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Response of a land-terminating sector of the western Greenland Ice Sheet to early Holocene climate change: Evidence from ^{10}Be dating in the Søndre Isortoq region

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ABSTRACT

The prevalence of land-terminating Greenland Ice Sheet margins is expected to increase as tidewater glaciers retreat onto land, yet few studies have characterized the sensitivity of these slow-moving margins to climatic variability. The response of land-terminating ice sheet sectors to climate forcing can be assessed by examining records of paleo-ice margin positions preserved in ice sheet moraine systems. In western Greenland, the extensive Fjord Stade moraine system was deposited by minor readvances or stillstands of the Greenland Ice Sheet margin during early Holocene net recession. Here, we combine new moraine mapping and cosmogenic ^{10}Be exposure dating to constrain the timing of Fjord Stade moraine deposition in the Søndre Isortoq region. We find that the Fjord Stade moraines are composed of a western stage and an eastern stage, which we constrain to 9.7 ± 0.7 ka (n = 7; 1 SD) and 9.0 ± 0.3 ka (n = 7; 1 SD), respectively. Synchronous deposition of the Fjord Stade moraine complex across at least 350 km of western Greenland implies a widespread response of the western Greenland Ice Sheet to the 9.3 ka event. Furthermore, these new moraine ages may correlate with Laurentide Ice Sheet-sourced freshwater pulses into the North Atlantic Ocean. We also show that the response of the western Greenland Ice Sheet to early Holocene freshwater forcing was not restricted to fast-flowing, marine-terminating outlet glaciers; the land-terminating margin in the Søndre Isortoq region halted or reversed its pattern of retreat in response to climatic change.

1. Introduction

Over the past two decades, the rate of mass loss from the Greenland Ice Sheet (GrIS) has increased (Rignot et al., 2008; Shepherd et al., 2012; Enderlin et al., 2014). Much of this mass loss, particularly for Greenland's marine-terminating outlet glaciers, has been attributed to dynamic processes (e.g., calving) acting at the margins (Howat et al., 2007; Csatho et al., 2014; Aschwanden et al., 2016). Yet many dynamic processes, and the resultant effects on ice margin behavior and sea level rise, are poorly understood (Vieli and Nick, 2011; Nick et al., 2013), which has led to large uncertainties about the long-term behavior of the GrIS under a rapidly changing climate (Pfeffer et al., 2008; Price et al., 2011; Bindschadler et al., 2013). In contrast, records of ice sheet fluctuations on land-terminating margins, which are influenced to a lesser degree by ice dynamics than marine-terminating outlet glaciers (e.g., Sole et al., 2008), can help to reduce these uncertainties and provide additional information about the sensitivity of the GrIS to climate variability. Moreover, the prevalence of these slow-moving margins is expected to increase in the coming years as tidewater glaciers retreat onto land (Nick et al., 2013; Morlighem et al., 2014). Assessing how land-terminating margins of the GrIS have responded to abrupt climate change in the past is therefore important for informing models that predict the ice sheet's future behavior.

Moraines are a key source of information about the former extents of glaciers and ice sheets, and direct age control on moraines can constrain the magnitude and timing of past ice margin changes. In western Greenland, four major north-south trending moraine systems have been identified between the coast and the modern ice margin (Ten Brink, 1975), the most widely traceable of which are the Fjord Stade moraines (Weidick, 1968). Fjord Stade moraines are a nearly continuous moraine belt that spans approximately 600 km of western Greenland (Fig. 1; Weidick,

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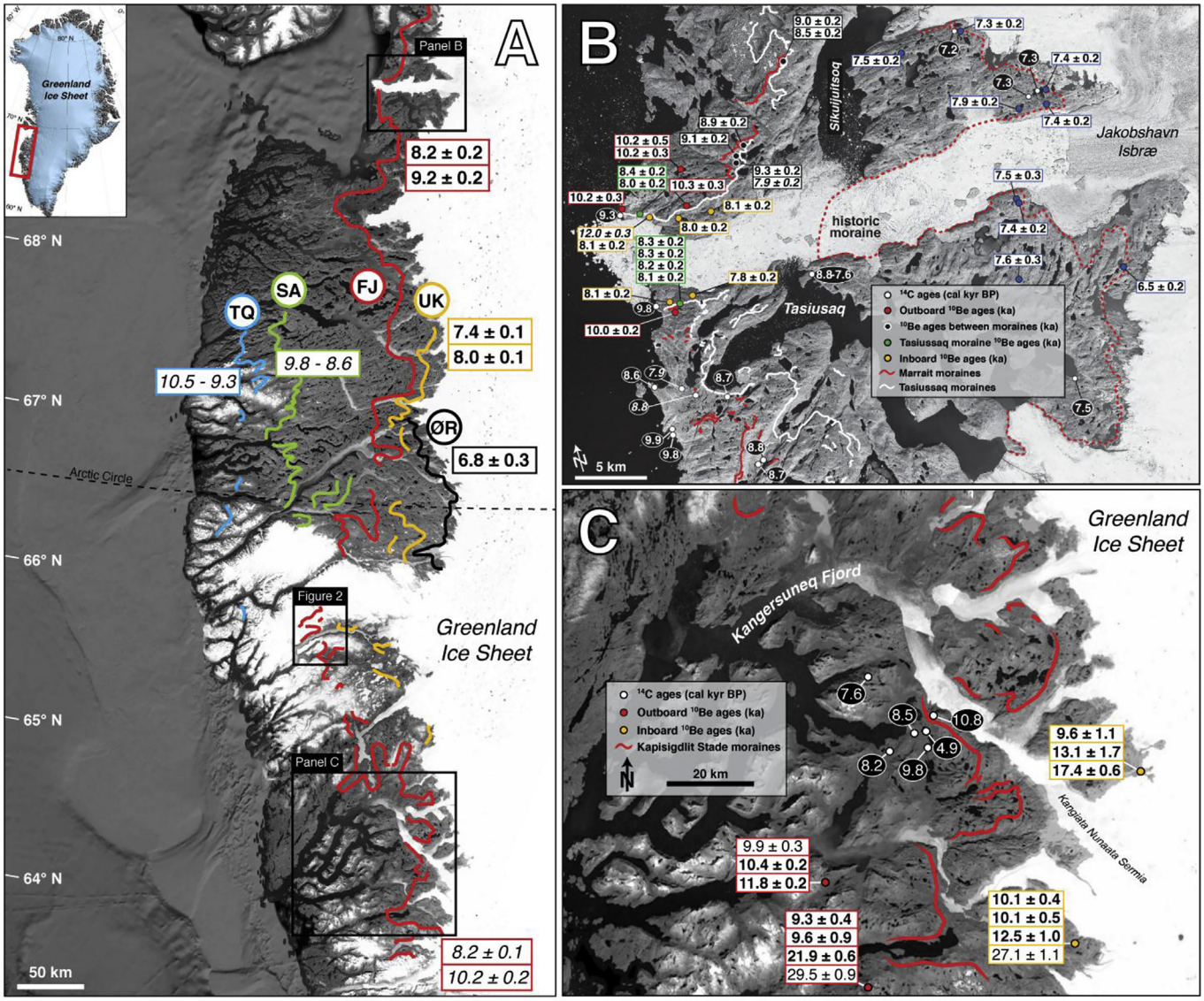

Fig. 1. (A) Major moraine systems in western Greenland (Weidick, 1968; Ten Brink, 1975). TQ = Taserqat; SA = Sarfartôq-Avatdleq; FJ = Fjord Stade; UK = Umîvît-Keglen; ØR = Ørkendalen. Age controls published prior to this study are shown in boxes. Bold text indicates direct age controls from ^{10}Be dating (Levy et al., 2012; Young et al., 2013a; Levy, 2014; Winsor et al., 2015a). Uncertainties are reported at 1SD. Italic text indicates indirect age controls on the moraines from ^{14}C dating and relative sea level curves (Weidick, 1972; Ten Brink, 1975; Larsen et al., 2014). (B) The Disko Bugt region and the Fjord Stade moraines (red and white lines; Weidick, 1968). Age controls on the moraines are from ^{14}C dating (cal kyr BP; white dots) and ^{10}Be dating (ka, 1 SD; Corbett et al., 2011; Young et al., 2013a). (C) The Kangersuneq Fjord region and the Kapisigdlit Stade moraines (red lines; Weidick et al., 2012). Existing age controls on the moraines are from ^{14}C ages (cal kyr BP; white dots; Weidick et al., 2012), and ^{10}Be ages (ka) from outside (red dots) and inside (yellow dots) the moraines (Larsen et al., 2014). Normal and bold fonts in the white boxes refer to boulder and bedrock ^{10}Be ages, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

1968). Radiocarbon ages across western Greenland broadly constrain the timing of Fjord Stade moraine deposition to the early Holocene (e.g., Ten Brink, 1975), but direct age control on the moraines has only been obtained along primarily marine-terminating margins in the Disko Bugt region (Young et al., 2013a). Farther south, along a marine-terminating margin in the Kangersuneq Fjord region, two separate studies reached different conclusions about the age of these moraines (Weidick et al., 2012; Larsen et al., 2014). Consequently, questions concerning the processes driving Fjord Stade moraine formation across large areas of western Greenland remain unresolved. Do these moraines represent a large-scale response of the western GrIS to early Holocene abrupt climate change (Alley et al., 1997; Fleitmann et al., 2008; Young et al., 2013a), even along land-terminating margins that are far removed fast-flowing outlet glaciers? Or, alternatively, are the moraines of little climatic significance (Warren and Hulton, 1990; Long et al., 2006)?

Here, we reconstruct the early Holocene history of a land-terminating ice sheet margin in the Søndre Isortoq region of western Greenland. This area contains an extension of the Fjord State moraine belt that stretches from Disko Bugt to Kangersuneq Fjord (Weidick, 1968; Funder et al., 2011), and is far from locations where the Fjord Stade moraines have been previously dated (e.g., Weidick et al., 2012; Young et al., 2013a). By obtaining new ^{10}Be exposure age constraints on the moraines in the Søndre Isortoq region, we test the hypothesis that the Fjord Stade moraines record a widespread response of the western GrIS to early Holocene abrupt cooling events. Furthermore, we assess the sensitivity of land-terminating GrIS margins to abrupt climate change.