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Evidence of an ice-dammed lake outburst in the North Sea during the last deglaciation

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ABSTRACT

Recent reconstructions suggest that the British-Irish and Fennoscandian ice sheets coalesced and covered the central and northern North Sea from ca. 26 cal. ka BP and until ca. 19 cal. ka BP. At ca. 19 cal. ka BP the Norwegian Channel Ice Stream started to retreat and the ice sheets broke apart at ca. 18.7 cal. ka BP. This led to a drainage of an ice-dammed lake in the southern North Sea northwards via the Norwegian Channel into the SE Nordic Seas. In this paper we combine information from high resolution TOPAS profiles, bathymetric records and shallow borings to study the ice-dammed lake outburst, a common deglaciation process but which rarely has been evidenced in such a detail from the marine realm. A 12 m deep and 3 km wide incision at the northeastern part of the Dogger Bank is suggested to represent the point where the ice-dammed lake breached. The glacial lake outburst flood, which had an estimated peak discharge of 9.8×10^4–2.9×10^5 m^3/s and lasted for about 5–15 months, flowed between the withdrawing British-Irish and Fennoscandian ice sheets following the crest of the Ling Bank northwards. Along this path, about 300 km downstream of the break-through point, an up to 10 m thick sediment package with a prograding-aggrading sedimentation pattern, typical for ice-dammed lake outburst deposits, has been deposited. This sediment package was deposited in a high-energy environment, immediately following extensive erosion of the underlying till unit of Last Glacial Maximum age. An oxygen isotope anomaly and an associated ultra-rapidly deposited meltwater plume on the Norwegian continental margin, dated to ca. 18.7 cal. ka BP, also witness this lake outburst. The ice-dammed lake outburst flood occurred when evidence suggest a sea level at least 110 m lower than at present in the region. As the sea level rose, following the melting of the Last Glacial Maximum ice sheet, the Ling Bank Delta developed on top the outburst deposits. The delta, indicating a sea level close to 80 m below present, has an extent of 80 km and up to 12 m deep fluvial channels are associated with the topset beds. This fluvial environment may have lasted until the end of the Younger Dryas time period when the Ling Bank was submerged and attained its present water depth.

1. Introduction

Ice-dammed lakes develop supraglacially, subglacially or ice-marginally and their formation and length of existence are strongly dependent on the dynamics of the ice sheet and the character of the neighboring environment (Carrivick and Tweed, 2013). Well-studied examples of paleo ice-dammed lakes are Lake Agassiz (Laurentide Ice Sheet) which existed for a time period of 4000 years during the last deglaciation, the late Wisconsin Glacier Lake Missoula (Cordilleran Ice Sheet), and the Younger Dryas Baltic Ice Lake (Scandinavian Ice Sheet) (e.g. Jensen et al., 1997; Teller and Leverington, 2004; Alho et al., 2010). Such ice-dammed lakes can cover considerable areas and contain huge volumes of water. The 9700 km^2 Glacier Lake Missoula held a water volume of 2600 km^3, whereas the Baltic Ice Lake was nearly four times larger in area and 10 times larger in volume (Björck, 1995; Smith, 2006; Jakobsson et al., 2007; Alho et al., 2010). On the other hand, Lake Agassiz covered a total area of 841,000 km^2 and contained a water volume of 163,000 km^3 when it merged with Lake Ojibway about 8200 years ago (Teller et al., 2002). For comparison the largest lake on Earth today, the Caspian Sea, covers 371,000 km^2 and has a volume of 78,200 km^3 (Rodionov, 2012).

Ice-dammed lakes can be drained, often periodically, and such glacial lake outburst floods (GLOFs) commonly represent abrupt discharges of large volumes of water. It has been estimated that the prominent 8.2 cal. ka BP drainage of Lake Agassiz was ongoing for 6 months, with an average flux of 5 Sv, and involved a total water volume of 10^{14} m^3 (Clarke et al., 2004). Signatures of GLOFs are reported from onshore areas as canyons and giant gravel bars, whereas in the marine domain such sudden release of dense fresh water can give rise to prominent meltwater peaks (e.g. Alley and Ágústsdóttir, 2005;

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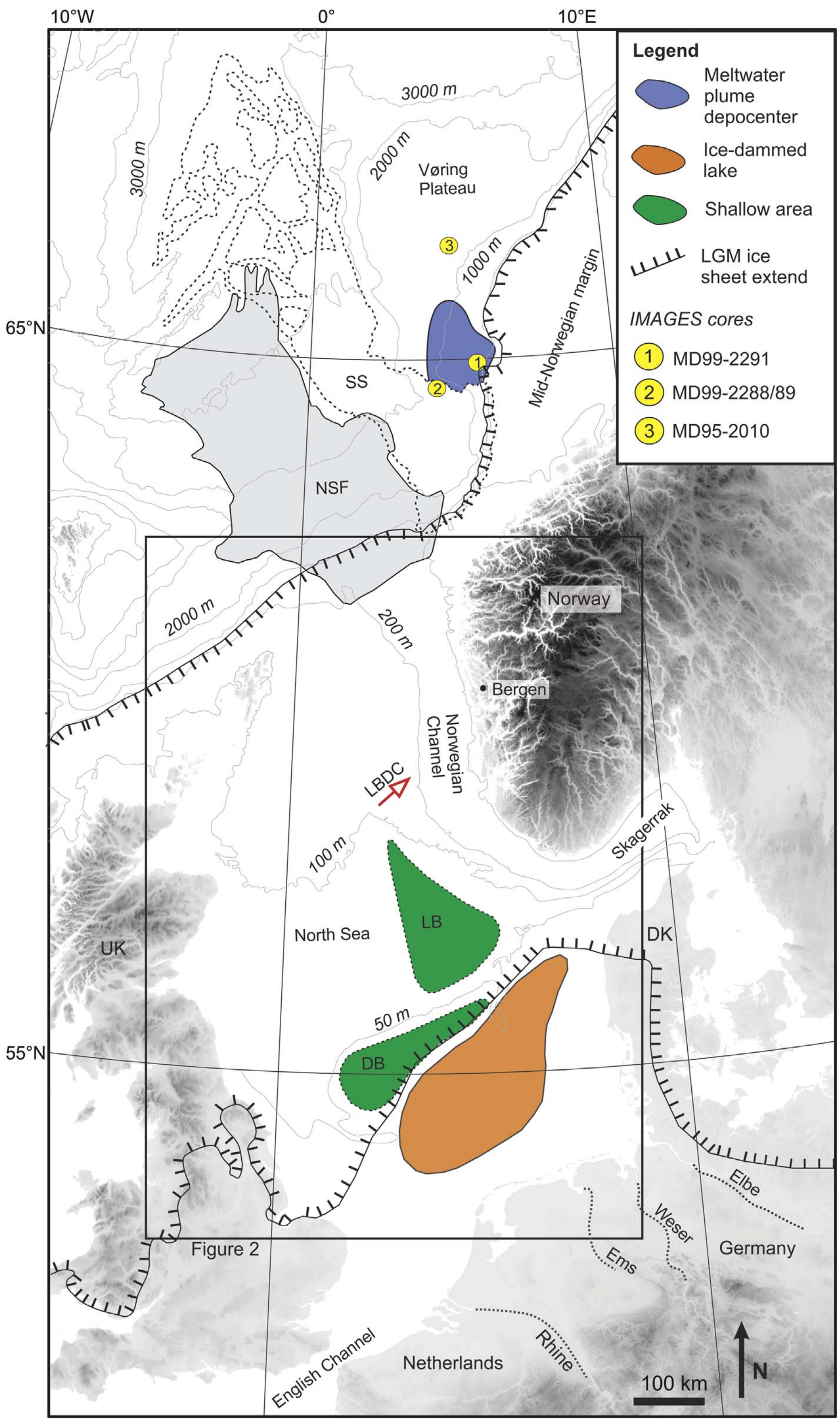

Fig. 1. a) Overview map of North Sea and Norwegian continental margin. Outline of meltwater plume depocentre on the south Vøring Plateau (from Hjelstuen et al., 2004), Late Weichselian North Sea Lake, Dogger Bank, Ling Bank, Ling Bank Drainage Channel (from Sejrup et al., 2016), North Sea Fan (from Nygård et al., 2005), Storegga Slide (from Haflidason et al., 2004) and LGM ice extent (based on Sejrup et al., 2005) are shown. Location of major rivers entering the southern North Sea and sediment cores mentioned in this study are also indicated. SS: Storegga Slide; NSF: North Sea Fan; LBDC: Ling Bank Drainage Channel; DB: Dogger Bank; LB: Ling Bank; LGM: Last Glacial Maximum.

Høgaas and Longva, 2016).

It is of importance to have knowledge on GLOFs, and their associated processes, as they give information on deglaciation character and as they may have a strong impact on climate and ocean circulation (Carrivick and Tweed, 2013). Notably, the around 1000 year-long Younger Dryas event has been suggested to be related to the 9500 km^3 Herman Drainage Stage of Lake Agassiz (Broecker et al., 1989; Teller et al., 2002). Smaller ice-dammed lakes are at present located on e.g. Iceland, in Scandinavia and in the Central European Alps and it is suggested that the number of such lakes will increase in the years to come due to the inferred warming climate (Carrivick and Tweed, 2016). Thus, outburst floods may increase in frequency and become an increasing threat to infrastructure and buildings.

In this study we investigate the drainage route of a paleo-GLOF from an ice-dammed lake predicted by many authors (e.g. Hijma et al., 2012; Sejrup et al., 2016) to have existed during the Last Glacial Maximum (LGM) in the southern North Sea (Fig. 1), and which we here name the Late Weichselian North Sea Lake. In this effort, we integrate high