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The Drangajökull ice cap, northwest Iceland, persisted into the early-mid Holocene

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ABSTRACT

Most glaciers and ice caps in Iceland experienced rapid deglaciation in the early Holocene, reaching a minimum extent during the Holocene Thermal Maximum. Here we present evidence of the Holocene glacial history from lake sediment cores retrieved from seven threshold lakes around the Drangajökull ice cap in the Vestfirðir peninsula, NW Iceland. The sediment cores show on/off signals of glacial meltwater activity, as minerogenic material deposited from glacial meltwater alternates with organic-rich material (gyttja) deposited without glacial meltwater. We base the chronology of the sediment cores on ^{14}C ages and geochemical identification of key tephra layers with known ages. A 25-cm thick layer of the Saksunarvatn tephra in Lake Skorarvatn indicates that the northern part of the ice cap had reached a similar size as today or was smaller already by 10.2 cal kyr BP. However, ^{14}C ages of lake sediment cores from the highlands southeast of Drangajökull suggest that this part of the ice cap was larger than today until 7.8–7.2 cal kyr BP. Even today, the Drangajökull ice cap has a different behavior than the main ice caps in Iceland, characterized by a very low glaciation limit. Because palaeoclimatic proxies show an early-mid Holocene temperature optimum in this part of Iceland, we suggest that the persistence of Drangajökull into the early Holocene and, possibly, also the entire Holocene was due to high winter precipitation.

1. Introduction

Following the Late Weichselian deglaciation of the Icelandic Ice Sheet, local ice caps and glaciers formed but they rapidly reached a minimum extent, and some may have disappeared completely during the Holocene Thermal Maximum (HTM) (e.g. Gudmundsson, 1998; Norðdahl et al., 2008; Geirsdóttir et al., 2009; Norðdahl and Ingólfsson, 2015). Proglacial lake sediment records document that the two largest modern ice caps in Iceland, Vatnajökull and Langjökull were considerably smaller already by 9 cal kyr BP than at present (Geirsdóttir et al., 2009; Striberger et al., 2011). There is no evidence of significant early-mid Holocene glacier activity of the largest ice caps in Iceland, and only after the HTM, glaciers and ice caps re-formed and expanded (Flowers et al., 2008; Geirsdóttir et al., 2009, 2013). In proglacial lake sediment records from Lögurinn and Hvítárvatn, glacial meltwater sediments and varved clay sequences appear after c. 4.5–3 cal kyr BP, indicating the onset of Neoglaciation in Iceland (e.g. Geirsdóttir et al., 2009; Striberger et al., 2011). Holocene plant macrofossil, pollen

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and chironomid records suggest that the HTM summer temperatures were 1.5–3° warmer than the meteorological normal period from 1961 to 1990 (Wastl et al., 2001; Caseldine et al., 2006; Axford et al., 2007; Eddudóttir et al., 2015).

Drangajökull is the fifth largest ice cap in Iceland, covering 142 km^2 (Jóhannesson et al., 2013), and is located on the eastern highland plateau of the Vestfirðir peninsula in northwest Iceland (Fig. 1). Its major outlets terminate c. 100 m a.s.l. and the ice cap reaches up to 915 m a.s.l. with an equilibrium line altitude (ELA) of 550–600 m a.s.l. (Jóhannesson et al., 2013). This is about half the altitude of the ELA on the other ice caps in Iceland, reflecting low summer temperatures, short ablation season, and high precipitation over the eastern Vestfirðir peninsula (Eythorsson, 1935; Crochet et al., 2007; Björnsson and Pálsson, 2008). Despite the suggestion of Eythorsson (1935), that the Drangajökull ice cap was particularly interesting to study because its variations probably closely reflected climate changes over the region, it has received considerably less attention than the four larger Icelandic ice caps. Drangajökull is located at the gateway to the Arctic, where the relatively warm Irminger branch of the North Atlantic Current and the cold East Greenland Current meet, and is *sensu strictu* in an Arctic climate setting, with mean summer temperature (June–September) of 6–7 °C on the northeast coast of the ice cap and 8–9 °C on the west coast of the ice cap (Eythorsson, 1935; Hanna et al., 2004).

The Holocene history of the Drangajökull ice cap is poorly known. Deglaciation of the shelf areas off the northwest peninsula after the Last Glacial Maximum (LGM) was probably in tune with other parts of the Icelandic Ice Sheet, mostly controlled by rapidly rising sea levels and warming ocean currents (Norðdahl and Ingólfsson, 2015). Deposition of ice-rafted debris in the fjords of the Vestfirðir peninsula ceased 12–10 cal kyr BP (Geirsdóttir et al., 2002), suggesting that glaciers had retreated onto land by then. The 10.2 cal kyr BP Saksunarvatn tephra has been described from several localites on land around the Drangajökull ice cap and elsewhere on the Vestfirðir peninsula (Hjort et al., 1985; Principato et al., 2006; Hole, 2015), also indicating that glaciers had retreated onto land at that time. Based on cosmogenic ^{36}Cl exposure ages, Brynjólfsson et al. (2015a) suggested that valleys and highland plateaux southwest of Drangajökull were ice free at 14–15 kyr ago. Exposure ages of 9.3 kyr from boulders on moraine ridges in the mouth of Leirufjörður (Brynjólfsson et al., 2015a), suggest that this part of Drangajökull re-advanced, possibly in response to a cooler climate forced by reduced Atlantic Meridional Overturning Circulation as seen elsewhere in the North Atlantic (Alley and Ágústsdóttir, 2005; Yu et al., 2010; Lewis et al., 2012; Young et al., 2011, 2013). Recently, Brynjólfsson et al. (2014, 2015a, b) outlined the history of Drangajökull outlets since the Little Ice Age as well as highlighting the surge-type outlet glacier dynamics. Brynjólfsson et al. (2014, 2016) and Ingólfsson et al. (2016) pointed out that the Drangajökull surge-type glaciers behaved more like the polythermal Svalbard surging outlets than the warm-based surging outlets of other Icelandic ice caps. Understanding the Holocene pattern of Drangajökull's oscillations can improve our understanding of the dynamics of Holocene environmental changes in this key area. Lake sediment cores can be regarded as multi-channel recorders, but the aim of this study is to analyse proxies that highlight the deglaciation and early Holocene glacial history of Drangajökull as reflected in proglacial threshold lake sediment records.

2. Regional setting

2.1. Physiography of the Drangajökull area

The landscape on the Vestfirðir peninsula is characterized by 400–700 m high Miocene plateau basalts with fjords and U-shaped valleys carved by Pliocene-Pleistocene glacial activity (Kristjánsson and Jóhannesson, 1994; Harðarson et al., 1997; Eiríksson, 2008). The plateaux around Drangajökull and the mountains separating the valleys contain numerous lakes (Guðmundsdóttir, 2006; Principato and Johnson, 2009). We targeted seven lakes around Drangajökull for sediment coring (Fig. 1, Table 1). Only Lake Skeifuvatn receives glacial meltwater at present; the other six lakes receive local runoff from their catchments (Table 1).

2.2. Lakes

2.2.1. Brattihjalli (66.21 °N; 22.56 °W)

The lake on Brattihjalli is located at a bench, 206 m a.s.l. at the southern valley side of Leirufjörður, c. 6 km in front of the glacier snout (Figs. 1 and 2A). Its surface area is 0.012 km^2, and it presently has neither an inlet nor an outlet. Two sets of moraines are situated

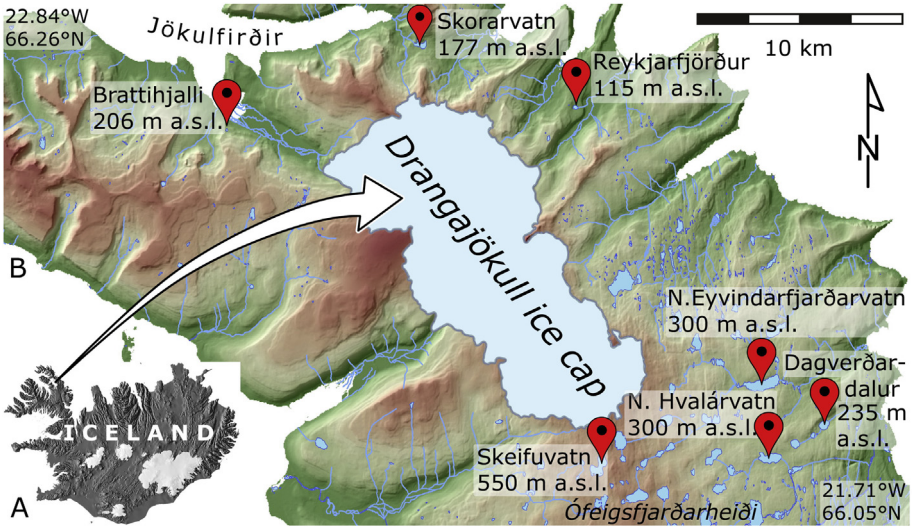

Fig. 1. A. Location of the study area in northwest Iceland. B. Detail map of Drangajökull and the location and names of the lakes that were cored (red pins). The elevation of each lake is shown in meters above sea level (m a.s.l.). The geographical coordinates of the upper left and lower right corner of the map are indicated. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)