Quaternary Science Reviews 59 (2013) 87–100

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

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

Holocene temperature history at the western Greenland Ice Sheet margin reconstructed from lake sediments

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A R T I C L E I N F O

Article history:
Received 27 February 2012
Received in revised form
15 October 2012
Accepted 19 October 2012
Available online 29 November 2012

Keywords:
Greenland
Jakobshavn
Holocene thermal maximum
Neoglaciation
Paleoclimate
Lake sediments
Chironomidae

A B S T R A C T

Predicting the response of the Greenland Ice Sheet to future climate change presents a major challenge to climate science. Paleoclimate data from Greenland can provide empirical constraints on past cryospheric responses to climate change, complementing insights from contemporary observations and from modeling. Here we examine sedimentary records from five lakes near Jakobshavn Isbræ in central West Greenland to investigate the timing and magnitude of major Holocene climate changes, for comparison with glacial geologic reconstructions from the region. A primary objective of this study is to constrain the timing and magnitude of maximum warmth during the early to middle Holocene positive anomaly in summer insolation. Temperature reconstructions from subfossil insect (chironomid) assemblages suggest that summer temperatures were warmer than present by at least 7.1 ka (the beginning of the North Lake record; ka = thousands of years before present), and that the warmest millennia of the Holocene occurred in the study area between 6 and 4 ka. Previous studies in the Jakobshavn region have found that the local Greenland Ice Sheet margin was most retracted behind its present position between 6 and 5 ka, and here we use chironomids to estimate that local summer temperatures were 2–3 °C warmer than present during that time of minimum ice sheet extent. As summer insolation declined through the late Holocene, summer temperatures cooled and the local ice sheet margin expanded. Gradual, insolation-driven millennial-scale temperature trends in the study area were punctuated by several abrupt climate changes, including a major transient event recorded in all five lakes between 4.3 and 3.2 ka, which overlaps in timing with abrupt climate changes previously documented around the North Atlantic region and farther afield at ∼4.2 ka.

1. Introduction

Greenland's present-day climate and cryosphere are currently subjects of intensive investigation, in part because ongoing changes in the mass balance of the Greenland Ice Sheet have worldwide ramifications via contributions to global sea level (Alley et al., 2008; Rignot et al., 2011). Paleotemperature data, in combination with glacial geologic reconstructions, can help clarify how the Greenland Ice Sheet responds to climate change. Paleo-data provide empirical constraints on past ice-sheet responses to climate change (Long, 2009), and are useful for testing and improving general circulation models and the physics-based ice sheet models that are central to forecasting future mass balance changes (Simpson et al., 2009; Robinson et al., 2011).

The pre-industrial Holocene was characterized by changes in insolation and other climate forcings that caused significant climate changes in the Arctic and elsewhere (Kaufman et al., 2004; Mayewski et al., 2004; Renssen et al., 2009; Zhang et al., 2010). Thanks to widely preserved geologic archives, this most recent epoch of Earth's history provides opportunities to reconstruct those natural climate variations – and their impacts on ecosystems and ice sheets – in more detail than for earlier periods. Knowledge of Greenland's Holocene climate history comes from a combination of geomorphic and paleoecological evidence e.g., glacial deposits, beach ridges and remains of thermophilous species found north of their present-day habitat e.g. (Hjort and Funder, 1974; Bennike, 2004; Kelly and Lowell, 2009; Funder et al., 2011), ice sheet borehole temperatures (Dahl-Jensen et al., 1998), and continuous proxy

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0277-3791/$ – see front matter © 2012 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.quascirev.2012.10.024

records from ice cores, lake sediments, and marine sediments (e.g., Johnsen et al., 2001; Jennings et al., 2002; Andersen, 2004; Masson-Delmotte et al., 2005; de Vernal and Hillaire-Marcel, 2006; Moros et al., 2006; Wagner et al., 2007). Many records indicate that Greenland – like much of the Arctic and subarctic – experienced warmer summers for some portion of the early to middle Holocene, in response to high boreal summer insolation, and that early to mid-Holocene warmth was followed by cooling and glacier expansion in the late Holocene as summer insolation declined (Kaufman et al., 2004, 2009). The timing and magnitude of these changes were spatially variable (Kaufman et al., 2004; Kaplan and Wolfe, 2006; Renssen et al., 2009; Sundqvist et al., 2010), and remain uncertain in many parts of the Arctic.

Lake sediments from Greenland's ice-free margin provide continuous archives of past environmental change, including climate and glacier extent, which begin in the Lateglacial to middle Holocene depending on the timing of local basin deglaciation (Björck et al., 2002; Kaplan, 2002; Anderson et al., 2004). Here we present Holocene climate reconstructions from five lakes along the western Greenland Ice Sheet margin, near Jakobshavn Isbræ and Disko Bugt (Fig. 1). Insect (chironomid) remains from North Lake are used to generate quantitative estimates of summer temperatures. Changes in sediment composition at the five study lakes are interpreted as evidence for ice sheet fluctuations, changes in lake productivity, and regional climate changes throughout the Holocene.

2. Study sites

The landscape between Disko Bugt and the Greenland Ice Sheet margin comprises a ~25–40 km wide swath of ice-scoured exposed bedrock with sparse moraines, and is dotted with hundreds of lakes. This landscape is bisected by Jakobshavn Isfjord and Jakobshavn Isbræ, a major outlet glacier of the Greenland Ice Sheet (Fig. 1). The land surface throughout most of the region was deglaciated in the early Holocene following the last glaciation, when this sector of the Greenland Ice Sheet terminated on the continental shelf (Weidick and Bennike, 2007). Young et al. (2011a, 2011b) provide the most recent chronological control on deglaciation of the region: According to those results, following deglaciation of the coastal terrain fringing Disko Bugt ~10.2 ka (ka = thousands of years before present, calibrated age), the ice margin re-advanced to deposit the prominent Fjord Stade moraines at ~9.2 (Marrait moraine) and 8.2 ka (Tasiussaq moraine). These early Holocene advances were followed by ice retreat to a location inland of the present ice margin by ~7 ka. Accordingly, the timing of lake inception for the five study sites ranges from ~10 ka near the Disko Bugt coast (Pluto and Fishtote lakes) to ~7 ka near the present-day ice sheet margin (North, Iceboom and Loon lakes; Fig. 1). All five lakes in the present study lie well above the marine limit, at elevations between 170 and 285 m asl.

All lakes have surface areas <1 km^2, and lake depths range from 4.2 to 41 m (Table 1; all lake names are informal). Secchi depth measured at Fishtote Lake in August 2009 was 5.8 m; no other limnological data are available from the sites. The landscape surrounding each of the study lakes is dominated by scoured siliceous bedrock with very little soil cover and sparse low arctic tundra vegetation including heath and low willow scrub (Fig. 3). As can be seen in Fig. 3, there is subtle variation between sites, for example with sparser vegetation cover occurring at higher-elevation Fishtote Lake in comparison with North Lake. At the town of Ilulissat (Fig. 1), which is situated closer to the coast and at lower elevation than the study sites, mean July temperature for the years 1971–2000 was 7.7 °C and mean annual temperature was −4.8 °C.

The five study lakes were selected to represent a range of Holocene paleoenvironmental histories with respect to ice sheet influence: Fishtote and North lakes (Figs. 1–3) have not received

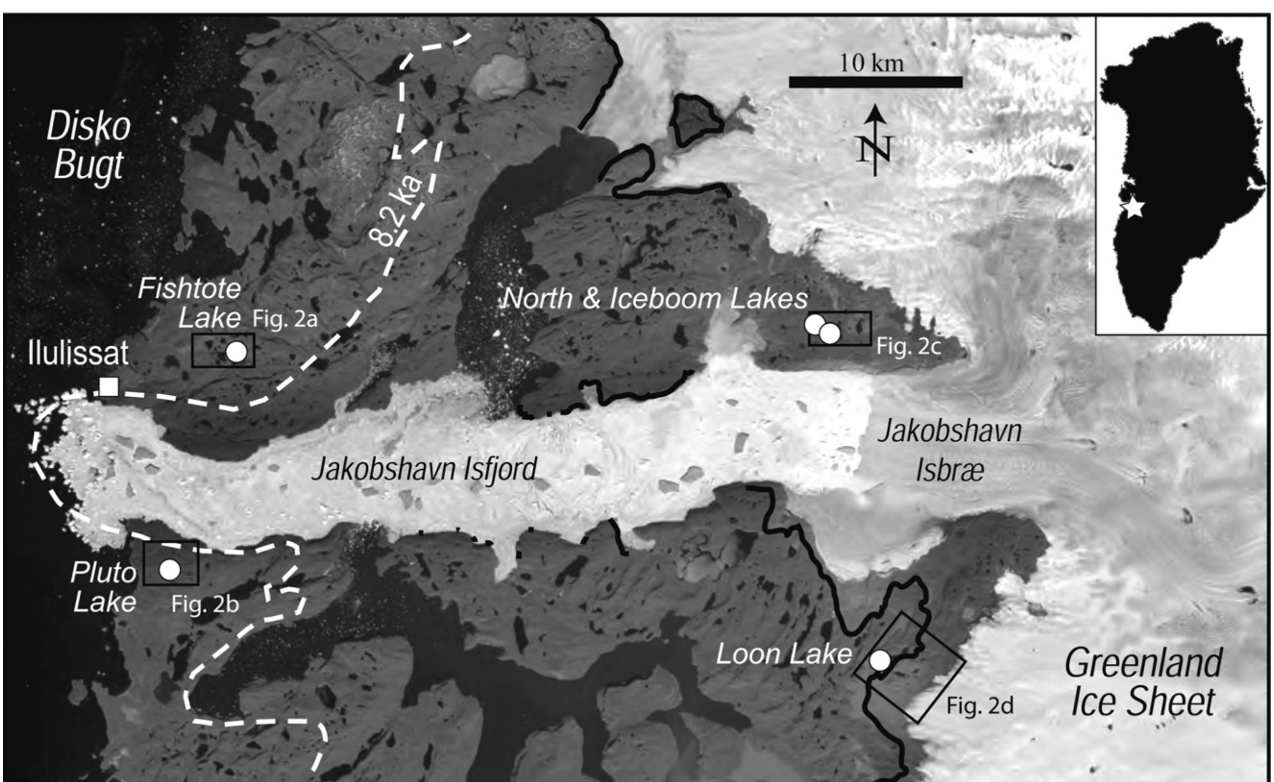

Fig. 1. Locations of the five studied lakes in the Jakobshavn region of West Greenland. Base image is 2001 LANDSAT. Dashed line shows the location of the ~8.2 ka Tasiussaq moraine; thick black line represents historical moraine.