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The last glaciation and deglaciation of the Northeast Greenland continental shelf revealed by hydro-acoustic data

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ABSTRACT

About 16% of the Greenland Ice Sheet drains in the area of the Northeast Greenland shelf between 76°N and 80.5°N via marine terminating glaciers. Most of it is via the Northeast Greenland Ice Stream, the largest ice stream of Greenland. During ice ages, the ice sheet extended onto the continental shelf and modern-day cross-shelf troughs were filled by ice streams. In this study, high-resolution hydro-acoustic data acquired during three decades of research were jointly investigated to reveal the past glacial conditions. Our data shows that Westwind Trough and Norske Trough were filled by fast flowing ice streams that extended to the shelf edge during the last glacial maximum. In between the cross-shelf troughs, ice domes resided on shallow banks that may have contributed about a decimetre to global sea level. Most probably these ice domes initiated fast ice flow through sinks in the inter-trough area. In Westwind Trough, ice sheet retreat to the inner shelf after the last glacial maximum was intermittent. In contrast, in Norske Trough the ice sheet retreat appears relatively rapid with no evidences for phases of grounding line stabilization. Probably during the Younger Dryas, the ice sheet readvanced to a mid-shelf position in both troughs documented by grounding zone wedges. During this time, a thick ice shelf was present in Norske Trough releasing tabular icebergs. Ice sheet retreat from the mid-shelf to the coastline during Holocene deglaciation was rapid.

1. Introduction

The Greenland Ice Sheet is identified as one of the tipping elements in the Earth's climate system (Lenton et al., 2008). Recent changes observed in the Greenland Ice Sheet need to be considered in the context of past responses of the ice sheet to changing climatic conditions and hence necessitates refined reconstructions (Vaughan et al., 2013). The maximum extent of the Greenland Ice Sheet for the time frame of the last glacial maximum (LGM, 24 to 16 ka) is still predominantly based on conceptual models and not on direct observations (Funder et al., 2011). In contrast to the relatively well studied southern section of the Greenland Ice Sheet (south of 70°N), investigations are particularly scarce for the northern part (north of 70°N) (Funder et al., 2011), where only a few studies with direct but sparse observations exist to constrain the extent of the ice sheet (e.g. Evans et al., 2002; Evans et al., 2009; Hubberten et al., 1995; Winkelmann et al., 2010).

Approximately 16% of the modern-day Greenland Ice Sheet is drained via marine terminating outlet glaciers at the coast of Northeast Greenland, most of it via the Northeast Greenland Ice Stream, the largest ice stream of the ice sheet (Fig. 1a) (Joughin et al., 2000; Zwally et al., 2012). Offshore Northeast Greenland, the continental shelf is about 300 km wide, representing the broadest continental shelf of Greenland. It predominantly consists of Pleistocene sediments that have been transported by ice sheets and ice streams since the onset of glaciations in the late Miocene (Berger and Jokat, 2009). The extent of the ice sheet in Northeast Greenland during the LGM is still debated. Minimum estimations suggest that the ice margin was located at the middle or inner shelf, maximum estimations suggest that the ice margin was located on the outer shelf or at the shelf edge (Bennike and Björck, 2002; Evans et al., 2009; Funder et al., 2011; Winkelmann et al., 2010). Direct morphologic evidence for the suggested larger ice extent e.g. glacial landforms produced at the ice sheet bed during LGM on the outer shelf, however, has so far been missing.

Glacial landforms can furthermore provide information on the setting of ice streams that are affecting the mass balance of the ice sheet as well as their retreat rate during deglaciation. Glacial lineations and mega-scale glacial lineations (elongation ratio > 1:10

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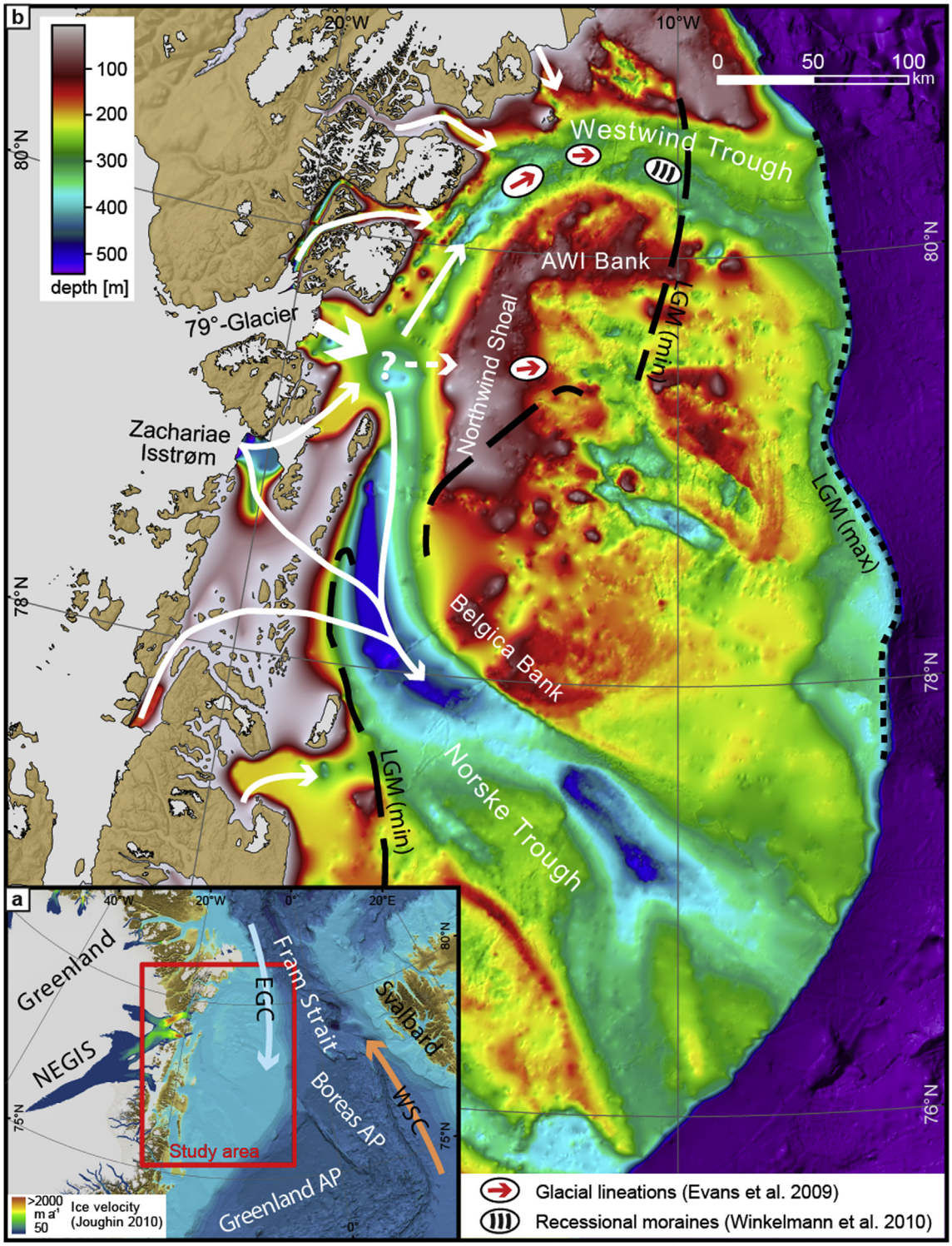

Fig. 1. (a) Geographical setting of the study area (bathymetry outside study area and topography from IBCAO V3 (Jakobsson et al., 2012)), including major oceanographic currents (EGC = East Greenland Current, WSC = West Spitsbergen Current) and ice velocities (NEGIS = Northeast Greenland Ice Stream). (b) Bathymetry and inferred palaeo-ice flow pathways (white arrows) in the study area (Arndt et al., 2015), black dashed lines indicate proposed minimum (LGM min, Funder et al., 2011) and maximum (LGM max, Evans et al., 2009) last glacial maximum ice extents.

and lengths > 10 km) located in formerly glaciated troughs and beneath a present day ice stream were/are formed at the bed of fast flowing ice streams (e.g. Clark, 1993; Graham et al., 2009; King et al., 2009; Ó Cofaigh et al., 2002; Ottesen et al., 2005, 2008; Stokes and Clark, 1999, 2001). Typically, these lineations were/are formed in an acoustically transparent sediment unit (e.g. Blankenship et al., 1986; Dowdeswell et al., 2004; Ó Cofaigh et al., 2005) that is made of subglacial basal till (Dowdeswell et al., 2004; Mosola and Anderson, 2006). Internal deformation of the till facilitates sediment flux to the grounding line and allows fast ice