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Holocene fluctuations of Bregne ice cap, Scoresby Sund, east Greenland: a proxy for climate along the Greenland Ice Sheet margin

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ABSTRACT

The Greenland Ice Sheet is a major component of the Arctic cryosphere and the magnitude of its response to future climate changes remains uncertain. Longer-term records of climate near the ice sheet margin provide information about natural climate variability and can be used to understand the causes of past changes in the Greenland Ice Sheet. As a proxy for Holocene climate near the ice sheet margin, we reconstruct the fluctuations of Bregne ice cap in the Scoresby Sund region of central east Greenland. Bregne is a small ice cap (2.5 km^2 in area) and responds sensitively to summer temperatures. We employ a multi-proxy approach to reconstruct the ice cap fluctuations using geomorphic mapping, ^{10}Be ages of boulders and bedrock and lake sediment records.

Past extents of Bregne ice cap are marked by moraines and registered by sediments in downvalley lakes. ^{10}Be ages of bedrock and boulders outboard of the moraines indicate that Bregne ice cap was within ~250 m of its present-day limit by at least 10.7 ka. Multi-proxy data from sediments in Two Move lake, located downvalley from Bregne ice cap, indicate that the ice cap likely completely disappeared during early and middle Holocene time. Increasing magnetic susceptibility and percent clastic material from ~6.5 to ~1.9 cal ka BP in Two Move lake sediments suggest progressively colder conditions and increased snow accumulation on the highlands west of the lake. Laminated silt deposited at ~2.6 cal ka BP and ~1.9 cal ka BP to present registers the onset and persistence of Bregne ice cap during the late Holocene. ^{10}Be ages of boulders on an unweathered, unvegetated moraine in the Bregne ice cap forefield range from 0.74 to 9.60 ka. The youngest ^{10}Be age (0.74 ka) likely represents the age of the moraine whereas older ages may be due to ^{10}Be inherited from prior periods of exposure. This late Holocene moraine marks the second largest advance of the ice cap since deglaciation of the region at the end of the last ice age. The oldest moraine in the forefield dates to ≤2.6 cal ka BP. The fluctuations of Bregne ice cap were likely influenced by Northern Hemisphere summer insolation throughout the Holocene and abrupt late Holocene cold events.

1. Introduction

Although the potential contribution to future sea-level rise by the Greenland Ice Sheet is large, the sensitivity of the ice sheet to climate changes is not fully understood (e.g. IPCC, 2007; Rignot et al., 2011; AMAP, 2012; Yoshimori and Abe-Ouchi, 2012). In response to recent warming, the ice sheet is experiencing increased ice-flow velocities, dynamic thinning of its outlet glaciers and extensive surface melting (Gregory et al., 2004; Pritchard et al., 2009; Nghiem et al., 2012; Sasgen et al., 2012). Determining how the sensitive ice sheet margins have responded to past climate changes may offer insight into how they will respond to future climate changes. Historical records of ice sheet extents exist for limited areas and only extend as far as the 18th century (e.g. Weidick, 1968). Geologic records of both ice margin fluctuations and regional climate conditions provide a means to examine how the ice sheet responded to both warmer and colder climate conditions over longer time periods.

In an effort to further the understanding of longer-term climate conditions near the ice sheet margins, we present a geologic record

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of Holocene climate changes in the Scoresby Sund region of central east Greenland. We focus on a small ice cap known as Bregne ice cap (informal name), located only ~90 km east of the ice sheet margin. Small glaciers and ice caps respond sensitively to summer temperatures (Lowell, 2000; Oerlemans, 2001, 2005) and we use the Holocene fluctuations of Bregne ice cap to examine hypothesized forcings of Holocene climate change such as Northern Hemisphere summer insolation (Berger and Loutre, 1991) and more abrupt climate events (Bond et al., 1997, 2001; Mayewski et al., 2004; Wanner et al., 2011). We suggest that the climate conditions which influenced Bregne ice cap also influenced the nearby ice sheet margin.

2. Study area

2.1. Geographic setting and Holocene history of Scoresby Sund

The largest embayment in east Greenland is a wide, shallow fjord known as Scoresby Sund (Fig. 1). West of Scoresby Sund, an extensive system of deep fjords (as much as 1600 m below sea level in Nordvest fjord) extends as far as 300 km inland, with the fjords hosting outlets of the Greenland Ice Sheet (Funder et al., 1998). The upland regions between the fjords reach as high as 2500 m asl. Small glaciers and ice caps occur on these uplands and are independent from the Greenland Ice Sheet. Annual precipitation in the Scoresby Sund region is low (15–50 mm water equivalent per year) and monthly mean temperatures range from −14 °C to 5 °C (at Ittoqqortoormiit; Carstensen and Jørgensen, 2009). The low saline, cold East Greenland Current flows southward along the east Greenland coast, and strongly influences the climate of the Scoresby Sund region (Aagaard and Coachman, 1968). As a result of the East Greenland Current, surface air temperatures by the coast are colder than those inland, near the ice sheet (Funder, 1978). Vegetation in the Scoresby Sund region is in the High Arctic zone. Upland regions host fell fields (Funder, 1989) with minor vegetation consisting of *Salix arctica*, *Cassiope tetragona*, *Dryas octopetala*, and *Vaccinium uliginosum*.

Much of what is known about Holocene climate and environmental conditions in east Greenland has been determined using lake sediment records. Numerous records indicate rapid warming during the early Holocene (e.g. Funder, 1978; Funder and Hansen, 1996; Wagner et al., 2000; Cremer et al., 2001; Wagner and Melles, 2002; Funder et al., 2011) and sustained widespread warm climate conditions during the middle Holocene (i.e. the Holocene Thermal Maximum; Kaufman et al., 2004; Vinther et al., 2009). Palynological and lake sediment records register the warmest conditions of the Holocene between 9.0 and 6.7 cal ka BP (Funder, 1978; Wagner et al., 2000), slightly earlier than the period of greatest warmth (8–5 ka) measured in boreholes at the summit of the Greenland Ice Sheet (Dahl-Jensen et al., 1998).

The onset of cooler climate conditions as early as 5.6 cal ka BP is inferred from palynological studies in the Scoresby Sund region, with an abrupt decrease in temperature at ~2.8 cal ka BP (Funder, 1978). Farther afield, 250 km north of Scoresby Sund, lacustrine proxies register cool and dry conditions from 3.0 to 1.0 cal ka BP on Geographical Society Ø (Wagner et al., 2000). A diatom record from Raffles Ø, 25 km north of Scoresby Sund, indicates the onset of perennial lake ice and "the greatest environmental change of the

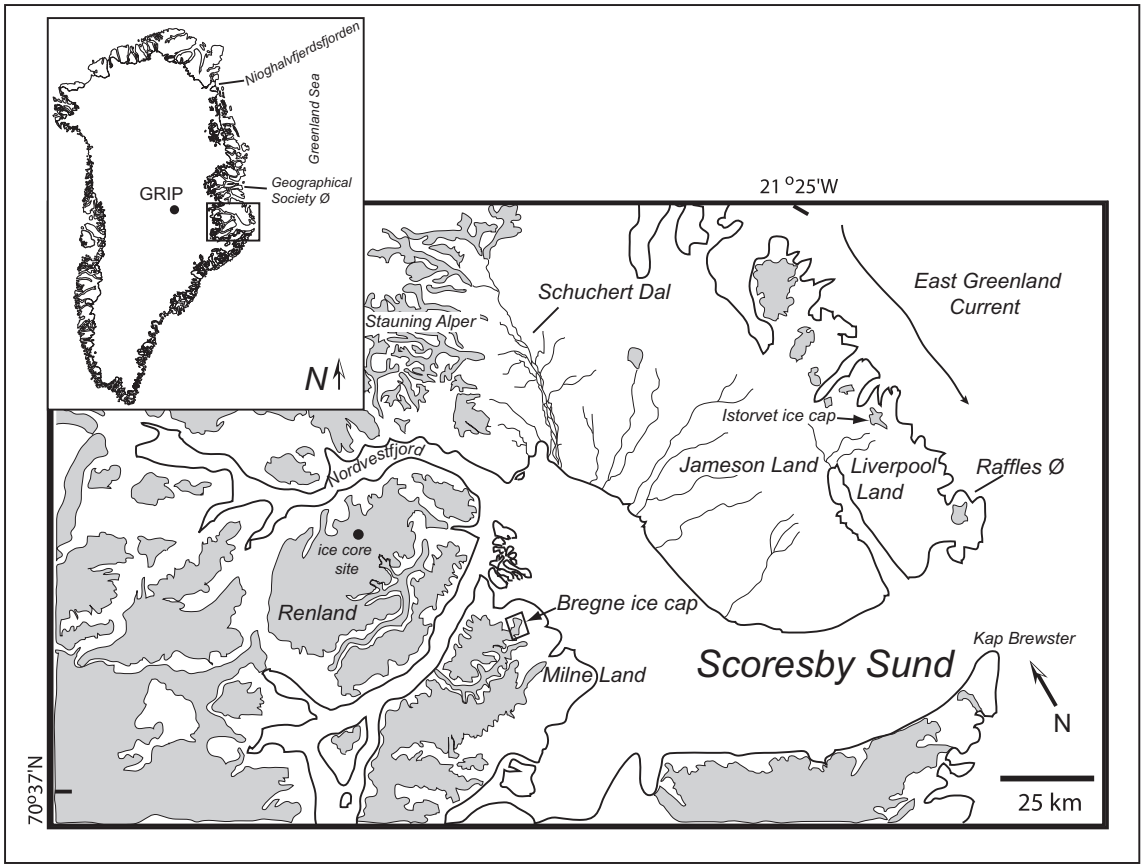

Fig. 1. Map of Greenland (inset) and the Scoresby Sund region with the locations of Bregne ice cap in northeastern Milne Land and other studies discussed in the text. Gray shaded areas indicate present-day ice cover. Bregne ice cap is located ~90 km east of the Greenland Ice Sheet margin and 60 km southeast of the Renland ice core site.