ARTICLE IN PRESS

Quaternary Science Reviews xxx (2016) 1–7

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Opinion paper

Early Holocene deglaciation of Drangajökull, Vestfirðir, Iceland

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ARTICLE INFO

Article history:
Received 24 August 2016
Received in revised form
29 September 2016
Accepted 30 September 2016
Available online xxx

Keywords:
Iceland
Deglaciation
Drangajökull
Threshold lakes

ABSTRACT

The status of Icelandic ice caps during the early Holocene provides important constraints on North Atlantic climate and the mechanisms behind natural climate variability. A recent study postulates that Drangajökull on Vestfirðir, Iceland, persisted through the Holocene Thermal Maximum (HTM, 7.9–5.5 ka) and may be a relic from the last glacial period. We test this hypothesis with a suite of sediment cores from threshold lakes both proximal and distal to the ice cap's modern margin. Distal lakes document rapid early Holocene deglaciation from the coast and across the highlands south of the glacier. Sediment from Skorarvatn, a lake to the north of Drangajökull, shows that the northern margin of the ice cap reached a size comparable to its contemporary limit by ~10.3 ka. Two southeastern lakes with catchments extending well beneath modern Drangajökull confirm that by ~9.2 ka, the ice cap was reduced to ~20% of its current area. A continuous 10.3ka record of biological productivity from Skorarvatn's sediment indicates local peak warmth occurred between 9 and 6.9 ka. The combination of warm and dry summers on Vestfirðir suggests that Drangajökull very likely melted completely shortly after 9.2 ka, similar to most other Icelandic ice caps.

1. Introduction

Constraining the early Holocene deglaciation of Icelandic ice caps provides valuable information about North Atlantic climate and the mechanisms behind natural climate variability. Lake sediment records and numerical modeling experiments have shown that most Icelandic glaciers were receding rapidly before 10.3 ka and likely melted completely or were reduced to small local residuals by the early-mid Holocene (Flowers et al., 2008; Geirsdóttir et al., 2009a; Larsen et al., 2012; Striberger et al., 2012). In contrast, Schomacker et al. (2016) employed basal dates from a network of lake sediment cores to conclude that Drangajökull in Vestfirðir, Iceland, probably survived the entire Holocene, in response to increased humidity during the HTM. If correct, this provides an important inference about precipitation gradients across Iceland during the Holocene and a vital parameter to be included in future numerical glacier models.

To test this hypothesis we use a suite of threshold lake sediment cores both proximal and distal to Drangajökull's contemporary margin to more accurately constrain the ice cap's early Holocene deglaciation and to test the plausibility that the ice cap persisted through the Holocene. As supporting evidence, we provide a continuous lacustrine-based biogenic silica record to derive inferences about local Holocene summer temperature change. Collectively, these new data demonstrate that contrary to the conclusions of Schomacker et al. (2016) Drangajökull was already reduced to ~20% of its current area by 9.2 ka and very likely disappeared shortly thereafter.

2. Regional setting

2.1. Vestfirðir peninsula and local climate

Vestfirðir comprises Iceland's northwesternmost extension into the North Atlantic Ocean where the warm and saline Irminger Current (IC) flows along the west coast and the cooler, lower-salinity North Iceland Irminger Current (NIIC) and East Icelandic Current (EIC) dominate to the north and east (Fig. 1A). A multitude of over-deepened lake basins remnant from prior glaciations surround the region's local ice cap, Drangajökull (~142 km^2 area in 2011; Jóhannesson et al., 2013). Drangajökull's modern (2000–2015 CE) glacier-wide equilibrium line altitude (ELA, ~660 m asl; Harning et al., 2016) is considerably lower than other

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http://dx.doi.org/10.1016/j.quascirev.2016.09.030
0277-3791/

Please cite this article in press as: Harning, D.J., et al., Early Holocene deglaciation of Drangajökull, Vestfirðir, Iceland, Quaternary Science Reviews (2016), http://dx.doi.org/10.1016/j.quascirev.2016.09.030

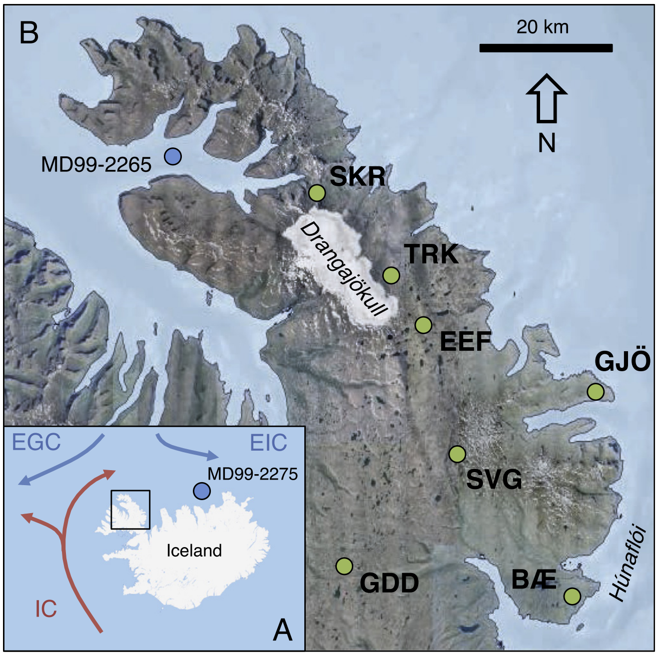

Fig. 1. A) Modern ocean currents around Iceland. Black box marks the location of B) Eastern Vestfirðir and this study's lakes (green circles). Blue circles mark locations of marine sediment cores referred to in the text. 2005 base image courtesy of Loftmyndir ehf. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Icelandic ice caps such as Langjökull (~1080 m asl) and Vatnajökull (~1215 m asl) (Björnsson and Pálsson, 2008). This low ELA likely reflects the ice cap's proximity to the relatively low sea surface temperatures (SST) of the adjacent ocean resulting in relatively short, cool summers. A correlation between JJA SSTs and JJA air temperature over Drangajökull between 1950 and 2000 CE imply oceanic SSTs on the North Iceland Shelf impart the greatest influence on Vestfirðir summer temperatures (Harning et al., 2016). Mean annual precipitation (1961–1990 CE) over Drangajökull (~3000 mm) is considerably less than precipitation receipts for ice caps along the south coast of Iceland (e.g. 7000 mm over Vatnajökull) (Crochet et al., 2007; Björnsson and Pálsson, 2008). Drangajökull's low ELA and periods of positive or near-zero net mass balance between 1946 and 2011 CE (Magnússon et al., 2016) have led to speculation that the ice cap has behaved differently than other Icelandic ice caps during the Holocene.

3. Methods

3.1. Lake sediment cores

Seven lakes (elev. 42–463 m asl) were targeted for sediment cores to maximize the spatio-temporal constraint of the Icelandic Ice Sheet (IIS, henceforth referred to as proto-Drangajökull) during deglaciation of northeastern Vestfirðir (Table 1, Fig. 1B). Each lake serves as a threshold, documenting when proto-Drangajökull left the lake catchment and ice-erosional products ceased to dominate the sediment input (e.g. Briner et al., 2010). During field campaigns in 2010, 2012, 2014 and 2015, sediment cores were recovered using a percussion driven piston corer from each lake's deepest basin. The cores were subsequently split and lithology described. Magnetic susceptibility (MS), a proxy for the proportion of clastic sediment (e.g. Larsen et al., 2011; 2012), was measured at 0.5 cm intervals on each split core using a GeoTek Multi-Sensor Core Logger at the University of Iceland (UoI).

3.2. Biogenic silica, a relative summer temperature proxy in Skorarvatn sediment

Skorarvatn (25 m deep) is a lake 3 km north of Drangajökull (Fig. 1B). Sediment subsamples ($n = 154$) were taken at ~1.5 cm intervals from sediment core SKR14-6A, freeze-dried, then ground and homogenized at the UoI. Biogenic silica (BSi) was measured following the procedures of Florian (2016) via Fourier Transform Infrared Spectroscopy (FTIRS) at the University of Colorado Boulder (UCB). Since published calibrations are linear and do not influence the nature of the proxy curve, we report measured BSi values in FTIR absorbance units rather than %BSi.

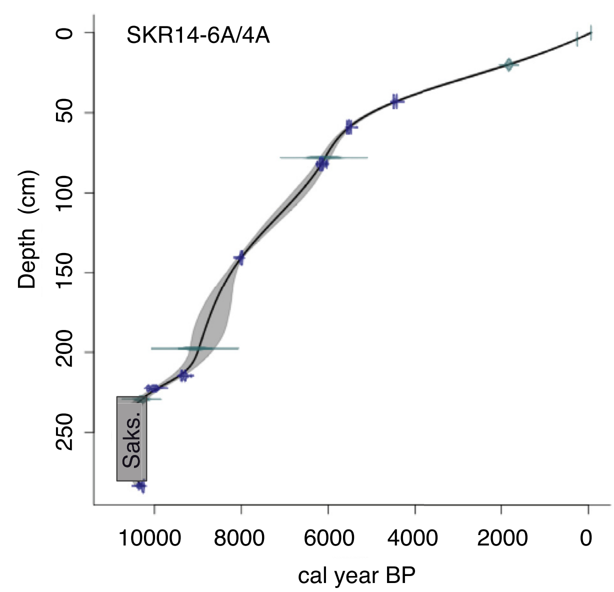

Fig. 2. Skorarvatn's smooth-spline regression age-depth model produced in CLAM version 2.2 (Blaauw, 2010). Gray shaded areas represents 95% confidence limit. Saksunarvatn tephra units and interbedded deglacial units represented by gray 'Saks.' box.

Table 1
Lake information.

Lake	Core name	Sediment core coordinates	Elevation (m asl)	Saksunarvatn?	Sampler
Skorarvatn (SKR)	SKR14-6A/4A-1N	66° 15.376′N 22° 19.328′W	183	Yes	D. Harning
Tröllkonuvatn (TRK)	TRK14-3A-2B	66° 8.551′N 22° 3.364′W	336	No	D. Harning
Efra-Eyvindarfjarðarvatn (EEF)	EEF14-3A	66° 4.668′N 21° 57.187′W	408	No	D. Harning
Svartárgilsvatn (SVG)	SVG10-1B-1N	65° 54.508′N 21° 49.318′W	430	Yes	K. Zalzal
Bæjarvötn (BÆ)	BAE10-2B-1N	65° 43.266′N 21° 26.172′W	140	Yes	K. Zalzal
Gedduvatn (GDD)	GDD10-1A-1B	65° 45.287′N 22° 10.810′W	409	Yes	K. Zalzal
Gjögurvatn (GJÖ)	GJÖ15-2A-2B	65° 99.744′N 21° 36.289′W	42	Yes	S. Gunnarson

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