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Early break-up of the Norwegian Channel Ice Stream during the Last Glacial Maximum

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ABSTRACT

We present 18 new cosmogenic ^{10}Be exposure ages that constrain the breakup time of the Norwegian Channel Ice Stream (NCIS) and the initial retreat of the Scandinavian Ice Sheet from the Southwest coast of Norway following the Last Glacial Maximum (LGM). Seven samples from glacially transported erratics on the island Utsira, located in the path of the NCIS about 400 km up-flow from the LGM ice front position, yielded an average ^{10}Be age of 22.0 ± 2.0 ka. The distribution of the ages is skewed with the 4 youngest all within the range 20.2–20.8 ka. We place most confidence on this cluster of ages to constrain the timing of ice sheet retreat as we suspect the 3 oldest ages have some inheritance from a previous ice free period. Three additional ages from the adjacent island Karmøy provided an average age of 20.9 ± 0.7 ka, further supporting the new timing of retreat for the NCIS. The ^{10}Be ages from Utsira and Karmøy suggest that the ice stream broke up about 2000 years earlier than the age assignment based on ^{14}C ages on foraminifera and molluscs from marine sediment cores. We postulate that the Scandinavian Ice Sheet flowed across the Norwegian Channel to Denmark and onto the North Sea plateau during early phases of the LGM. When the NCIS started to operate this ice supply to the North Sea was cut off and the fast flow of the NCIS also led to a lowering of the ice surface along the Norwegian Channel and thereby drawdown of the entire ice sheet. This facilitated rapid calving of the ice front in the North Sea and we reconstruct a large open bay across the entire northern North Sea by ~20 ka based on our ^{10}Be ages in the east and radiocarbon ages from marine cores in the west. Additional ^{10}Be ages show that the mainland slightly east of the islands Utsira and Karmøy remained ice covered until about 16 ka, indicating almost no net ice-margin retreat for the 4000 years between 20 and 16 ka. After 16 ka the ice margin retreated quickly up-fjord.

1. Introduction

Ice streams are important components of ice sheets, influencing both their geometry and dynamic behaviour (Stokes and Clark, 2001; Bennett, 2003; Pritchard et al., 2009). Considering that they have the capacity to discharge large volumes of ice during short periods of time, they may potentially destabilize entire ice sheets and thus enforce fast eustatic sea-level rise (Alley et al., 2005; Pritchard et al., 2009). In this respect the Norwegian Channel Ice Stream (NCIS) may offer some insights into both ice-sheet dynamics and forcing mechanisms (Ottesen et al., 2005; Sejrup et al., 2003, 2009). Here, we also point out implications that may have bearing on the causal connection for such early deglaciation of the NCIS.

The Norwegian Channel is an 800-km-long and 50- to 100-km-wide glacially eroded trough that trends along the coast of southern Norway terminating at the shelf break in the northern North Sea (Figs. 1 and 2). During Quaternary glaciations, this trough hosted a major ice stream that drained a large part of the Scandinavian Ice Sheet over southern Norway and Sweden (Sejrup et al., 2003, 2009). The time frame for the last break-up of the NCIS so far has been established by radiocarbon dating of foraminifera and molluscs from marine sediment cores. These ages suggest that the ice front started to retreat from the shelf break at ~19 ka (King et al., 1998; Sejrup et al., 2009) and reached inside the Troll oil field area not later than ~18.5 ka (Fig. 2; Sejrup et al., 2009). In this paper

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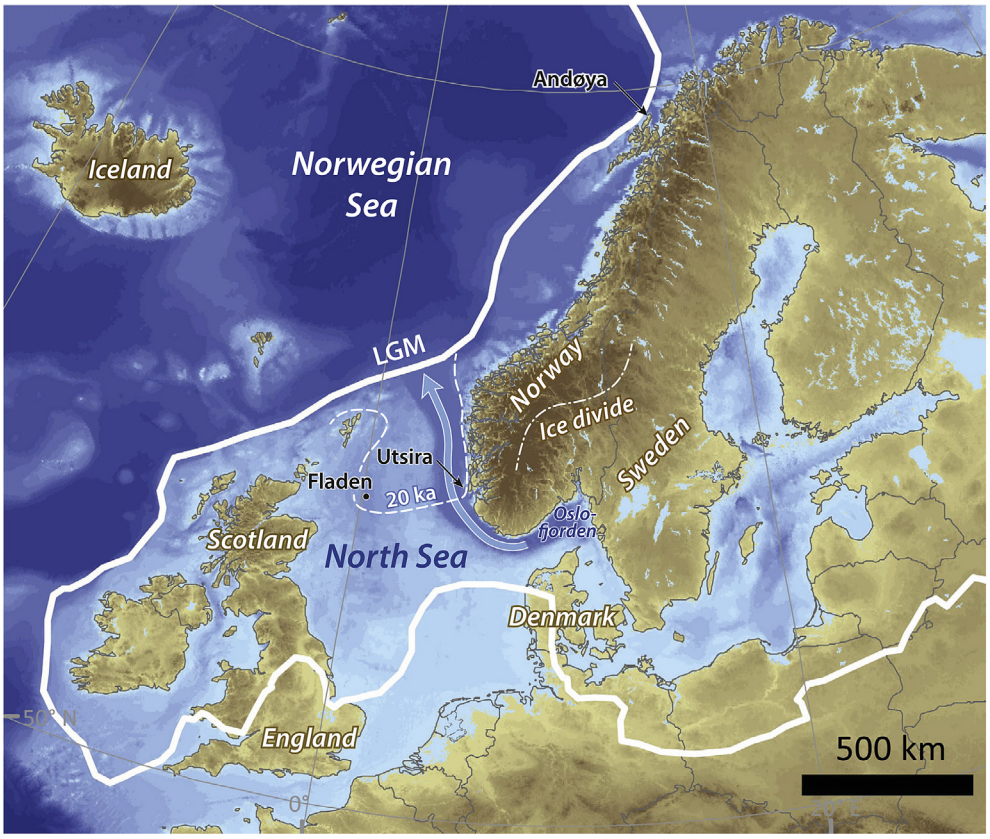

Fig. 1. Overview map of NW Europe. The map shows the Last Glacial Maximum (LGM) extent of the Scandinavian and British Ice Sheets; ice margin not time synchronous [modified from Svendsen et al. (2004) and Clark et al. (2012)]. The Norwegian Channel Ice Stream is marked with an arrow. Dashed white lines show schematically a possible reconstruction of the ice margin about ~20 ka accepting that both Utsira and the Fladen Ground area were ice free at this time.

we present a series of cosmogenic ^{10}Be exposure ages (hereafter ^{10}Be ages) from glacially transported boulders on the islands Utsira and Karmøy that are situated near the eastern flank of the Norwegian Channel in south-western Norway (Table 1; Figs. 2 and 3). The ^{10}Be ages from these islands reveal that the ice front had retreated 400 km up-stream from its LGM position by ~20 ka, about 2000 years earlier than suggested by the data from marine sediment cores. We also present several ^{10}Be ages from sites on the adjacent mainland suggesting that these coastal areas remained ice covered until ~16 ka, at which time the wide embayment of Boknafjorden became permanently ice free. In a companion study we have dated the further ice sheet retreat towards the inner fjord and mountain areas (Briner et al., 2014).

2. Glacial geologic setting and sample locations

The Norwegian Channel starts at the mouth of Oslofjorden and extends along the west coast of Norway throughout our study area between Jæren and the shelf break (Figs. 1 and 2). The shelf-crossing channel is eroded into relatively soft Mesozoic sedimentary strata that verge onto crystalline rocks near the landward margin (Rise et al., 2008). The frequent occurrence of glacial striae on land show that ice flow was directed almost due west during the maximum ice sheet extent (e.g., Aarseth and Mangerud, 1974; Holtedahl, 1975), but lineations that are recorded on the adjacent sea floor show that the ice flow turned northward and merged with the NCIS a short distance beyond the coastline (Sejrup et al., 1998).

The deglaciation of the northern segment of the Norwegian Channel between the shelf margin and the Troll site (Fig. 2) is previously considered to have taken place between 19 and 18.5 ka (Sejrup et al., 2009). After this retreat of the NCIS, the western margin of the Scandinavian Ice Sheet remained along the outer coast for several thousand years before it continued to retreat towards the east (Mangerud et al., 2013). We used ^{10}Be dating on 18 rock samples from coastal areas in the county of Rogaland, south-western Norway (Figs. 2 and 3; Table 1). This includes 12 samples that were collected on the islands Utsira and Karmøy and six samples from sites located in Tananger and Våg on the mainland in the Boknafjorden area (Fig. 3). A description of each sampling area is provided below.

2.1. Utsira

Utsira is a small island, only 3 km across, located in the open ocean to the west of the town of Haugesund (Figs. 1–3). It is situated on the inner shelf just east of the Norwegian Channel, about 400 km to the south of the shelf break and the LGM limit of the Scandinavian Ice Sheet (Fig. 3). All glacial striae that have previously been reported from the island reflect an ice flow that was directed towards the north (Undås, 1948). During fieldwork we searched for glacial striae in various parts of the island, especially on the east coast, to determine if there was younger ice flow from the east, i.e. a glacial imprint from the period after the ice stream collapsed. However, like previous investigators, we found only diffuse striations directed towards the north (350-010°). We therefore assume that Utsira was overridden by the NCIS just prior to the last deglaciation.

Utsira is unique in the sense that it is the only island along the coast that is located within the track of the last NCIS and it was not affected by ice flow from the east during deglaciation. We thus