Quaternary Science Reviews 114 (2015) 78–99

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Reconstructing Holocene glacier activity at Langfjordjøkelen, Arctic Norway, using multi-proxy fingerprinting of distal glacier-fed lake sediments

Hella E. Wittmeier [a, b, *], Jostein Bakke [a, b], Kristian Vasskog [a, c], Mathias Trachsel [d]

[a] Department of Earth Science, University of Bergen, Allégaten 41, N-5007 Bergen, Norway
[b] Bjerknes Centre for Climate Research, Allégaten 70, N-5007 Bergen, Norway
[c] Uni Climate, Uni Research, Allégaten 55, N-5007 Bergen, Norway
[d] Department of Biology, University of Bergen, Thormøhlensgate 53A, N-5006 Bergen, Norway

ARTICLE INFO

Article history:
Received 24 September 2014
Received in revised form
4 February 2015
Accepted 6 February 2015
Available online 4 March 2015

Keywords:
Glaciers
Lake sediments
Late Glacial
Holocene glacier activity
PCA
Arctic Norway
Langfjordjøkelen

ABSTRACT

Late Glacial and Holocene glacier fluctuations are important indicators of climate variability in the northern polar region and contain knowledge vital to understanding and predicting present and future climate changes. However, there still is a lack of robustly dated terrestrial climate records from Arctic Norway. Here, we present a high-resolution relative glacier activity record covering the past ~10,000 cal. a BP from the northern outlet of the Langfjordjøkelen ice cap in Arctic Norway. This record is reconstructed from detailed geomorphic mapping, multi-proxy sedimentary fingerprinting and analyses of distal glacier-fed lake sediments. We used Principal Component Analysis to characterize sediments of glacial origin and trace them in a chain of downstream lakes. Of the variability in the sediment record of the uppermost Lake Jøkelvatnet, 73% can be explained by the first Principal Component axis and tied directly to upstream glacier erosion, whereas the glacial signal becomes weaker in the more distal Lakes Store Rundvatnet and Storvatnet. Magnetic susceptibility and titanium count rates were found to be the most suitable indicators of Holocene glacier activity in the distal glacier-fed lakes. The complete deglaciation of the valley of Sør-Tverrfjorddalen occurred ~10,000 cal. a BP, followed by a reduced or absent glacier during the Holocene Thermal Optimum. The Langfjordjøkelen ice cap reformed with the onset of the Neoglacial ~4100 cal. a BP, and the gradually increasing glacier activity culminated at the end of the Little Ice Age in the early 20th century. Over the past 2000 cal. a BP, the record reflects frequent high-amplitude glacier fluctuations. Periods of reduced glacier activity were centered around 1880, 1600, 1250 and 950 cal. a BP, while intervals of increased glacier activity occurred around 1680, 1090, 440 and 25 cal. a BP. The large-scale Holocene glacier activity of the Langfjordjøkelen ice cap is consistent with regional temperature proxy reconstructions and glacier variability across Norway. Long-term changes in the extent of the northern outlet of the Langfjordjøkelen ice cap largely followed trends in regional summer temperatures, whereas winter season atmospheric variability may have triggered decadal-scale glacial fluctuations and generally affected the amplitude of glacier events.

1. Introduction

Past glacier fluctuations can provide important knowledge about natural climate variability (Oerlemans, 2005) and thereby add to our understanding of natural atmospheric and oceanic driving forces in the global climate system, which is essential for making robust predictions of future climate change (Jansen et al., 2007). The ongoing climate warming has been more pronounced in the Arctic than in any other part of the world during the past decades (Mann et al., 2008; Leclercq and Oerlemans, 2012), and the majority of Norwegian mountain glaciers have reflected this polar amplification of modern climate change by retreating significantly (Oerlemans, 2005; Nesje et al., 2008). Distal glacier-fed lake sediments have proven to be an important tool in reconstructing local glacier activity in Scandinavia, because they fill the gaps given by dated moraines

* Corresponding author. Department of Earth Science, University of Bergen, Allégaten 41, 5007 Bergen, Norway.
E-mail address: Hella.Wittmeier@geo.uib.no (H.E. Wittmeier).

http://dx.doi.org/10.1016/j.quascirev.2015.02.007
0277-3791/

that record snapshots of the history of glacier advance and retreat (Karlén, 1976, 1981; Matthews et al., 2000; Nesje et al., 2000, 2001; Lie et al., 2004; Rosqvist et al., 2004; Bakke et al., 2005b, 2009, 2010; Kirkbride and Winkler, 2012; Vasskog et al., 2012; Bakke et al., 2013). Assuming that the basal conditions remain unchanged, glaciers in general erode the subglacial bed more effectively with increasing size, thereby producing a higher amount of minerogenic material available for downstream transport by meltwater. This implies that relative changes in the upstream glacier cover are reflected in the sedimentary deposits of downstream glacier-fed lakes (Karlén, 1981; Leemann and Niessen, 1994). In relation to the power of the transporting stream to hold particles in suspension, a downstream sorting of sediment grain size is seen, with finer grains being carried longest (Sundborg, 1956; Karlén, 1981). Distal glacier-fed lakes act as traps for glacier-derived sediment, and the minerogenic content can therefore vary considerably in these sediments in contrast to lakes without glacial meltwater inflow (Karlén, 1981; Bakke et al., 2005b).

While distal glacier-fed lake sediment studies have been applied widely across Scandinavia to reconstruct past glacier and climate variability, the northern European high latitudes still remain a region where robust terrestrial Late Glacial (LG) and Holocene climate proxy data are sparse. Even though the glacial history since deglaciation after the Last Glacial Maximum (LGM) has been studied for decades in Arctic Norway (Marthinussen, 1962; Andersen, 1968; Møller and Sollid, 1972; Sollid et al., 1973; Andersen, 1979; Vorren and Elvsborg, 1979; Andersen et al., 1981; Vorren et al., 1988; Kverndal and Sollid, 1993; Andersen et al., 1995; Olsen et al., 1996a, 1996b; Andreassen, 2000; Evans et al., 2002; Vorren and Plassen, 2002; Bakke et al., 2005b; Mangerud et al., 2011), the age constraint of past glacier and ice sheet events in the far north is poor, because it mainly is based on correlations with the local sea level history (Sollid et al., 1973) and indirect radiocarbon dating of moraine deposits (Andersen, 1968). Even though the use of isolation basins has resulted in major improvements in terms of age control of the local sea level history (Romundset et al., 2011), the lack of direct dating of past glacier activity prevents robust comparisons and correlations between climate states in northern Scandinavia and other parts of the world. The sparse coverage of well-dated paleoclimatic reconstructions combined with its high climatic sensitivity makes the Arctic and area of particular interest for further studies of past glacier and climate variability. Here, we present a continuous glacier activity reconstruction of the Langfjordjøkelen ice cap's northern outlet in Arctic Norway based on detailed geomorphic mapping and distal glacier-fed lake sediment analyses from a chain of lakes in the valley of Sør-Tverrfjorddalen. The main objective of our study was to contribute a continuous, robustly dated, high-resolution record of Holocene glacier activity, with the aim of improving knowledge about past natural climate variability in Arctic Norway. We applied Principal Component Analysis (PCA) on a multi-proxy dataset obtained from terrestrial sediment samples in order to fingerprint deposits connected to local glacier activity. This approach allowed us (i) to trace the sedimentary signal of glacier variability in cores retrieved from a chain of distal glacier-fed lakes, and (ii) to reconstruct continuous Holocene glacier activity from a site in Arctic Norway, opening up for a better understanding of the natural climate variability in the northern polar region.

2. Study area

2.1. Geographic, climatic and geologic setting

The Langfjordjøkelen ice cap (70°8′N 21°43′E) is located on the Bergfjord Peninsula in the coastal part of Finnmark County in Arctic Norway (Fig. 1) and covers an area of 7.49 km^2 (Andreassen et al., 2012). The present-day Equilibrium Line Altitude (ELA) of the east-facing outlet of the Langfjordjøkelen ice cap lies at 1005 m a.s.l. (2010 CE), and the annual mass balance has been negative for more than one decade (Kjøllmoen et al., 2011). The northern outlet of the Langfjordjøkelen ice cap drains sediment-laden glacial meltwater into the valley of Sør-Tverrfjorddalen, which passes a chain of six lakes before it enters the sea in Langfjorden to the north.

The present-day climate is maritime due to the glacier's proximity to the North Atlantic Ocean. Mean (1961–1990) summer/ablation-season temperature (1 May to 30 September) of 8.7 °C was measured at climate station No. 92700 Loppa (10 m a.s.l.), which is ~20 km north-northwest of the study site (DNMI, 2012). Applying an environmental lapse rate of 0.65 °C/100 m altitude (Sutherland, 1984) gives a mean ablation season temperature of ~2.2 °C at the present-day ELA of the Langfjordjøkelen ice cap. Mean winter/accumulation–season precipitation (1 October to 30 April) measured at the Loppa climate station was 563 mm (DNMI, 2012). A mean exponential precipitation increase of 8%/100 m (Haakensen, 1989; Dahl and Nesje, 1992) gives a mean accumulation season precipitation of ~1250 mm at the present-day ELA of the Langfjordjøkelen ice cap. Using the 'Liestøl equation' (Ballantyne, 1989), a substituted mean summer temperature of 2.2 °C results in an estimated winter precipitation of ~1930 mm at the present-day ELA.

The bedrock beneath the Langfjordjøkelen ice cap and the valley of Sør-Tverrfjorddalen is allochthonous-metamorph of supposedly Eocambrium–Cambrium age. The bedrock consists of gabbro, olivine gabbro and alternating layers of garnet psammite and amphibolite (Sigmond et al., 1984).

The regional LG and Holocene glacial and sea level history in Arctic Norway has been subject to extensive studies (Marthinussen, 1962; Andersen, 1968, 1979; Vorren and Elvsborg, 1979; Corner and Haugane, 1993; Andreassen, 2000; Romundset et al., 2011). Sollid et al. (1973) linked Scandinavian Ice Sheet (SIS) marginal moraines to raised shorelines in Finnmark by tracing and dating distinct halts of ice sheet retreat in reference to seven post-LGM sub-stages. The retreating SIS made way for local glaciation along the outer coast of Arctic Norway during the LG (Møller and Sollid, 1972; Kverndal and Sollid, 1993; Olsen et al., 1996a, 1996b; Bakke et al., 2005b). Evans et al. (2002) mapped and modeled the deglaciation history of three plateau icefields on the Bergfjord Peninsula in Troms and Finnmark, with major emphasis on the Younger Dryas (YD) extent in relation to the distinct regional Main shoreline.

2.2. Catchment lakes and topography

Sediment cores were retrieved from Lake Jøkelvatnet (70°10′21″N 21°42′3″E), Lake Store Rundvatnet (70°11′30″N 21°41′12″E) and Lake Storvatnet (70°13′1″N 21°41′20″E) in the valley of Sør-Tverrfjorddalen (Fig. 1). The valley of Sør-Tverrfjorddalen is surrounded by mountain ridges with elevations of 400–900 m a.s.l., featuring steep valley sides in the southern part and gentler slopes in the northern part, which are covered by marginal moraines, till, and rapid mass-movement deposits. Two side valleys enter the main valley from the west, but no glaciers presently occupy these valleys. Including the catchments of any upstream lakes, the catchment areas of Lake Storvatnet and Lake Store Rundvatnet cover ~31 km^2 and ~23 km^2, respectively, while the drainage basin of Lake Jøkelvatnet is smaller, covering ~11 km^2. The northern outlet of the Langfjordjøkelen ice cap that drains into these lakes covers ~2 km^2, which corresponds to 6% (Lake Storvatnet), 9% (Lake Store Rundvatnet) and 18% (Lake Jøkelvatnet) of the total catchment areas of the respective lakes. Lake Jøkelvatnet (0.16 km^2, 156 m a.s.l.) features a glaciofluvial river delta at its main inlet in the south, and the bathymetry reveals a sub-aquatic ridge