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Holocene history of Fiskesø, Prinsesse Ingeborg Halvø, eastern North Greenland

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Sediment cores up to 92 cm in length were recovered with gravity and Russian peat corers from Fiskesø, Prinsesse Ingeborg Halvø, eastern North Greenland, during the summer 2014. The correlated sediment succession consists of clastic sediments that are interspersed in the upper part with layers of organic material and likely record the environmental history of the lake since deglaciation. The paucity of macrofossil remains hampered radiocarbon dating of the sediments from Fiskesø. According to published data, the deglaciation of the region took place *c.* 10 cal. ka BP. Relative sea-level reconstructions from the region suggest that the Fiskesø basin, which is today located at 33 m above sea level, was characterised by marine conditions until *c.* 8.1 cal. ka BP. Marine fossils in the lower part of the sediment succession support the prevalence of marine conditions. A reliable radiocarbon age from 5 cm above the isolation horizon in Fiskesø sediments indicates an age of 6.1 cal. ka BP and supports the isolation of the basin prior to this time. Cooling is indicated in the upper part of the sediment succession and is reported to have taken place in the region stepwise shortly after 6.1 cal. ka BP and at *c.* 4.5–4.0 cal. ka BP. Despite the poor chronology the data from Fiskesø support existing terrestrial and marine reconstructions from the region.

Keywords: Holocene, lake sediments, macrofossils, geochemistry.

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Eastern North Greenland is one of the most remote regions on Earth, which is also expressed in a paucity of environmental records spanning the Holocene history of the region. Such records are needed to gain a better understanding of land-ocean interactions, including changes in temperatures and precipitation, history of local ice caps and sea-ice cover. For example, the shelf area off eastern North Greenland is discussed as one of the source regions of the East Greenland Current (EGC), which exports cold, polar water masses from the Arctic Ocean into the North Atlantic and is strongly interconnected with Atlantic water circulation patterns (e.g. Rudels & Quadfasel 1991; Jeansson *et al.* 2008; Foukal *et al.* 2020).

From the terrestrial perspective, information from North Greenland ice cores is very limited and amplified by large problems in obtaining reliable age control of these cores. The Hans Tausen Iskappe in central North Greenland retreated behind present position around 8.5 cal. ka BP and only the northern part may have survived the early Holocene Thermal Maximum (HTM; Landvik *et al.* 2001; Zekollari *et al.* 2017). Studies of a 345-m-long core from the ice cap revealed that the oldest ice at the coring location may be dated to around 4.0 cal. ka BP (Madsen & Thorsteinsson 2001). The chronological constraints allow interpretation only for the last 2000 years (Hammer *et al.* 2001). In eastern North Greenland, local ice caps may also have survived the HTM (Larsen *et al.* 2019). However, a 425-m-long ice core drilled from Flade Isblink in 2006 may have captured only the last 2800–3300 years of environmental history and chronological constraints are poor (Lemark 2010).

Lacustrine records are also sparsely available from eastern North Greenland and partly exhibit very limited age control. Palynological studies of sediment records from Klaresø in Peary Land (Fredskild 1969) and Sommersø on Prinsesse Ingeborg Halvø (Funder & Abrahamsen 1988) showed a decline in vegetation during the Middle Holocene around 4.0–4.5 cal. ka BP. In a sediment record from Bliss Lake, Peary Land, 24 samples were used for radiocarbon dating, but only six samples provided reliable ages (Olsen *et al.* 2012). The record from this lake provides a valuable record of environmental change in the region, showing a transition from lacustrine to marine conditions in the earliest Holocene and an isolation from the sea again at 7.2 cal. ka BP. A sediment record from Kaffeklubben Sø in northernmost Peary Land covers the last *c.* 3000 years only (Perren *et al.* 2012). Further to the east, a number of lakes on Finderup Land provided valuable information on relative sea-level (RSL) changes and fluctuations of the Flade Isblink during the Holocene (Strunk *et al.* 2018; Larsen *et al.* 2019). Sediment records from Skallingen, south of Flade Isblink, show various changes in environmental conditions over the last 8000 years in a location further inland, but the age control is also quite limited (Wagner & Bennike 2015; Kusch *et al.* 2019).

We here present data from sediment successions recovered from Fiskesø on Prinsesse Ingeborg Halvø. The data will help to set the existing data from other terrestrial and marine records in a broader regional context and will help to better understand land-ocean interactions in the closer surrounding.

Study area

Fiskesø (81°33′N, 16°14′W) is located at 33 m above sea level (a.s.l.), ~8 km to the southeast of Station Nord on Prinsesse Ingeborg Halvø, Kronprins Christian Land, eastern North Greenland (Fig. 1). The lake has an irregular shape with a maximum extension of ~800 m along the N–S-axis. Fiskesø was visited between 16 and 20 July 2014. At these days, the ice cover on the lake had started to disintegrate, with the formation of a moat and holes of up to ~2 m diameter in the ice cover (Fig. 1C). Measurements with a handheld echosounder at eight sites in the central part of the lake indicated an undulated bathymetry and a maximum water depth of at least 22.2 m (Fig. 1D). According to measurements in early December 2017, the ice cover on Fiskesø was 58 cm thick and the lake water showed a pH of 7.35 and a conductivity of 200 μS/cm (Christoffersen 2018).

The bedrock surrounding the lake is dominated by Upper Permian carbonates and shales, with the latter prevailing north of the lake towards the present marine shoreline (Håkansson & Pedersen 2001, 2015). Lower Permian limestone and tectonic breccia occur south of Fiskesø, but is, as the areas north of the lake, predominantly covered by till (Goodsite *et al.* 2014). The Prinsesse Ingeborg Halvø (peninsula) is bordered by the Flade Isblink ice cap to the east and south and the Wandel Sea to the west and north. The subdued landscape of the peninsula scarcely exceeds 150 m a.s.l. (Håkansson *et al.* 1989). Several beach ridges can be found ~500 m to the north of Fiskesø (Goodsite *et al.* 2014) and document the relative sea-level lowering of the region after deglaciation.

The High Arctic climate on Prinsesse Ingeborg Halvø, with mean annual temperatures of –16.9°C and a mean July temperature of 3.4°C (during the period from 1961 to 1990; Cappelen *et al.* 2001), causes a short snow-free period that lasts from late July to early September (Funder & Abrahamsen 1988). The vegetation cover on the very shallow active layer (probably around 10 cm; Goodsite *et al.* 2014) is extremely sparse and mainly composed of algae, lichens, mosses and very few angiosperms, which classifies the area as a polar desert (Funder & Abrahamsen 1988). The dwarf shrubs *Salix arctica* and *Dryas integrifolia* are the only woody plants, they grow in areas that become snow-free relatively early.

Material and methods

Based on the echosounder measurements, two locations were selected for the recovery of sediment cores from Fiskesø. The first location was in the western central part of the lake, where the maximum water depth of 22.2 m was measured (Fig. 1D). At this location (81°33′33.2′′N, 16°14′23.6′′W), two deployments of a gravity corer (GC; UWITEC Co.) with a recovery of 21 and 40 cm, respectively, indicated dark silty sediments and a series of small turbidites through the transparent PVC liner. In order to obtain longer and undisturbed sediment successions with the gravity corer and a Russian peat corer with a 100-cm-long and 7.5-cm-wide chamber, a shallower location in the more central part of the lake was selected, where the echosounder revealed a water depth of 8.6 m (Fig. 1D). At this location, two gravity cores of 52 cm (GC1) and 34 cm (GC2) length with an undisturbed sediment surface were recovered. Subsequently, three sediment cores were recovered with the peat corer. Hammering on the peat corer at a sediment depth of ~1 m provided only marginal further penetration. The surfaces of the cores were partly washed out due to incomplete closure of the corer during retrieval through the water column. Immediately after recovery, the cores obtained with the peat corer were photographed, transferred to PVC half pipes and wrapped in cling film.

Opening of the gravity cores in the laboratories of the University of Cologne revealed a good match between the surface sediments and the sediment successions recovered with the peat corer. Visual correlation of marker layers allowed splicing of the cores and revealed that Russian core (RC) 1 covered 8–92 cm, RC2 0–81 cm and RC3 0–91 cm (appendix).

For grain-size analyses on core RC3 and in order to

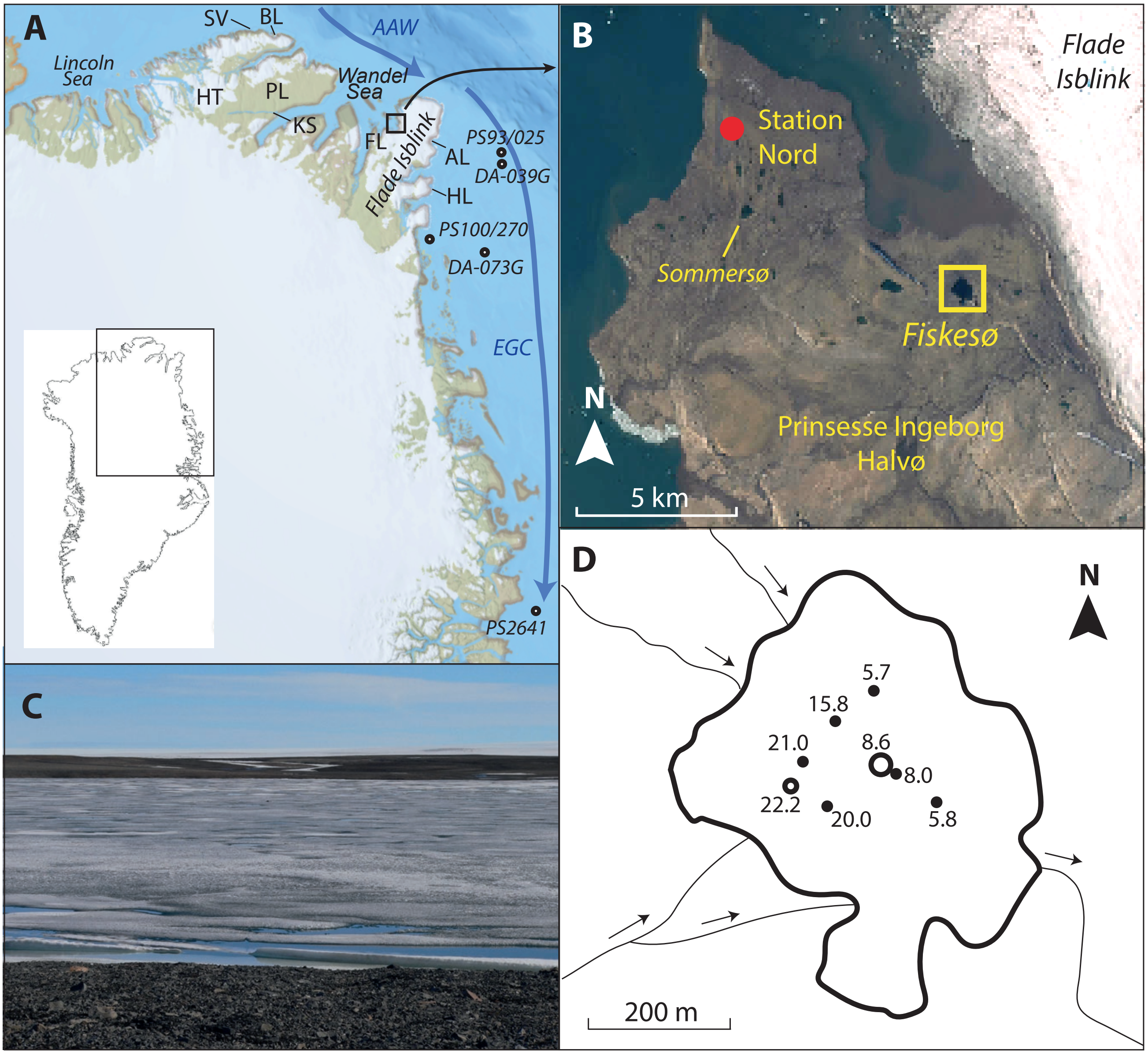

Fig. 1. A, Map of Greenland with zoom in on northeastern Greenland (screenshot from National Geographic Mapmaker) showing the location of Prinsesse Ingeborg Halvø in eastern North Greenland and place names mentioned in the text (PL: Peary Land, HT: Hans Tausen Iskappe, SV: Sifs Valley, BL: Bliss Lake, KS: Klaresø, FL: Finderup Land, AL: Amdrup Land, HL: Holm Land, SK: Skallingen). Blue arrows indicate simplified currents with Arctic Atlantic Water (AAW) and the East Greenland Current (EGC). Locations and names of marine sediment cores mentioned in the text are indicated by black dots with core names in italics (DA-039G=DA17-NG-ST03-039G and DA-073G=DA17-NG-ST03-073G). **B,** Satellite image (Google Earth screenshot, with map data from Maxar Technologies, U.S, Geological Survey, with tonal value modified) of Prinsesse Ingeborg Halvø with the locations of Station Nord and Fiskesø. **C,** Photo of Fiskesø taken on 19 July 2014 with a view from the west. **D,** Close-up of Fiskesø with main inlets in the western part and the outlet at the southeastern corner of the lake. Locations, where the water depth was measured with a handheld echosounder, are indicated by black dots with the respective water depths in metres. Open circles indicate coring locations. Core data shown here are from the central location, where 8.6 m water depth was measured.

remove authigenic matter ~1 g of the sample material taken in 1-cm-intervals was treated with hydrogen peroxide (H_2O_2, 30 %), hydrochloric acid (HCl, 10 %), and sodium hydroxide (NaOH, 1M). Prior to the analyses, the sample material was dispersed with $Na_4P_2O_7$ on a shaker for 12 h and underwent 1 min of ultrasonic treatment. Sample aliquots were then measured three times with a Laser Diffraction Particle Analyser LS 13320 (BECKMANN COULTER Co.) and the individual results were averaged. Data processing was carried out by using the GRADISTATv8 program (Blott & Pye 2001). For geochemical analyses, a spliced sediment succession from GC1 and RC3 was sampled in 1-cm-intervals. The samples were freeze-dried, ground to <63 μm, and homogenised. Total carbon (TC) and total inorganic carbon (TIC) were measured using a DIMATOC 200 (DIMATEC Co.) analyser and allowed calculation of total organic carbon (TOC) by subtraction. Total sulphur (TS) and total nitrogen (TN) were analysed with a Vario Micro Cube combustion CNS elemental analyser (ELEMENTAR Co.).

Macrofossil analyses were carried out on RC2. Macrofossils were recovered from the >0.4, >0.2, and >0.1 mm residues obtained from wet sieving of subsamples, placed onto petri dishes and analysed using a dissecting microscope.

Radiocarbon dating was carried out at the CologneAMS accelerator mass spectrometry facility and followed standard methods (Rethemeyer *et al.* 2013). For radiocarbon dating two horizons of core RC2 were selected. These horizons were at 32–34 cm and 37–38 cm, which was corrected to 30–32 cm and 35–36 cm, when compared with GC1 and RC1 (Table 1, Fig. 2, appendix). The upper horizon contained very few *Salix arctica* remains. The lower horizon did not contain terrestrial macrofossil remains but showed a maximum in TOC. Therefore, bulk organic matter in this horizon was used for radiocarbon dating. The radiocarbon ages were calibrated into calendar years using the Calib 8.2 software (Stuiver & Reimer 1993). Published radiocarbon ages were also calibrated to calendar ages using this software.

Results and discussion

Lake history and terrestrial environment

The restricted progress in penetration with the Russian corer below a sediment depth of ~1 m implies that the sediments underlaying the recovered cores from Fiskesø have likely been deposited during or shortly after deglaciation of the region. This is supported by a few rock fragments and sand, which were found at the base of core RC2, and indicates that the recovered sediment successions contain the complete history of the lake. Radiocarbon dating of the basal sediments of the recovered sediment succession from Fiskesø was not possible, because only very few and tiny macrofossils were found and organic matter (OM) content, which is represented by TOC and TN, was low (Fig. 2). However, former studies provide some information on the timing of the last deglaciation of the Prinsesse Ingeborg Halvø. A marine bivalve shell, which was found 1 km to the southwest of Fiskesø, provided the oldest reliable age in the area and constrains the minimum age of deglaciation at 9.86 cal. ka BP (Funder *et al.* 2011). Finderup Land, which is located ~20 km to the west of Prinsesse Ingeborg Halvø, became ice free shortly before 10 cal. ka BP (Strunk *et al.* 2018). This matches well with deglaciation dates from the eastern margin of Flade Isblink, where the ice retreated between *c.* 11.0–9.4 cal. ka BP to the present margin and thereafter beyond the present margin (Hjort 1997; Funder *et al.* 2011; Larsen *et al.* 2019). These data indicate that the basal sediments of the Fiskesø sediment succession date around 10.0 cal. ka BP (Fig. 2). The timing of the last deglaciation and onset of sedimentation around this period could be triggered by a relatively high temperature anomaly, as derived from oxygen isotope values in the Agassiz and Renland ice cores (Vinther *et al*. 2009, Lecavalier *et al*. 2017). Although this shift in oxygen isotope values is less pronounced in most ice cores from the Inland Ice, the Greenland Ice Sheet likely experienced a substantial thinning around 10.0

Table 1. AMS radiocarbon ages from core RC2, Fiskesø, North Greenland

Laboratory no.	Depth (cm)	Spliced depth (cm)	Material	$\delta^{13}C$ (‰)	^{14}C age (a BP)	Calendar[1] (cal. a BP)
COL3496.1.1	32–34	30–32	*Salix artica*	–28.7	5333 ± 43	5995–6211
COL3497.1.12[2]	37–38	35–36	bulk sediment	–25.4	17381 ± 86	20779–21332

[1] Calibrated according to the INTCAL20 dataset (Reimer *et al.* 2020). Ages are ± 2 std.

[2] No marine reservoir correction was applied, as the age is regarded as erroneous.

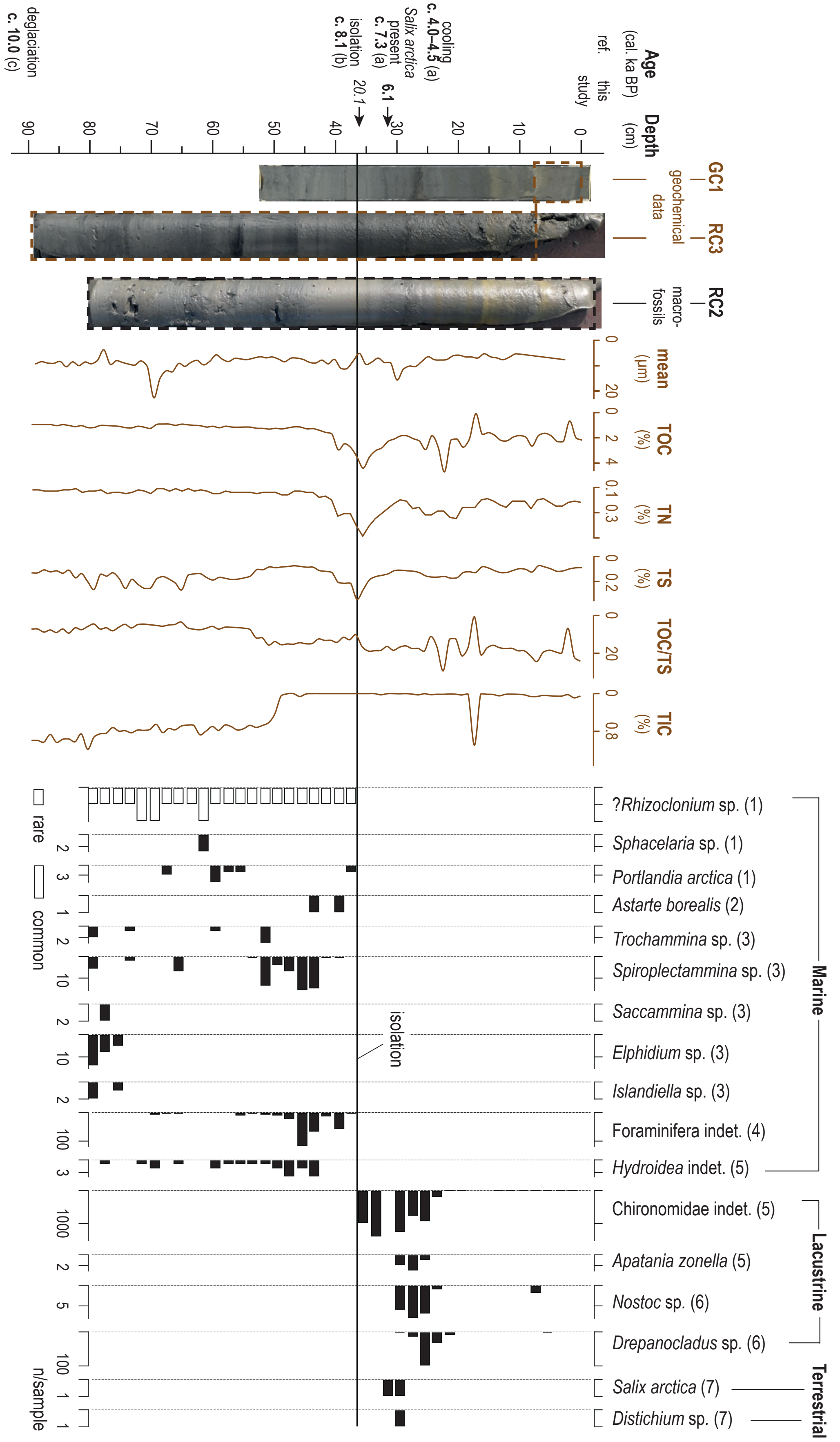

Fig. 2. Photos, grain-size mean, geochemical data and fossils of cores from Fiskesø. Brown dashed lines framing GC1 and RC3 indicate core sections that were used for analyses on a composite sediment succession. Core RC2 was used for macro-fossil analyses. Numbers in brackets behind taxa names indicate 1: tallus, 2: periostracum fragments, 3: tests, 4: foraminiferal linings, 5: exo-skeleton parts, 6: colonies, 7: stems, leaves. Radiocarbon dating was performed at samples from two horizons, of which the sample from 36 cm depth (italics) is regarded as erroneous (left). Age and environmental information from literature refer to a: Funder & Abrahamsen (1988), b: Funder *et al.* (2011), c: Strunk *et al.* (2018), see text for further information.

cal. ka BP (Vinther *et al*. 2009), which likely correlates with the deglaciation of the Station Nord region.

The fine-grained, greyish sediments deposited in the lower part of the Fiskesø sediment succession show low OM, relatively high TS and TIC contents, a low TOC/TS ratio, and contain marine macrofossils with very few and tiny fragments of shells and tests of foraminifera below 36 cm depth (Fig. 2). This indicates that marine conditions prevailed in the Fiskesø basin immediately after deglaciation and matches with former studies from eastern North Greenland, where marine waters inundated the lowland areas during and immediately after deglaciation. Marine bivalve shells from Prinsesse Ingeborg Halvø postdating the deglaciation are reported from altitudes up to 58 m a.s.l. (Funder *et al.* 2011), i.e. well above the present altitude of Fiskesø at 33 m a.s.l. On Amdrup Land and Finderup Land (Hjort 1997; Larsen *et al.* 2019) the marine limit is around 80 m a.s.l. Noteworthy is the distinct decrease in TIC at ~50 cm depth in the Fiskesø sediment succession (Fig. 2). This could indicate a change in sediment supply from a larger marine environment to a more local source, particularly the Upper Permian shales to the north of Fiskesø (Håkansson & Pedersen 2015), in the course of ongoing RSL fall during the early Holocene. The RSL fall is, however, only marginally indicated in the grain-size data. A single coarser horizon at 69 cm depth with a mean of ~22 μm might originate from a thin mass flow deposit (Fig. 2). Above, mean values range around 7 μm. A faint increase in grain size mean to ~10 μm around 38 cm depth may indicate slightly shallower waters and more wave action before the isolation of Fiskesø.

The isolation horizon at 36 cm in the Fiskesø sediment succession is characterised by increasing OM, a maximum in TS and an abrupt shift from the occurrence of marine to lacustrine fossils (Fig. 2). The bulk OM sample (COL3497.1.1) from the isolation horizon in the Fiskesø sediment succession gave an age of *c.* 20.1 cal. ka BP (Fig. 2, Table 1). This age is regarded as unreliable because of the supposed much later deglaciation of the region and RSL information from other studies in the vicinity. The study of lake Sommersø located nearby on Prinsesse Ingeborg Halvø at an altitude of 25 m a.s.l. revealed that the lake became isolated between *c.* 7.0 and 8.0 cal. ka BP (Funder & Abrahamsen 1988). A skeleton from a whale that likely stranded at 20 m a.s.l. on Prinsesse Ingeborg Halvø provided an age of 6.7 cal. ka BP (Bennike 1997). Based on radiocarbon dating of marine bivalve shells and driftwood a RSL curve for Prinsesse Ingeborg Halvø was constructed by Funder *et al.* (2011), according to which the isolation of Fiskesø took place at *c.* 8.1 cal. ka BP. The emergence curve for Prinsesse Ingeborg Halvø is in good agreement with RSL reconstructions from the surrounding regions. Radiocarbon dates from Holm Land and Amdrup Land suggest a RSL fall from ~55 to 26 m a.s.l. between *c.* 8.5 and 7.4 cal. ka BP (Hjort 1997), which provides an average rate of ~2.6 cm a^{-1} for the RSL fall. This would place the timing of an isolation of a lake at 33 m a.s.l. as for Fiskesø at *c.* 7.7 cal. ka BP. The average rate of RSL fall is consistent with a RSL reconstruction from Finderup Land, where a RSL fall from ~60 to ~20 m a.s.l. was reconstructed for the period between *c.* 9.5 and 8.0 cal. ka BP (Strunk *et al.* 2018). This would place the timing of the isolation of a basin at 33 m a.s.l. to *c.* 8.5 cal. ka BP. Although there are some differences between the ages constraining the isolation of Fiskesø, all ages are much younger than the age of sample COL3497.1.1 (Table 1) and indicate that the bulk OM from this sample likely contains redeposited material, probably from the Upper Permian shales to the north of Fiskesø. Assuming a deglaciation of Fiskesø around 10 cal. ka BP and an isolation at *c.* 8.1 cal. ka BP, a relatively high sedimentation rate prevailed during the marine phase of the basin.

The maximum in TS and the corresponding minimum in TOC/TS at the isolation horizon in Fiskesø indicate a shift in bottom water redox conditions. A similar shift has been observed in other lakes from Greenland at the transition from marine to brackish or freshwater conditions (e.g. Wagner & Melles 2002; Wagner *et al.* 2010). However, the OM increase below might also indicate increasing productivity promoting oxygen consumption during decomposition. Relatively high temperatures during the Early Holocene may have caused a minimum extent of Flade Isblink after 8.7 cal. ka BP (Larsen *et al.* 2019). This matches well with the regional HTM and a minimum in sea-ice cover between *c.* 8.5 and 6.0 cal. ka BP (Funder *et al.* 2011; Olsen *et al.* 2012; Briner *et al.* 2016) and data from Nioghalvfjerdsfjorden, where glacial recession culminated between 7.7 and 4.5 cal. ka BP (Bennike & Weidick 2001). The maximum in OM proxies and specific macrofossil remains confirm a HTM during and after the isolation of the Fiskesø basin. Chironomid remains can be found in the highest numbers directly after the isolation and document a rapid shift from marine to freshwater conditions. The first occurrence of *Salix arctica* is radiocarbon dated by sample COL3496.1.1, which provides a reliable age of 6.1 cal. ka BP. This age is from only 4–6 cm above the isolation horizon and implies that the sedimentation rate in Fiskesø distinctly lowered directly after the isolation. Taken that the 4–6 cm between the presumed timing of isolation and the dated horizon contains approximately 2000 years, the 2-cm-thick sample might comprise several hundred years. This could at least partly explain why the first occurrence of *Salix arctica* in the Fiskesø sediment succession is much later than its first occurrence in the area at 7.3 cal. ka BP (Funder & Abrahamsen 1988).

Shortly after 6.1 cal. ka BP, around 30 cm depth, the grain-size mean shows a faint maximum and OM content is low again (Fig. 2). This indicates that the environmental conditions may have slightly changed again. Coarser grain sizes, the occurrence of terrestrial moss remains (*Distichium* sp.) and subsequent occurrence of aquatic mosses (*Drepanocladus* s.l. sp.), algae (*Nostoc* sp.) and caddis fly larvae (*Apatania zonella*) imply that the lake level of Fiskesø lowered shortly after 6.1 cal. ka BP. This lowering might be due to relatively high temperatures and restricted precipitation and might correspond with a glacier retreat that was reconstructed in Sifs Valley, Peary Land, between 6.3 and 5.5 cal. ka BP (Möller *et al.* 2010; Larsen *et al.* 2019). It might also correspond to the time-period when Flade Isblink had a minimum extent, which occurred sometime between ~8.7 to 4.1 cal. ka BP (Larsen *et al.* 2016, 2019).

A distinct decline of lacustrine and terrestrial macrofossils is observed at ~23 cm in the Fiskesø sediment succession. Interpolation of sedimentation rates to the top of the Fiskesø sediment succession suggests that this decline took place *c.* 4.4 cal. ka BP. This matches well with palynological studies from nearby Sommersø, where cooling is reported between *c.* 4.5–4.0 cal. ka BP (Funder & Abrahamsen 1988). Reworked marine shells from the western margin of the Flade Isblink, i.e. from less than 2.5 km from Fiskesø, imply that the margin of the glacier expanded from behind its present position to its present position at 4.1 cal. ka BP (Larsen *et al.* 2019). The readvance might have been promoted by a still existing but dwindling presence of temporarily open water conditions in the marine realm off North Greenland, due to which these open waters could act as a moisture source (Zekollari *et al.* 2017). An increase in precipitation may have led, in combination with a cooling, to longer persisting snow cover during the short summer, which makes the growing conditions for plants less favourable. In the wider vicinity, also Klaresø on Peary Land shows a decline in pollen concentration and particularly *Salix arctica* at this time (Fredskild 1969). Two small lakes in Skallingen, Lille Sneha Sø and Trifna Sø, show maximum macrofossil abundances of warmth-demanding plants (*Salix arctica* and *Dryas integrifolia*) and invertebrates (*Daphnia pulex* and Chironomidae) between *c.* 7.4 and 6.2 cal. ka BP and a decrease of OM contents and increasing minerogenic input at *c.* 4.4 cal. ka BP, which probably also reflects the end of the HTM (Wagner & Bennike 2015; Kusch *et al.* 2019).

In the Fiskesø sediment succession, OM proxies show another small decline at ~18 cm and negligible changes in all studied proxies above. The decline at ~18 cm would correspond to an age of *c.* 3.5 cal. ka BP, when assuming a fairly constant sedimentation rate in the upper, lacustrine part of the succession. It could indicate a further cooling and may correspond with an expansion of a Flade Isblink margin a few kilometres to the south of Fiskesø from a minimum extent to its present position around 3.1 cal. ka BP (Larsen *et al.* 2019). An increase in soil erosion and clastic matter input is also observed to the south of Flade Isblink, in the Lille Sneha Sø and Trifna Sø sediments from Skallingen, around *c.* 3.4 to 3.0 cal. ka BP (Kusch *et al.* 2019). The sediment record from Bliss Lake on Peary Land shows a higher sedimentation rate after *c.* 3.3 cal. ka BP, but this was probably connected to slightly warmer conditions and somewhat reduced winter sea-ice cover (Olsen *et al.* 2012). On the other hand, driftwood data suggest an increase in sea-ice cover at the coast of North and eastern North Greenland around 2.5 cal. ka BP (Bennike 1987; Landvik *et al.* 2001; Funder *et al.* 2011). Overall, the upper 18 cm of the Fiskesø sediment succession suggest that the climatic and environmental conditions remained fairly constant during the late Holocene and similar to those of today, where the region is described as a polar desert (Funder & Abrahamsen 1988).

Marine environment

The environmental history of Fiskesø is closely related to the marine environment. Arctic Atlantic Water (AAW), which is a subsurface water mass (T ~0.8–2 °C, S ~34.8) and underlies cold and low salinity surface waters (T <0 °C, S <31.2), passes the coast to the north of Kronprins Christian Land (e.g. Dmitrenko *et al.* 2017, Hansen *et al.* 2022 and references therein). AAW contributes to the lower section of the EGC (Fig. 1), which conveys cold low-saline (T < 0 °C, S < 34.5), Polar surface waters, together with glacial meltwater and drift ice along the eastern Greenland margin and into the North Atlantic (e.g. Hansen *et al.* 2022 and references therein).

The closest marine sediment records were taken from the Wandel Sea less than 30 km northwest and west of Station Nord (Nørgaard-Pedersen *et al.* 2008; Van Nieuwenhove *et al.* 2020). The core data suggest that a semi-permanent fast-ice cover characterised the sites between 10.0 and 8.9 cal. ka BP and that the deeper troughs in the mouth region of the Independence Fjord system were intruded by subsurface Atlantic water in this period (Nørgaard-Pedersen *et al.* 2008). This is probably in line with modelling data from the southern Lincoln Sea ~500 km to the west, where a widespread transition from perennial to seasonal sea-ice was reconstructed (Detlef *et al.* 2023). The data from the Wandel Sea cores support a deglaciation of the Fiskesø basin around 10.0 cal. ka BP or slightly earlier. Unfortunately, the cores provide only limited evidence of changes in environmental conditions after *c.* 9.0 cal. ka BP. Extremely low sedimentation rates were tentatively explained by a strongly restricted influx of meltwater-derived sediments (Nørgaard-Pedersen *et al.* 2008) but contradict with relatively high sedimentation rates presumed for marine Fiskesø basin at that time. A higher inflow of subsurface Atlantic water into the Independence Fjord system in the last 2000 years (Van Nieuwenhove *et al.* 2020) seems to have not affected the environmental conditions in the Fiskesø basin.

Marine sediment records from the continental shelf off eastern Kronprins Christian Land show a slightly inconsistent pattern with respect to temperature and sea-ice conditions during the early and middle Holocene. Cores PS93/025 and PS100/270 show prolonged open-water conditions between 10.2 and 9.3 cal. ka BP, which was linked to the HTM and followed by a steady increase in sea-ice conditions in the area during the middle Holocene (Syring *et al.* 2020a, b). Data from neighbouring core DA17-NG-ST03-039G indicated a succession of a cold period with marginal ice zone conditions and enhanced EGC and Atlantic Water advection from 10.2 to 9.4 cal. ka BP, followed by harsher sea-ice conditions and Atlantic Water inflow from 9.4 to 7.5 cal. ka BP (Hansen *et al.* 2020). In contrast to Syring *et al.* (2020a, b), the timing of the HTM was defined to the period from *c.* 7.5 to 6.7 cal. ka BP, when high surface and subsurface water productivity prevailed and as promoted by the enhanced Atlantic Water flow to the shelf (Hansen *et al.* 2022). The transition towards a cold period with increased drift-ice transport via a strong EGC is recorded from *c.* 6.2 cal. ka BP. A bit further to the south, on the Northeast Greenland shelf in front of Nioghalvfjerdsfjorden, core DA17-NG-ST07-73G revealed a highly stratified water column with cold, sea-ice-loaded surface waters and a strong influx of warm Atlantic water in the subsurface between 9.4 and 8.2 cal. ka BP (Pados-Dibattista *et al.* 2022). This period was followed by a strong influence of the Return Atlantic Current and a weakened transport of Polar water in the upper EGC until 6.2 cal. ka BP. The inferred HTM from 8.2 to 6.2 cal. ka BP at this site is quite consistent with the HTM inferred from Fiskesø sediment data.

After the HTM, the marine sediment records from the continental shelf show that the EGC became stronger, with sea-ice-loaded surface waters and relatively warm Atlantic-sourced subsurface waters (Pados-Dibattista *et al.* 2022). Consistent with the reconstruction from Fiskesø, where stepwise harsher conditions are indicated at *c.* 4.4 and 3.5 cal. ka BP, increased Polar water at the surface of the EGC led to freshening and increased drift-ice transport with a (near) perennial sea-ice cover on the continental shelf along the coast of Northeast Greenland to the east and southeast of Flade Isblink between *c.* 4.5 and 4.2 cal. ka BP (Perner *et al.* 2015; Hansen *et al.* 2022; Pados-Dibattista *et al.* 2022). A further strengthening of the EGC at *c.* 3.2 cal. ka BP was characterised by a thick layer of cold and fresh polar water on the surface and a minimum in surface-water productivity (Pados-Dibattista *et al.* 2022). Foraminifera data from core PS2641-4 recovered from the central East Greenland shelf (Fig. 1) revealed that the EGC flow may have peaked between *c.* 2.3 and 1.4 cal. ka BP due to a complex interplay of Atlantic water masses and increased heat advection of the North Atlantic Currents into the Arctic Ocean (Perner *et al.* 2015). The record from Fiskesø, however, cannot provide information about this strengthening, probably because the region around Fiskesø was already too barren to record such environmental changes in the studied proxies.

Conclusions

The studies of sediment successions from Fiskesø on Prinsesse Ingeborg Halvø contributed to a better understanding of the environmental history of the region and linkages to the marine realm. Radiocarbon dating was problematic due to the low abundance of macrofossils in the sediments. According to existing data, the lake basin was deglaciated around 10 cal. ka BP. The isolation of the basin around 8.1 cal. ka BP is likely synchronous with the onset of the regional HTM, which may have lasted until shortly after *c.* 6.1 cal. ka BP. Lake-level lowering is recorded between *c.* 6.0 and 5.0 cal. ka BP. Stepwise cooling is recorded in macrofossils and OM content and likely occurred around 4.4 and 3.5 cal. ka BP. During the Late Holocene, absence of macrofossils and low organic matter contents document a harsh environment with low summer temperatures and long-lasting lake-ice cover.

Overall, the data from Fiskesø support the existing knowledge based on the few marine and terrestrial records in the region. They document the influence of Arctic Atlantic Water masses on the East Greenland Current during the Holocene. New techniques in radiocarbon dating, e.g. compound specific dating, and lower amounts of carbon requested for dating may help to improve the chronologies in sediment succession from such environments. This, however, does not improve other limitations of these sediment successions, such as redeposition of old material and often very low sedimentation rates, which hamper high-resolution studies. The comparison of macrofossil and geochemical data from Fiskesø reveals that macrofossil remains reflect well the general climatic and environmental settings, whereas geochemical data are more sensitive to lake-internal changes, such as changes in catchment settings, nutrient and redox conditions. The combination of the data provides a reliable basis for a reconstruction of the environmental history and the isolation of the basin from the marine environment.

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Appendix. Photos of sediment cores recovered with a gravity corer (GC) and a Russian peat corer (RC) from Fiskesø, Prinsesse Ingerborg Halvø, in July 2014. Note that the photos of the Russian cores were made in the field and thus show some distortion, particularly in the upper and lower parts. Green foam was used to stabilise the sediment surface of the gravity cores during transport. The black lines show the correlation of the cores based on marker horizons. The age-depth plot at the right side includes tie points at the year of core recovery (2014= 0 cm depth), the two ^{14}C dated horizons (circles; open circle: unreliable age), and the presumed age of deglaciation and onset of sedimentation in the Fiskesø basin at the base of the cores.