Quaternary Science Reviews 30 (2011) 2476–2486

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Varve and radiocarbon dating support the rapid advance of Jakobshavn Isbræ during the Little Ice Age

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A R T I C L E I N F O

Article history:
Received 4 February 2011
Received in revised form
25 May 2011
Accepted 29 May 2011
Available online 2 July 2011

Keywords:
Jakobshavn Isbræ
Varve
Radiocarbon dating
Lake sediments
Little Ice Age

A B S T R A C T

Large outlet glaciers draining the Greenland Ice Sheet significantly influence overall ice sheet mass balance. Considerable short term (years to decades) retreat and fluctuations in velocity of Jakobshavn Isbræ, western Greenland, illustrate the complex nature by which large outlet glaciers respond to climate change, making predictions of future ice sheet change challenging. To provide a longer-term view (centuries), we investigate the geological record of Jakobshavn Isbræ change. We use continuous sediment records from lakes that were influenced by the recent advance of Jakobshavn Isbræ, which took place during the Little Ice Age. In particular, we explore the use of annually laminated lake sediments (varves) to precisely constrain the advance of the ice margin as it approached its late Holocene maximum extent. We find that the ice margin advanced recently, at least after ~1650 to ~1700 AD, and more likely ~1800 AD. We suggest that during this period Jakobshavn Isbræ advanced at a rate that was similar to its historically documented average retreat since ~1850 AD. Our results indicate that Jakobshavn Isbræ, and presumably other large marine calving glaciers, have the ability to advance quickly in response to climate forcing.

1. Introduction

The Greenland Ice Sheet (GIS) is an integral part of the global climate system, and its potential contribution to sea level is of considerable importance (Alley et al., 2010). In particular, ice streams exert a disproportionate control on overall GIS mass balance, and thus have received increasing attention in the recent literature (e.g., Abdalati et al., 2001; Rignot and Thomas, 2002; Bamber et al., 2007; Thomas et al., 2009). Recent observations have revealed the dynamic nature and short timescales over which Greenland ice streams can adjust (Joughin et al., 2004, 2008; Rignot and Kanagaratnam, 2006; Howat et al., 2007). In particular, the importance of dynamic processes has been highlighted, prompting significant focus on the interplay between climatic and dynamic controls on ice stream change (Thomas et al., 2003; Csatho et al., 2008; Holland et al., 2008; Nick et al., 2009; Straneo et al., 2010). A greater understanding of the controls on ice stream change can be aided by longer-term reconstructions of past ice stream activity that extend beyond the relatively brief historic interval.

The GIS, like many glaciers across the globe, most recently advanced during the Little Ice Age (LIA), and throughout the 20th century many sectors of the GIS have experienced retreat (Weidick, 1968). We acknowledge that the term "Little Ice Age" has varying use in meaning and time; in this paper we follow Grove (2001) and use the term as a broad period of glacier advances across Greenland and define it as the time period ~1300 to ~1900 AD. This is the case for Jakobshavn Isbræ, the largest ice stream draining the western GIS. Historical observations around 1850 AD place the floating terminus ~40 km beyond its 2010 AD ice extent (Engell, 1904; Weidick, 1968; Csatho et al., 2008; Fig. 1), which was its most extensive position in the last 8000 yr (Weidick and Bennike, 2007; Young et al., 2011). When Jakobshavn Isbræ arrived at its maximum late Holocene position, or the precise timing of its advance, has only been broadly constrained to within the LIA (Weidick et al., 1990; Weidick and Bennike, 2007). Whereas mapping and dating LIA terminal moraines and obtaining at least some information on post-LIA behavior from historic records is relatively straightforward, determining when glaciers advanced is much more challenging. However, reconstructions of entire advance-retreat cycles of glaciation are most ideal for constraining the sensitivity of glaciers to climate perturbations. Maximum ages of recent glacier advances in Greenland are sparse, but have been obtained by radiocarbon dating marine fauna reworked into LIA moraines (e.g., Weidick et al., 2004) and organic material in sediments from proglacial-threshold lake basins (e.g., Kaplan et al., 2002).

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0277-3791/$ – see front matter
doi:10.1016/j.quascirev.2011.05.017

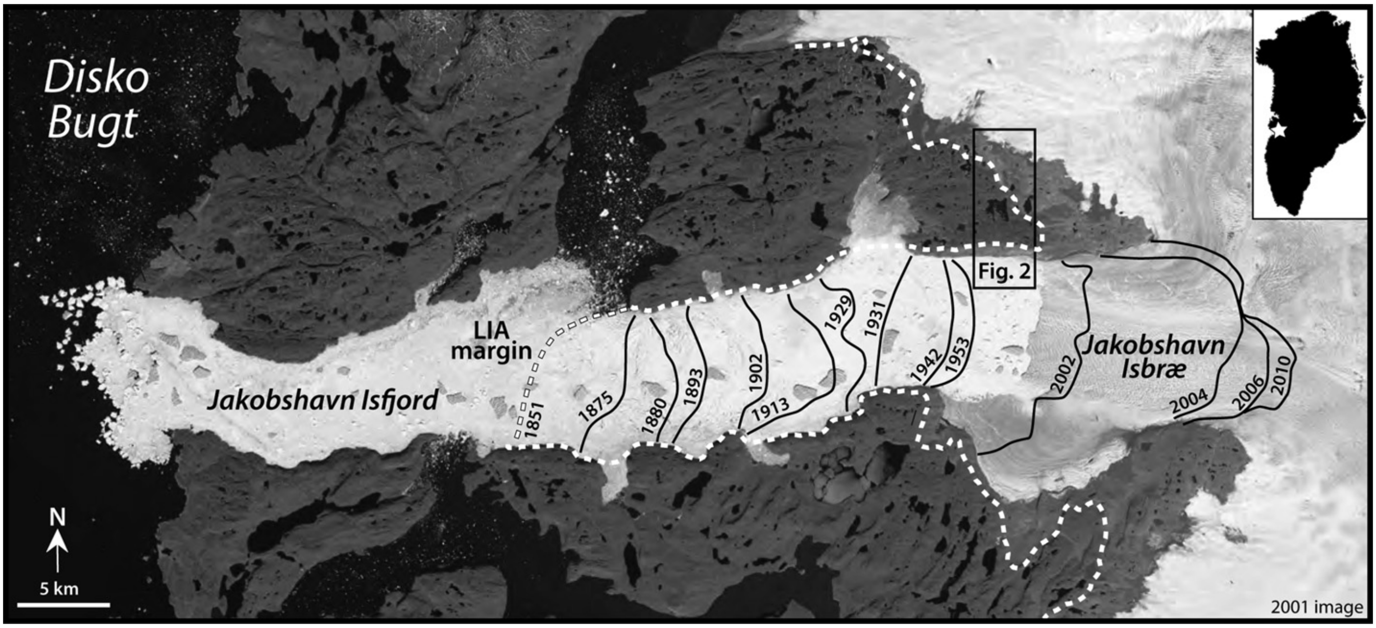

Fig. 1. Jakobshavn Isbrae region showing the maximum late Holocene extent (white dashed line) and historic positions of the marine terminus between 1851 and 2010. Inset shows map location (star) on west-central Greenland. Base map is 2001 Landsat image.

We build on our initial investigation of Jakobshavn ice margin change that used records from proglacial-threshold lakes (Briner et al., 2010). These are lakes that contain laminated minerogenic-rich glaciolacustrine sediments overlying non-glacial autochthonous organic-rich sediments, a sediment sequence diagnostic of advancing glaciers. We used radiocarbon ages from macrofossils nearest the transition from organic-rich to minerogenic-rich sediments to constrain the timing of GIS advance. Here, we utilize the lamination stratigraphy within glaciolacustrine sediments from two lakes to more precisely constrain the timing of the GIS advance during the LIA.

2. The Jakobshavn ice sheet margin

The west-central margin of the GIS is composed of land-terminating ice punctuated by marine-terminating outlet glaciers. Some of the marine-terminating glaciers are very large and fast-flowing; for example, Jakobshavn Isbræ flows many kilometers per year and drains ∼7% of the GIS (Joughin et al., 2004; Rignot and Kanagaratnam, 2006). Between the western GIS margin near Jakobshavn Isbræ and Disko Bugt is an ice-free corridor of land 40–50 km wide containing ice-sculpted bedrock dotted with hundreds of lakes (Fig. 1). This landscape was covered by the GIS during the last glaciation and became ice-free during the early Holocene (Weidick and Bennike, 2007; Young et al., 2011). Following a time period when the GIS margin terminated inland (eastward) of its current position, the GIS advanced (westward) during Neoglaciation, culminating in a maximum position that deposited the 'historical moraine,' which occurred during the LIA (Weidick, 1968; Weidick and Bennike, 2007). To improve the chronology of the LIA advance, we investigated the sediment sequences from two lakes. Iceboom Lake is an extant proglacial-threshold lake that no longer receives GIS meltwater due to ice recession, and Glacial Lake Morten was an ice-dammed lake that is now drained due to ice recession.

2.1. Iceboom Lake

Iceboom Lake (informal name, ∼180 m asl) lies ∼4 km west of the present ice margin (Fig. 2). The lake has a complex outline, contains several islands, a single outflow to the west, several minor inflows, and lies in a 5.18 km^2 catchment. Aerial photographs reveal that Iceboom Lake was glacier fed in 1944, 1953 and 1964, and that GIS meltwater had ceased to drain into the lake by 1985. An abandoned ∼200-m-long channel spans between the eastern shoreline and the historical moraine, and a boulder-rich proglacial delta resides in the northeastern corner of the lake, fed when the historical moraine was emplaced ∼280 m north of the delta. Iceboom Lake has complex bathymetry, with two relatively large basins ∼30–40 m deep and several minor sub-basins (Fig. 3).

2.2. Glacial Lake Morten

Glacial Lake Morten (informal name), now drained, occupied a north-south trending valley ∼1 km north of Iceboom Lake (Fig. 2). The lake formed when the GIS margin dammed the northward-draining valley. The resultant ice-dammed lake was ∼0.3 km wide and extended 1.2 km to the south, where it overflowed a threshold at ∼240 m asl. Aerial photographs acquired in 1944, 1953, 1964 and 1985 show a fully occupied lake basin, despite the ice margin having retreated from the historical moraine. The oldest available post-1985 cloud-free satellite image (1992) reveals a partially-drained lake, and the next available cloud-free images (starting in 1999) show the area beyond the historical moraine completely drained (Fig. 2). By 2001, the ice margin had retreated ∼1.3 km north of the historical moraine, and dams a small lake with an area ∼0.25 km^2 (Fig. 3).

The geomorphology and sedimentology of recently drained ice-dammed lakes provide rare insight into their history (Loso et al., 2004, 2006). Because a bedrock spillway controlled the level of Glacial Lake Morten, a prominent shoreline was formed that outlines the former lake (Fig. 3). Proglacial deltas along the lake's eastern shoreline reveal small ice-fed discharges into the lake, although the major source of inflow was likely the ice margin itself, which deposited a subaqueous moraine across the lake basin during its maximum Neoglacial extent. The lake basin itself is largely unvegetated, and in steep areas, its infill has been dissected by modern drainage. The basin floor proximal to the moraine lies