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A Younger Dryas re-advance of local glaciers in north Greenland

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A B S T R A C T

The Younger Dryas (YD) is a well-constrained cold event from 12,900 to 11,700 years ago but it remains unclear how the cooling and subsequent abrupt warming recorded in ice cores was translated into ice margin fluctuations in Greenland. Here we present ^{10}Be surface exposure ages from three moraines in front of local glaciers on a 50 km stretch along the north coast of Greenland, facing the Arctic Ocean. Ten ages range from 11.6 ± 0.5 to 27.2 ± 0.9 ka with a mean age of 12.5 ± 0.7 ka after exclusion of two outliers. We consider this to be a minimum age for the abandonment of the moraines. The ages of the moraines are furthermore constrained using Optically Stimulated Luminescence (OSL) dating of epishelf sediments, which were deposited prior to the ice advance that formed the moraines, yielding a maximum age of 12.4 ± 0.6 ka, and bracketing the formation and subsequent abandonment of the moraines to within the interval 11.8–13.0 ka ago. This is the first time a synchronous YD glacier advance and subsequent retreat has been recorded for several independent glaciers in Greenland. In most other areas, there is no evidence for re-advance and glaciers were retreating during YD. We explain the different behaviour of the glaciers in northernmost Greenland as a function of their remoteness from the Atlantic Meridional Overturning Circulation (AMOC), which in other areas has been held responsible for modifying the YD drop in temperatures.

1. Introduction

The Younger Dryas (YD) marks a cold period at the end of the last glaciation, from 12.9 to 11.7 ka ago (Rasmussen et al., 2006). In spite of rising insolation during the YD, temperatures dropped, probably because the Atlantic Meridional Overturning Circulation (AMOC) was reduced or even shut down by large amounts of meltwater running off the melting ice sheets (Broecker et al., 1989; Denton et al., 2005; Carlson, 2013). The YD is especially pronounced in areas bordering the North Atlantic, and nowhere is it seen more clearly than in ice cores from the top of the Greenland ice sheet where the oscillation began with a c. 6 °C drop in temperatures over a period of 200 years, and ended with an abrupt rise of c. 10 °C over a period of only 60 years (Steffensen et al., 2008; Buizert et al., 2014). Knowledge about how these abrupt climate changes are translated into ice marginal behaviour along the Greenland ice sheet is of importance for evaluating the impact of future warming on the ice margin.

Here we present new evidence of a YD advance and subsequent retreat by three outlet glaciers from the North Cap, the local ice cap over the North Greenland mountain range (Fig. 1). The maximum positions of this advance in respective valley are marked by prominent terminal moraines, which ages are determined by new and previously published surface exposure ages, combined with previously published Optically Stimulated Luminescence (OSL) ages. We furthermore discuss the implications of our findings in the view of previous studies on the YD ice margin behaviour in other parts of Greenland.

2. Study area

The north coast of Greenland represents the land area closest to

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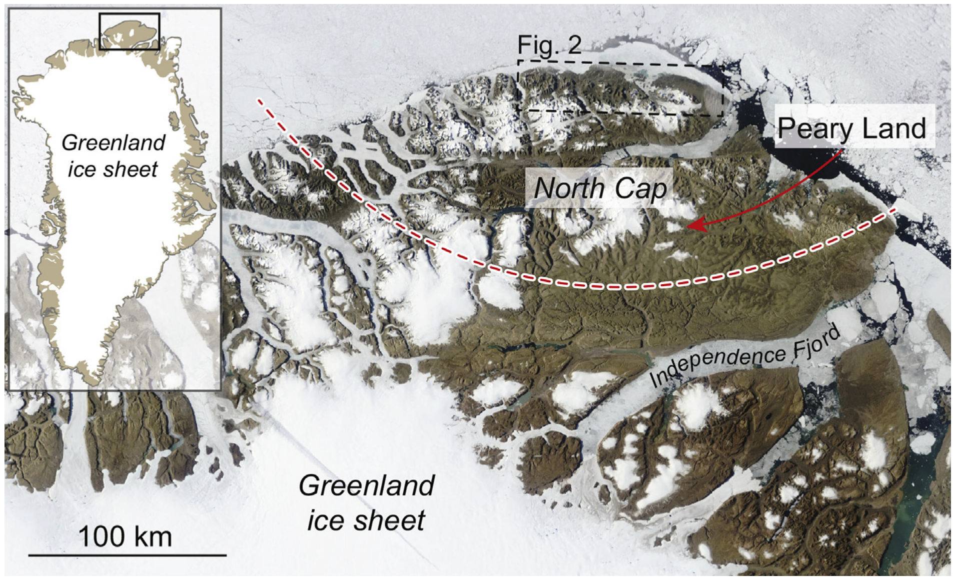

Fig. 1. Overview of North Greenland. Dashed line defines the boundary between the Greenland ice sheet and the independent North Cap (Koch, 1923).

the North Pole. It comprises a 10–15 km wide coastal plain, bordered to the south by 500–1500 m high mountains. The coastal plain and connected valleys impinging into the mountain range southwards, host landforms and sediments recording glacial and marine events since the Last Glacial Maximum (LGM) in Greenland (Larsen et al., 2010). Based on the distribution of erratic boulders it was established that a local ice cap, the North Cap, developed over the mountain range in Peary Land during LGM, which to the south and southeast merged with the Greenland ice sheet (Koch, 1923; Dawes, 1986; Funder, 1989). On the coastal plain, erratics, till fabric measurements, and striations show that the outlet glaciers from the local ice caps merged with the Greenland ice sheet to form shelf-based ice in the Arctic Ocean that was deflected eastwards along the coast (Funder and Larsen, 1982; Dawes, 1986; Larsen et al., 2010; Jakobsson et al., 2014). The deflection of the glaciers was most likely a result of buttressing by thick multiyear (palaeocrystic) sea ice in the Arctic Ocean (Bradley and England, 2008), which forced the local glaciers from Peary Land to flow along the coast (Larsen et al., 2010; Jakobsson et al., 2014). During the initial deglaciation large epishelf lakes were formed between the shelf-based ice and the mountains (Larsen et al., 2010; Möller et al., 2010). In these lakes, thick successions of laminated glaciolacustrine sediments were deposited on the coastal plain and in Sifs valley up to an elevation of 110 m a.s.l. (Figs. 2–3). OSL ages of the epishelf lake sediments ranged from 135 to 12.4 ka and the large spread suggests that they were differently affected by incomplete bleaching, with the youngest age serving as a maximum age for the deposition of the glaciolacustrine sediments (Larsen et al., 2010; Möller et al., 2010). During the final break-up of the shelf-based ice at ~10.1 cal ka BP the coastal plain and the major valleys were inundated and marine sediments were deposited up to 40 m a.s.l. (Möller et al., 2010; Funder et al., 2011a). The isostatic uplift of the coastal plain following the deglaciation left a succession of beach ridges with driftwood that was used to constrain the Holocene sea ice history in the Arctic Ocean (Funder et al., 2011a). Following the deglaciation the local glaciers re-advanced through all major valleys along the coast and formed major terminal moraines on the coastal plain. Previously one of these moraines (Constable Bugt) was dated to between 9.6 and 6.3 cal ka BP and there was further evidence of a second re-advance in Sifs Valley between 5.5 and 5.0 cal ka BP (Möller et al., 2010). The two Holocene re-advances were linked to increased precipitation caused by more open water conditions in the Artic Ocean during the warm Holocene Thermal Maximum. Our new results indicate that the moraine originated earlier, during the YD.

3. Methods

Ten samples from three terminal moraines on the coastal plain at Henson Bugt, Constable Bugt and Bliss Bugt were collected for surface exposure dating in this study (Fig. 2). Eight boulders were sampled using hammer and chisel, as well as a rock drill. The sampled boulder lithologies are meta-sandstone and quartz (Table 1). Two amalgamated pebble samples were collected from the sediment surface; rounded milky quartz pebbles were collected in sample bags in the field and split into uniform size categories (uniform a, b, c axis) before crushing. Sample locations and elevations were recorded in the field with a hand-held GPS. Clinometer measurements were taken for each sample for determination of the site-specific topographic shielding. Sample thickness was noted in the field (checked before crushing), as well as observations with regard to potential weathering loss (e.g. surface roughness, ventifacts, differential weathering, striae) and snow shielding (e.g. geomorphology, snow patch distribution, lichen distribution and type).

3.1. ^{10}Be sample preparation and ^{10}Be age calculation

All rock samples were crushed at the Swedish Museum of Natural History (Stockholm), and processed at the School of Geographical and Earth Sciences (University of Glasgow). The 0.25–0.5 mm fraction from crushing and pulverizing was enriched with respect to quartz by treatment with HCl/HNO_3, magnetic separation, and H_3PO_4. Purification of the quartz fraction was done by successive HF/HNO_3 leaches, and purity (i.e. [Al] < 100 μg/g) was assessed by measuring the Al concentration using flame atomic absorption spectrometry (AAS) and inductively coupled plasma optical emission spectrometry (ICP-OES).

Preparation of samples for Be measurement was done at the Glasgow University – Scottish Universities Environmental Research Centre (GU – SUERC) Cosmogenic Isotope Laboratory, following procedures modified from Child et al. (2000). After carrier addition (see Table 1 for amounts and concentrations), clean quartz