date only to the Younger Dryas or Allerød (Marienfeld 1991). A stillstand or readvance occurred in late-glacial time and produced the Milne Land stade moraines (Funder 1970) of Younger Dryas and Preboreal age (Kelly et al. 2008; Hall et al. unpubl. ms).

Surficial geology

Our results are based on surficial geologic mapping, coupled with the collection and dating of marine molluscs. We concentrate here on the Bjørnbo and Roslin valleys, both of which trend perpendicular to Schuchert Dal (Fig. 2). In each of these valleys, prominent thrust moraines characterize a fresh-looking, unvegetated, ice-cored drift sheet (Fig. 3). Kettle and kame topography is common. The drift sheets extend 3–5 km from the present ice fronts, and project into Schuchert Dal. Sediments consist of a mixture of till and thrust blocks of outwash and marine sediments. Fragments of mollusc shells are common in areas composed of reworked marine sediments.

In situ raised marine deposits occur immediately distal to the drift sheets to elevations as much as 134 m a.s.l. Flights of well-preserved deltas are common along every stream (Fig. 4). The most prominent feature is a broad marine terrace that extends along both sides of Schuchert Dal at an elevation of about 60 m a.s.l. Delta exposures reveal stratified sand and gravel topsets, and foresets overlying blue-grey clay. Both the deltas and the clay contain abundant marine shells in growth positions. Common species include *Mya truncata*, *Hiatella arctica*, *Chlamys islandica*, *Astarte elliptica* and *Macoma calcarea*.

The drift sheets and marine deposits show cross-cutting relationships. For example, at Roslin Gletscher, well-preserved marine terraces extend to the edge of the drift sheet (Fig. 3a). Within the drift limit, the terraces are

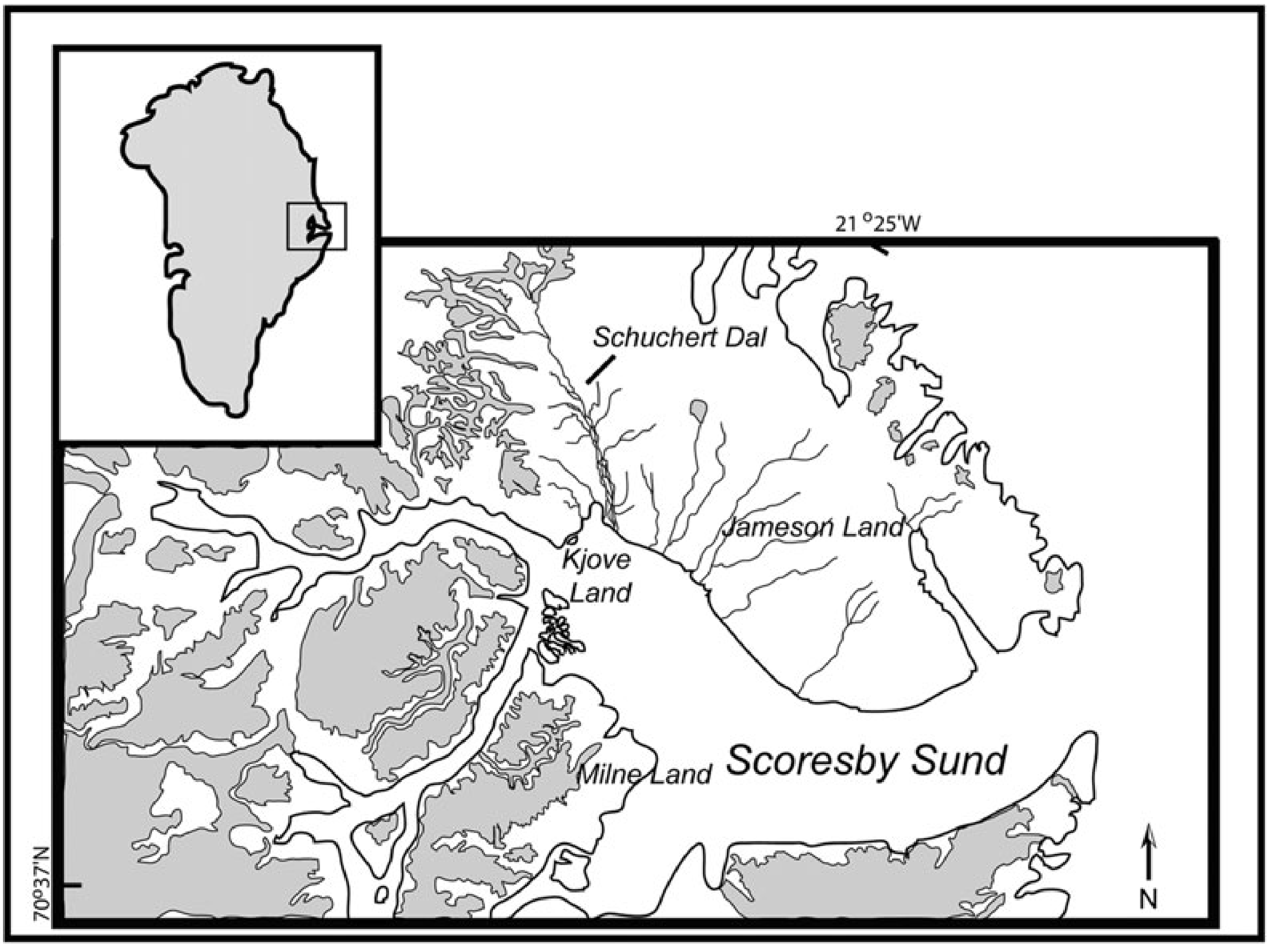

Fig. 1. Index map of Scoresby Sund, East Greenland.

absent and the glacial deposits contain reworked marine sediments.

Chronology

Our chronology comes from accelerator mass spectrometry (AMS) radiocarbon dates of shells contained within elevated marine deposits. These ages allow us to date marine deposits and also to place limits on former glacier extents. We present here only the oldest date at each site in Schuchert Dal (Table 1, Fig. 2), as these are the most pertinent to the discussion below. All dates have been converted to calendar years by using the CALIB Marine04 dataset (http://calib.qub.ac.uk/calib/) and applying a marine reservoir correction of 550 years. This correction, based on dates of historical samples within the Scoresby Sund region (Washburn & Stuiver 1962; Hjort 1973; Tauber & Funder 1975), could have changed throughout the Holocene, which is the time period covered by our samples. A paired date of terrestrial organics and marine shells from a delta in nearby Jameson Land suggests a correction of as much as 700 years for the early Holocene (Funder & Hansen 1996). A correction slightly larger than 550 years would not change our interpretation.

In situ marine deposits along both the east and west sides of Schuchert Dal are as much as 10 990 cal years old (Table 1). Dates of shells reworked into the fresh glacial drift (10 106 ± 109 and 10 143 ± 120 cal years B.P.) are similar, and must have been deposited originally when the sea flooded Schuchert Dal following deglaciation from the late-glacial Milne Land stade moraines.

Discussion

Little Ice Age

Fresh moraines and ice-cored drift of presumed "historical" age occur 1–2 km beyond the snouts of most land-based alpine glaciers in the Scoresby Sund region (Funder 1990). Similar moraines elsewhere in Greenland gener-

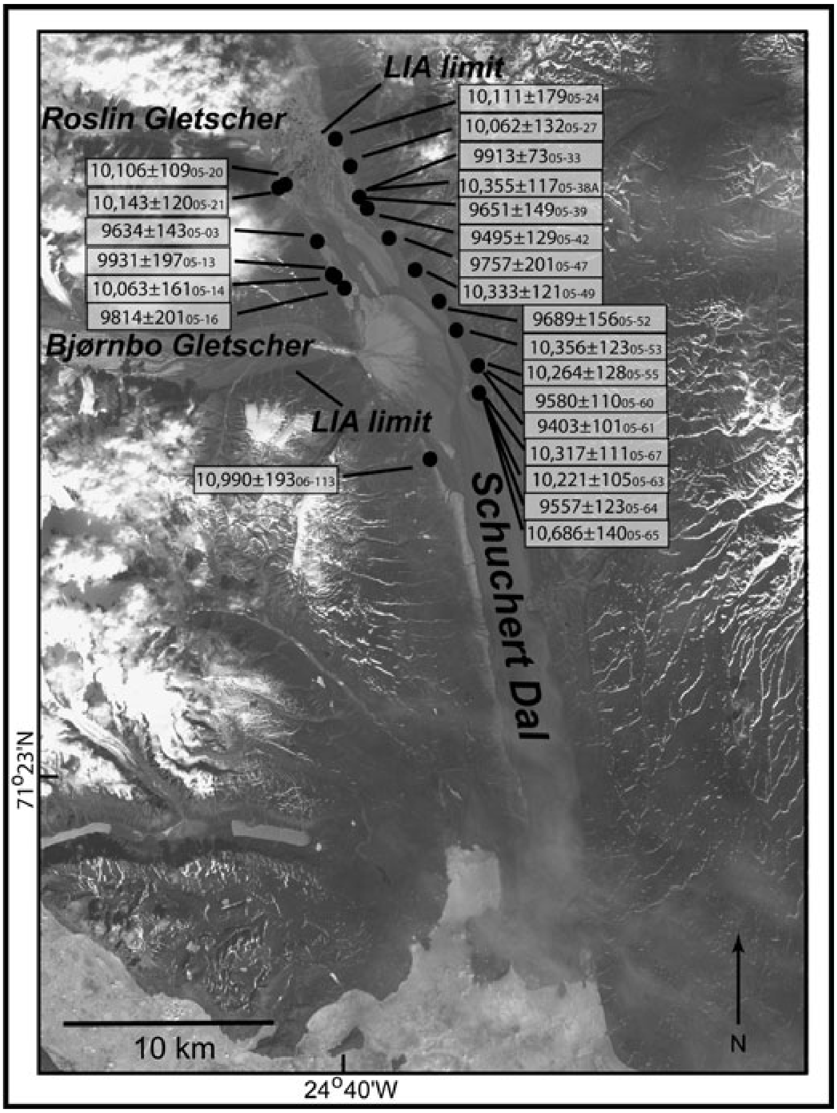

Fig. 2. Satellite image map of Schuchert Dal, showing the locations of Bjørnbo and Roslin glaciers. Note that the limits of the fresh Little Ice Age (LIA) drift are visible as a colour difference on the image. Dates are shown as calendar ages with a 2σ error. The small numbers refer to sample sites and are explained in Table 1.

ally date to the 19th century, based on historical data (Ahlmann 1941a, 1941b; Weidick 1963, 1968, 1994). Because of the similarities in position, composition, thick ice cores, and lack of weathering and vegetation, we correlate the fresh drift sheets at Roslin and Bjørnbo glaciers with "historical" moraines elsewhere in Greenland. Fresh-looking, unvegetated moraines of identical appearance and almost surely of the same age, occur in adjacent Gurreholmsdal. Kelly et al. (2008) recently obtained ^{10}Be dates of 300–800 years B.P. for the outermost moraine of this drift sheet. Therefore, we assume that most (if not all) of the unweathered deposits at Roslin and Bjørnbo glaciers date to roughly this time period. For simplicity, we hereafter refer to these features as Little Ice Age (LIA) moraines, although we cannot exclude the possibility that small segments may date to earlier, Neoglacial advances. We are unaware of any work on revegetation rates in East Greenland that might help us differentiate LIA moraines from those deposited in the previous millennium. The freshness of the drift, along with its ice core, strongly argues for recent deposition and ice retreat. Based on plant remains emerging from nearby receding glaciers, Lowell et al. (2007) suggested retracted ice and warmer temperatures during the Medieval Warm Period, making it less likely that an ice core would have survived from preceding advances.

There are no other moraines between the LIA limit and the late-glacial Milne Land stade position located more than 30 km down the valley. Instead, well-preserved marine terraces occur immediately adjacent to the drift sheets. These terraces yielded ages as old as ca. 11 000 years B.P., thereby precluding any overriding of ice since

Fig. 3. (a) Photograph of the Roslin Gletscher right lateral fresh (Little Ice Age) drift limit and adjacent marine terraces. Reworked marine deposits occur within the drift sheet. (b) Photograph of ice-cored, fresh drift deposits at Roslin Gletscher. Drift hummocks are as high as 10 m.

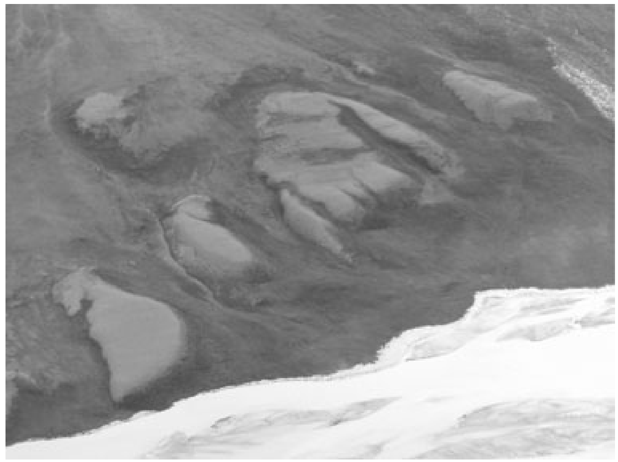

Fig. 4. Oblique aerial photograph of marine deltas and terraces on the east side of Schuchert Dal. The delta at the lower left is approximately 50 m wide.

that time. Where the terraces were overrun by the LIA advance, the landforms were destroyed and the molluscs were reworked. This geomorphology, combined with the shell chronology, indicate to us that the LIA advance was the most extensive glacial event of the Holocene in this region.

This pattern has been observed in some other areas of the Northern Hemisphere. For example, adjacent to Myrdalsjökull in Iceland, the maximum Holocene extent occurred during the LIA (Casely & Dugmore 2004). This is also the case in much (but not all) of southern Greenland (Weidick et al. 2003; Bennike & Sparrenbom 2007), and in other areas fringing the North Atlantic (e.g., Svendsen & Mangerud 1997; Lubinski et al. 1999; Grove 2004). This same situation, although not ubiquitous, has also been documented in more distant locations, such as the Sierra Nevada (Clark et al. 2007), Alaska (Wiles et al. 1995; Calkin et al. 2001) and in adjacent Canada (Denton & Stuiver 1966; Reyes, Luckman et al. 2006; Reyes, Wiles et al. 2006). Moreover, some pollen and treeline reconstructions from the Arctic (Kremenetski et al. 1998; Kullman & Kjallgran 2000; MacDonald et al. 2000; Wagner & Melles 2002), as well as sea-surface temperatures (SST) variations in some parts of the tropics (e.g., deMenocal et al. 2000) and the North Atlantic (Marchal et al. 2002; Moros et al. 2004), also indicate that the most significant Holocene cooling occurred in the LIA. Recently, Broecker & Denton (unpubl. ms) suggested that this pattern of decreasing Holocene temperatures is the result of a progressive weakening of the North Atlantic deepwater circulation. An alternative hypothesis is that the decrease in temperatures observed throughout the Holocene is a result of reduced solar insolation caused by changes in orbital parameters (Kutzbach & Gallimore 1988; Renssen et al. 2005; Grove 2008), and that the LIA itself, as well as earlier cool periods in the Holocene, was forced by a millennial-scale solar cycle (e.g., Denton & Karlén 1973; Bond et al. 2001). Although we cannot test either of these ideas directly, our data are consistent with a hypothesis of progressive cooling in the Holocene.

The 8200-year event

The 8200 years B.P. cold period is the most significant abrupt cold event of the Holocene that has been registered by the Greenland ice cores (e.g., Alley & Ågústdóttir 2005). It lasted approximately 160 years and was marked by a sharp 7.4°C temperature drop in the GRIP ice core (Leuenberger et al. 1999; Thomas et al. 2007). Despite being the most prominent Holocene cooling event in the ice cores, we have yet to find evidence of this in the

Table 1. Radiocarbon dates of mollusc samples collected from raised-marine sediments near Bjørnbo and Roslin glaciers. We converted radiocarbon years to calendar years using CALIB 5.1, with the Marine04 dataset and a reservoir correction of 550 years (see text for details). The errors quoted for calendar years are 2σ (those for radiocarbon dates are only 1σ). Unidentified fragments are likely to be either *Mya truncata* or *Hiatella arctica*. The field numbers are shown in Fig. 2.

Field no.	Lab no.	Species	$\delta^{13}C$	^{14}C year	±	Cal year	±
Roslin Gletscher							
05-03	OS-55609	*Mya truncata*	1.07	9 100	50	9 634	143
05-13	OS-55610	Unidentified frag.	1.6	9 300	50	9 931	197
05-14	OS-55724	*Mya truncata*	1.84	9 420	60	10 063	161
05-16	OS-55725	*Mya truncata*	2.51	9 230	45	9 814	201
05-20	OS-55726	Unidentified frag.	0.94	9 430	35	10 106	109
05-21	OS-55727	Unidentified frag.	1.07	9 470	45	10 143	120
05-24	OS-55611	Unidentified frag.	–2.71	9 470	60	10 111	179
05-27	OS-55728	*Mya truncata*	0.52	9 410	40	10 062	132
05-33	OS-51882	Unidentified frag.	1.59	9 290	55	9 913	210
05-38A	OS-55729	Unidentified frag.	0.91	9 650	40	10 355	117
05-39	OS-55612	Unidentified frag.	2.75	9 110	50	9 651	149
05-42	OS-55730	*Mya truncata*	1.7	8 970	60	9 495	129
05-47	OS-55613	Unidentified frag.	1.41	9 210	50	9 757	201
Bjørnbo Gletscher							
06-113	OS-62852	*Portlandia arctica*	–0.38	10 200	60	10 990	193
05-49	OS-51568	*Mya truncata*	–0.13	9 620	45	10 333	121
05-52	OS-55731	*Mya truncata*	1.24	9 150	45	9 689	156
05-53	OS-55732	*Mya truncata*	–0.41	9 650	45	10 356	123
05-55	OS-52956	*Mya truncata*	0	9 540	55	10 264	128
05-60	OS-55735	Unidentified frag.	1.45	9 060	45	9 580	110
05-61	OS-55614	*Mya truncata*	1.5	8 890	45	9 403	101
05-62	OS-52963	*Mya truncata*	1.74	9 610	40	10 317	111
05-63	OS-55736	*Mya truncata*	–0.18	9 510	45	10 221	105
05-64	OS-55737	Unidentified frag.	2.17	9 030	55	9 557	123
05-65	OS-52964	*Mya truncata*	1.41	9 950	45	10 686	140

nearby moraine record. Instead, our work in the Stauning Alper indicates that marine sediments, dating to about 11 000 cal years B.P., occur right up to (and beneath) the LIA moraines. Based on this site, we conclude that prior to 8200 years B.P., ice receded to a position inside the LIA limit—possibly to a size similar to that at present. If the glaciers did respond to the 8200-year cooling event, then the advance was less extensive than that of the LIA, and its record is not preserved.

Conclusions

Deglaciation of Schuchert Dal was accomplished by at least 11 000 cal yr B.P. The only recorded advance after this time occurred during the LIA. Therefore, we postulate that the LIA event represents the maximum glacier extent of the Holocene in this part of East Greenland. The cause of climate deterioration throughout the Holocene is unknown, but may result from a weakening of the Atlantic thermohaline circulation or from a decline in solar insolation.

Acknowledgements

We thank Mr. Gary Comer and the Comer Science and Education Foundation, without whom this work would never have been possible. We also thank Captain and Bev Walsh, and the crew of *Turmoil*, A. Lange, T. Allen and the Danish Polar Center for logistical support. Discussions with B. Andersen, S. Funder, M. Kelly and T. Lowell greatly improved this work. We thank two anonymous reviewers for their constructive comments.

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