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Final Laurentide ice-sheet deglaciation and Holocene climate-sea level change

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ABSTRACT

Despite elevated summer insolation forcing during the early Holocene, global ice sheets retained nearly half of their volume from the Last Glacial Maximum, as indicated by deglacial records of global mean sea level (GMSL). Partitioning the GMSL rise among potential sources requires accurate dating of ice-sheet extent to estimate ice-sheet volume. Here, we date the final retreat of the Laurentide Ice Sheet with ^{10}Be surface exposure ages for the Labrador Dome, the largest of the remnant Laurentide ice domes during the Holocene. We show that the Labrador Dome deposited moraines during North Atlantic cold events at ~10.3 ka, 9.3 ka and 8.2 ka, suggesting that these regional climate events helped stabilize the retreating Labrador Dome in the early Holocene. After Hudson Bay became seasonally ice free at ~8.2 ka, the majority of Laurentide ice-sheet melted abruptly within a few centuries. We demonstrate through high-resolution regional climate model simulations that the thermal properties of a seasonally ice-free Hudson Bay would have increased Laurentide ice-sheet ablation and thus contributed to the subsequent rapid Labrador Dome retreat. Finally, our new ^{10}Be chronology indicates full Laurentide ice-sheet had completely deglaciated by 6.7 ± 0.4 ka, which re quires that Antarctic ice sheets contributed 3.6–6.5 m to GMSL rise since 6.3–7.1 ka.

1. Introduction

During the early to middle Holocene (11.7–6.0 ka), warming from boreal summer insolation and greenhouse gases (Marcott et al., 2013) caused the disappearance of most Northern Hemisphere ice sheets. Despite this strong radiative and temperature forcing, global mean sea level (GMSL) was still ~60 m below present at the start of the Holocene (Lambeck et al., 2014), identifying a pronounced lag between climate forcing and subsequent ice-sheet mass loss. Partitioning this GMSL rise into its individual ice-sheet contributions remains uncertain, thus preventing a full assessment of ice-sheet sensitivity to climate change that is critical to understanding glacial-interglacial cycles (Bintanja and van de Wal, 2008; Carlson and Winsor, 2012; Tarasov et al., 2012; Abe-Ouchi et al., 2013; Ullman et al., 2015a, 2015b; Stokes et al., 2016).

The Laurentide Ice Sheet (LIS) was the largest contributor to Holocene GMSL rise (Peltier, 2004), but its retreat history is poorly constrained by minimum-limiting ^{14}C dates that may underestimate the age of deglaciation by up to several thousand years (Dyke, 2004; Carlson et al., 2007, 2008). Better constraints on the LIS retreat history would improve our understanding of its contribution to Holocene GMSL rise as well as address the question of its sensitivity to climate forcing, including whether its retreat was

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modulated by centennial climate variability that may itself have originated from forcing by the LIS (Hillaire-Marcel et al., 1981; Alley et al., 1997; Bond et al., 1997; Barber et al., 1999; Clark et al., 2001; Kleiven et al., 2008; Yu et al., 2010; Carlson et al., 2009b; Hoffman et al., 2012; Carlson and Clark, 2012; Jennings et al., 2015).

Here we focus on the final deglaciation of the Labrador Dome (LD) (Fig. 1), the largest of the LIS domes (Fig. 1) (Dyke, 2004). We report ^{10}Be surface exposure ages measured on glacial erratic boulders along 3 transects in Quebec and Labrador to directly date deglaciation, circumventing issues with minimum-limiting ^{14}C ages (Porter and Carson, 1971). In addition, we present results from new high resolution regional climate model simulations that suggest the loss of ice over Hudson Bay provided an additional forcing driving the negative mass balance of the LD. Finally, we use this new chronology to estimate the LD contribution to GMSL rise across the Holocene allowing us to infer the remaining contribution from Antarctic ice sheets.

2. Methods

2.1. Geomorphic setting and field methods

The sampling area is typical of the glacially-smoothed sub-arctic Canadian Shield. Boreal spruce forest and glacially-carved lake basins cover much of this low relief landscape, with exposed topographic highs dominated by streamlined and striated outcrops

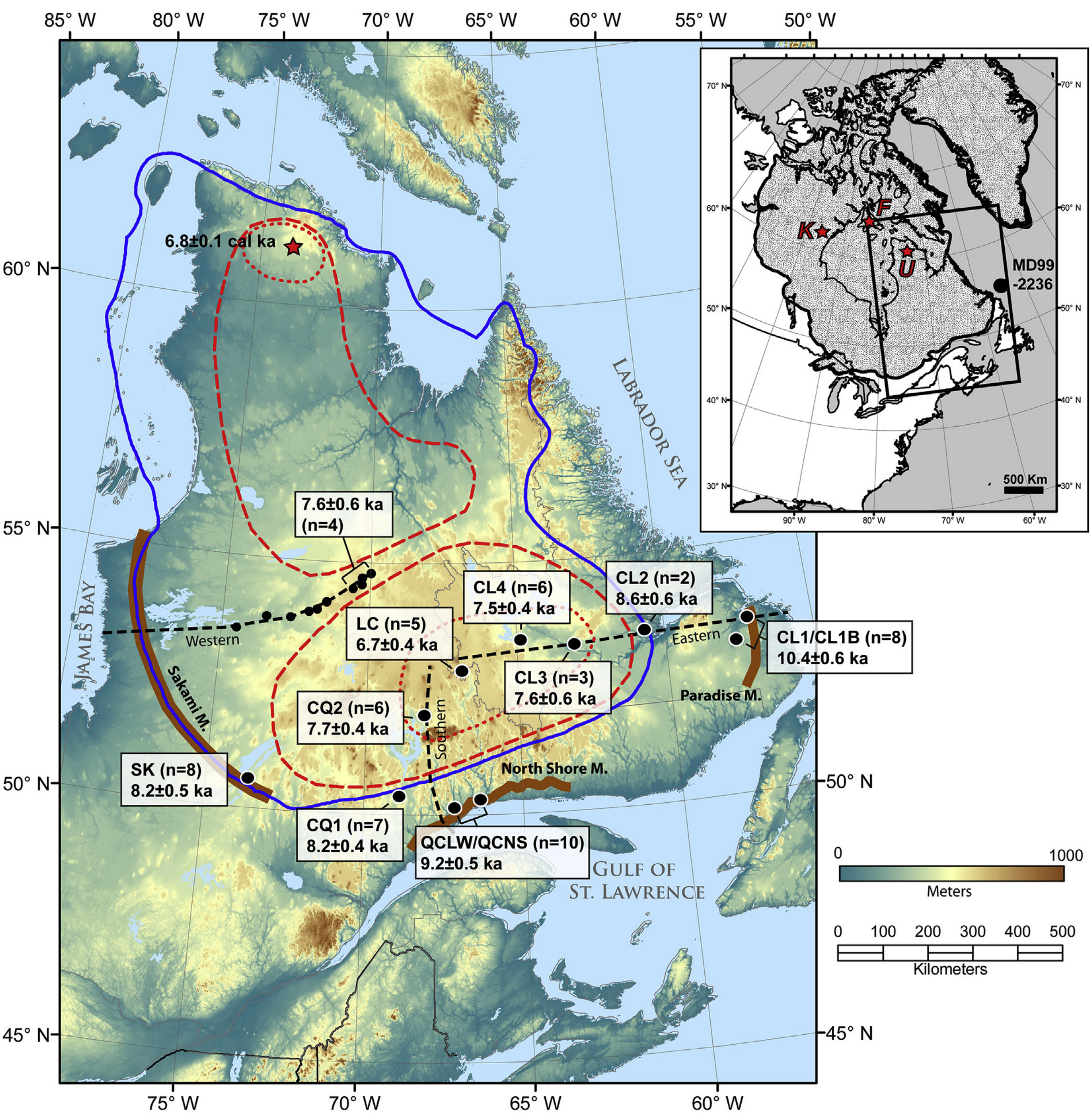

Fig. 1. Digital elevation model of Quebec and Labrador with the location of surface exposure sample sites (black circles). Site abbreviations (as used in text), number of samples, and average age are presented in white boxes, with black dashed lines indicating the path of time-distance transects used in Fig. 6. The 8.4–8.2 ka Labrador Dome ice extent according to Dyke (2004) is indicated in blue; red lines show maximum (dashed) and minimum (dotted) ice areas at 7.6 ± 0.6 ka. The Sakami, North Shore, and Paradise moraines (Occhietti et al., 2011) are labeled with brown lines. Location of the ^{14}C age in northern Quebec is indicated (Guyard et al., 2011). Inset map shows ~11.5 ka LIS extent (Dyke, 2004), the location the Cartwright Saddle (MD99-2236) core (Jennings et al., 2015), and locations of the minimum-limiting ^{14}C dates that constrain the disappearance of ice from the Keewatin (K: Simon et al., 2014) and Foxe (F: Ross et al., 2012) domes, and Ungava Peninsula (U; Guyard et al., 2011) (Fig. 6F). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)