RESEARCH NOTE

A bowhead whale vertebra embedded in marine limit beach sediment on Barentsøya, Svalbard

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Abstract

A cross-valley beach terrace in Iladalen, in the south-east of the island of Barentsøya, Svalbard, is interpreted as having been built by long-shore sediment transport and deposition, with its maximum height at about 88 m a.s.l., marking the marine limit at deglaciation. A whale vertebra—most probably from a bowhead whale (*Balaena mysticetus*)—was found embedded in the upper part of the littoral sediments at a height of ca. 80 m a.s.l., that is, about 8 m below the marine limit at deglaciation The bone is dated to 10 762 ± 137 cal yr BP, just a few hundred years after the generally accepted deglaciation of the coastal parts of Barentsøya, about 11 000 years ago. The vertebra's age and altitudinal position fit well with the relative sea-level curve constructed for the north-eastern tip of the island of Edgeøya, some 29 km east–south-east of Iladalen.

Keywords
Glacial history; shore level displacement; spit platforms; ZooMS; *Balaena mysticetus*; peptide mass fingerprinting

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Abbreviations
cal yr BP: calibrated years before the present.

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Introduction

The international project Polar North Atlantic Margins, Late Cenozoic Evolution devoted two field seasons to east Greenland (1990, 1992) and two field seasons to Svalbard (1991, 1993). The 1991 season concentrated on Svalbard's eastern islands—Edgeøya, Barentsøya and Kongsøya (Fig. 1a; Landvik et al. 1995), with the main aim of finding—if possible—pre-Late Glacial Maximum sediment successions and thus to probe into the earlier glacial history of the area. Except for Kongsøya (Ingólfsson et al. 1995), this aim met with only minor success. The end result was a number of studies on the Late Weichselian deglaciation of the Svalbard-Barents Sea ice dome and its continued palaeoenvironmental evolution into the later parts of the Holocene in different areas of those islands, as summarized by Landvik et al. (1995).

Reconnaissance during the first week of the 1991 field season involved field parties flying out by helicopter in the mornings from our vessel, the RV *Lance*, to prospective field survey areas. One of those reconnaissance days was spent in Iladalen, the small valley north of the mountain Büdelfjellet in the south-eastern corner of Barentsøya (Fig. 1). This valley leads up to the Freemanbreen outlet glacier, one of the ice-drainage routes for the Barentsjøkulen ice cap, which covers about 43% of Barentsøya. The Freemanbreen glacier flows southwards and terminates with a calving margin in the sea of Freemansundet (Fig. 1). The reconnaissance of Iladalen's glacial stratigraphy and morphology was not prioritized for further in-depth investigations during the expedition. However, a whale vertebra, collected close to the marine limit, has been decorating my office wall since 1991. Here, I summarize the results of recent efforts to determine the species and age of the vertebra, supplementing this with information drawn from my original field notes on the sedimentology and geomorphology of the area. The 'present' of the description below refers to conditions in 1991.

Field observations

The lateral bulge of the eastern margin of the glacier Freemanbreen into Iladalen has a foot that is ca. 90 m a.s.l. In front of this are two moraine ridge arcs (Fig. 1c), the inner one is 5-10 m high and the outer moraine is 15-20 m high. The valley bottom distal to the moraine arcs consists of silt, 2-3 m thick, which is overlain some 2.5 km east of the outer moraine arc by a cross-valley terrace of coarse littoral sediments. The terrace, which is about

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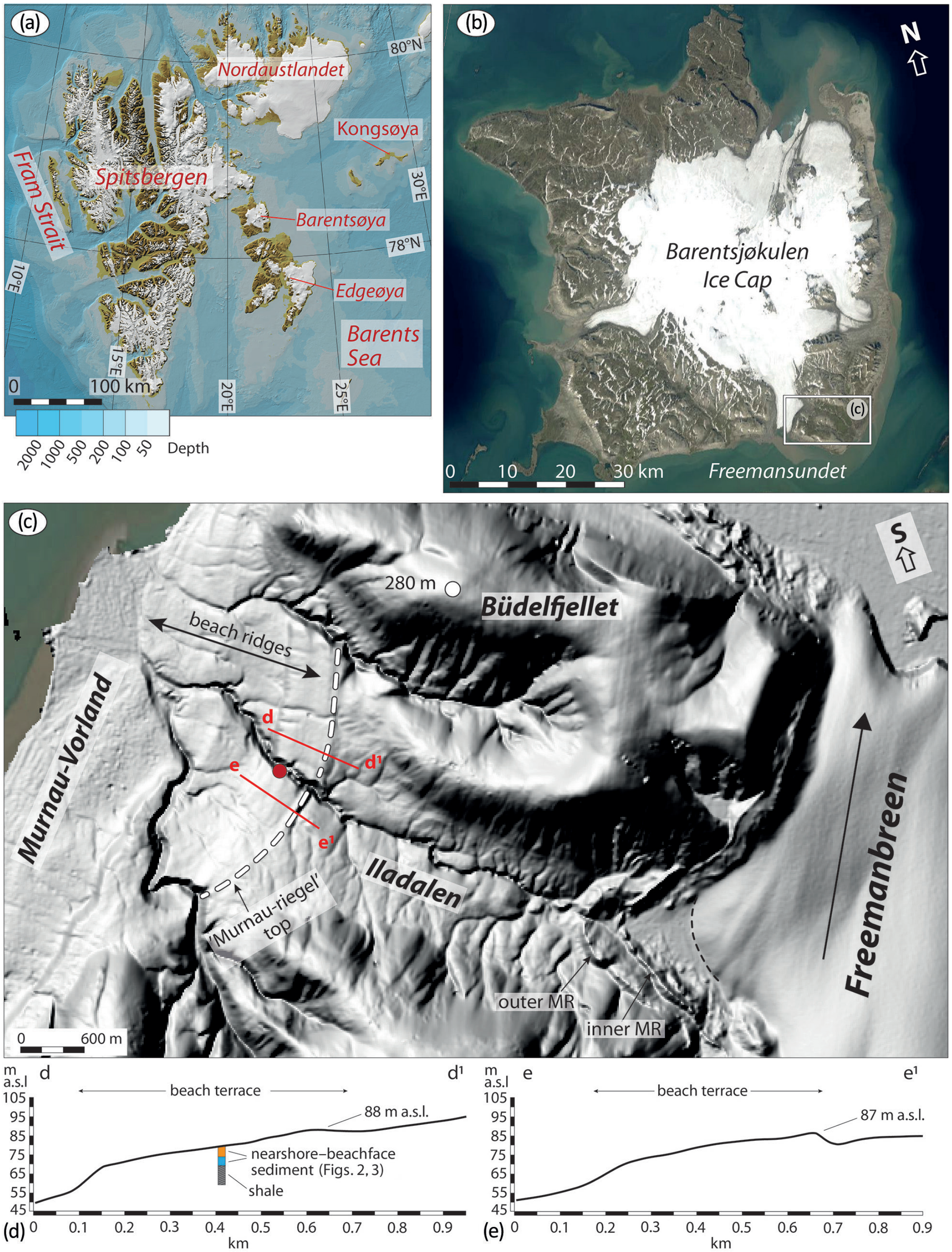

Fig. 1 (a) Svalbard (base map is from the *International Bathymetric Chart of the Arctic Ocean* (Jakobsson et al. 2008). (b) A Google Earth image of Barentsøya. (c) Digital elevation model of the area east of the Freemanbreen outlet glacier in the south-eastern corner of Barentsøya (note the 180° rotation for preserving the three-dimensional impression). North of the Büdelfjellet mountain is a small east-trending valley—Iladalen—leading out to what Büdel (1968) unofficially named "Murnau-Vorland". Freemanbreen has a small lateral bulge into Iladalen, in front of which are two recessional moraine ridges (inner and outer MR). The logged section (Fig. 3), marked with a red dot, is within a cross-valley beach terrace (Büdel's "Murnau-riegel") with a top surface at ca. 88 m a.s.l., which marks the marine limit. (d–e) Cross-profiles across the beach terrace, marked with red lines in (c). East thereof is a series of raised beach ridges towards the present coast, formed during isostatic uplift and thereto associated shore displacement. The digital elevation model and cross-profiles were constructed from Arctic-DEM (https://www.pgc.umn.edu/data/arcticdem).

400 m wide, has a proximal (to the west) maximum height of 88 m a.s.l., sloping eastwards to about 70 m a.s.l. and then dropping steeply to about 55-60 m a.s.l. (Fig. 1d-e). From this point, there is a series of beach ridges down towards the present-day shore of the Barents Sea (Fig. 1c).

A river has cut a 30 m deep canyon across the beach terrace and down into the bedrock (shale), exposing along its margins 10-15 m of sand and gravel on top of the shale (Fig. 2a). A section, about 7 m high and with a top surface at about 80 m a.s.l. and positioned in the central part of the beach terrace (red dot in Fig. 1c), was cleaned up and logged, and the sediment succession divided into two units: A and B (Fig. 3).

Unit A is 1.3 m thick but with a continuation downwards and consists of interbedded massive medium sand and clayey silt, and a bed of vaguely planar-laminated sandy gravel. The sediment was barren of any marine molluscs. The sediment unit is interpreted as having been deposited in a marine nearshore environment.

Unit B is 5.7 m thick and starts at the base with clast-supported massive cobbly gravel (maximum particle size ca. 10 cm) and clast-supported cobble-boulder (maximum particle size 20-30 cm), the latter with

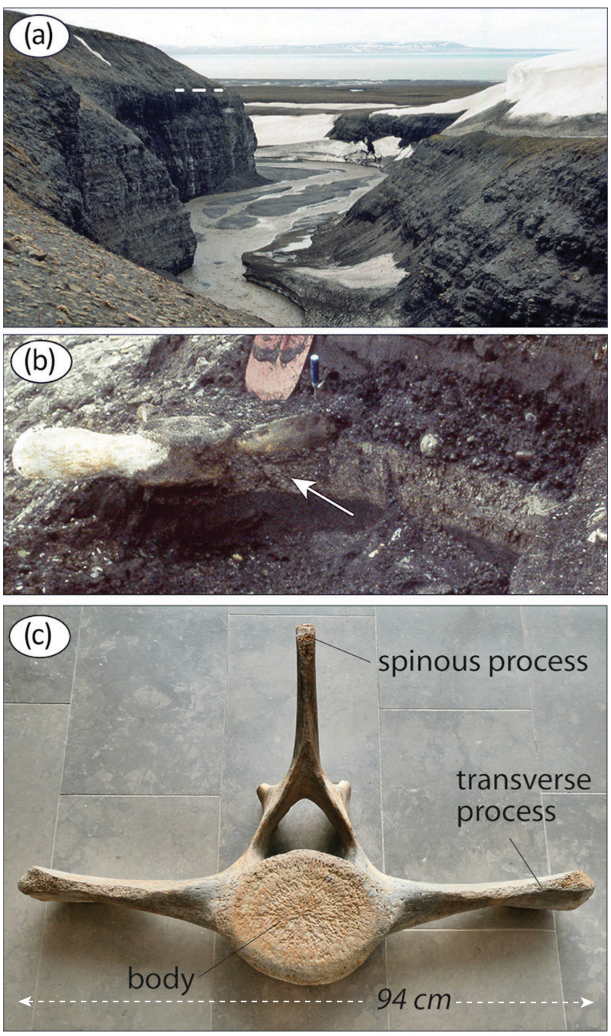

Fig. 2 (a) Canyon cutting through the beach terrace sediments in Iladalen. Contact to shale is marked by a dashed white line. The north-east tip of Edgeøya is seen in the background, across Freemansundet. (b) Whale vertebra in its in situ position (white arrow), embedded in the uppermost 1 m of the Unit B beachface gravel (Fig. 3). (c) The extracted whale vertebra, most probably *Balaena mysticetus*.

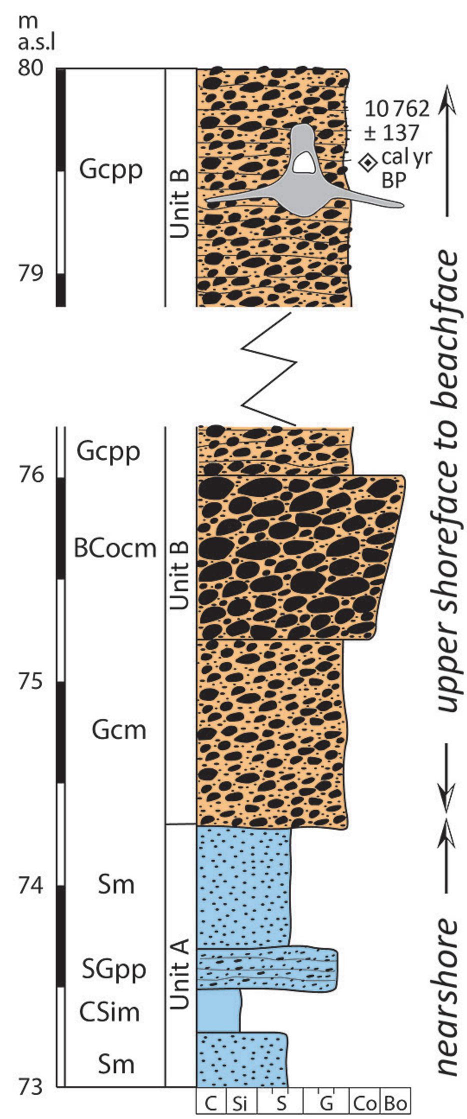

Fig. 3 Logged sediment succession as exposed in a river-cut section across the cross-valley beach terrace in the Iladalen valley (red dot in Fig. 1c). The collected whale vertebra is from the upper part of the section, embedded in beachface gravel.

inverse grading. This continues with clast-supported, vaguely planar-laminated cobbly gravel (maximum particle size 8-10 cm) to the top of the sediment succession. The sediment unit is interpreted as having been deposited in an upper shoreface grading into beachface environment, with sediment mainly supplied by longshore current transport.

A whale vertebra was found a few metres from the logged sediment succession (Fig. 2b), embedded within the upper part of the Unit B cobbly gravel, with one transverse process protruding out of the river-cut section. Only a very small part of the vertebra had been exposed before our extraction. The vertebra is 94 cm long from left to right transverse process and 55 cm high from the base of the body to the tip of the spinous process (Fig. 2b). In 1991, the elevation was determined by an electronic altimeter, but here it has been corrected to the ground surface elevation provided for the site's position by the digital surface model, ArcticDEM, which is ca. 80 m a.s.l. (Fig. 3), a difference of just +3 m. The vertebra was collected for later dating and species determination.

Species determination and radiocarbon dating

Determining the species of a vertebral specimen solely on the basis of its morphological characteristics can be challenging. Therefore, bone material was sampled through drilling in the vertebra's body (centrum), from which protein collagen was extracted. At BioArCh, Department of Archaeology, University of York, UK, the collagen was analysed with peptide mass fingerprinting (Buckley & Collins 2011), using ZooMS (see methods in the Supplementary material). Whale species are distinguishable by a variety of peptide markers (Supplementary Table S1). The results of the analysis on the Iladalen whale vertebra point to the right whale family (Balaenidae), the main marker differentiating the Balaenidae from other whales being marker a2292 (Supplementary Tables S1, S2).

The Balaenidae comprise a number of genera that died out before the time period that is relevant here, with only two surviving genera (Bisconti 2003). The extant members of the Balaenidae consist of the bowhead whale (*Balaena mysticetus* [Cooke & Reeves 2018]) and three species of right whale (*Eubalaena* spp. [Cooke & Clapham 2018; Cooke & Zerbini 2018; Cooke 2020]). The peptide markers do not provide the necessary differentiation between these closely related taxa. In light of the current geographical distribution of these species, with the bowhead whale generally being the northernmost one and the only whale endemic to Arctic and Subarctic waters (Burns et al. 1993), it is highly probable that the collected vertebra originates from a shallow-water-stranded bowhead whale. The size of the vertebra indicates a full-grown individual, which reaches lengths of 15-20 m.

The vertebra was sampled for radiocarbon dating, which was conducted at the Radiocarbon Dating Laboratory at Lund University, Sweden. Bone material was extracted through drilling in the vertebra's centrum, the densest part of the vertebra. This sample was subject to treatment with 1% NaOH, followed by collagen extraction (7.0 mg used for combustion), using a slightly modified method based on Longin (1971). This involved demineralization by hydrochloric acid (HCl) in a vacuum. After combustion, measurement was made with accelerator mass spectrometry (2.9 mg C). The obtained radiocarbon date (LuS 18 317) is 9760 ± 45 ^{14}C yr BP. This age has been recalculated with the software package Oxcal 4.4.4., using the Marine20 calibration curve (Heaton et al. 2020). Applying a marine reservoir offset (ΔDR_R) for cetaceans in the Svalbard region at -158 ± 41 ^{14}C years, as suggested by Pieńkowski et al. (2022), gave a date of 10 762 ± 137 cal yr BP.

Discussion and summary

Büdel included the cross-valley beach terrace in Iladalen in his so-called "Riegelserie" and named the ridge in Iladalen the "Murnau-riegel" (Büdel 1962, 1968). The "Riegelserie" encompassed a series of often prominent morphological elements forming transverse-to-valley ridges, situated at or somewhat inside the valley mouths. These were especially common in valleys on the island of Edgeøya (Fig. 1a), south of Barentsøya. Glaser (1968) described additional "riegels" on Edgeøya and reinvestigated some of those described by Büdel, often providing a more in-depth description of internal sediments. In total, 10 "riegels" were identified and discussed (see review by Möller et al. 1995). Some of these ridges were later investigated by Nagy (1984). While Büdel (1968) interpreted the ridges as having formed on top of (glacio)marine sediments by deposition from long-shore currents during isostatic rebound following deglaciation, Glaser (1968) and Nagy (1984) were of the opinion that they all formed as subaqueous ice-contact deltas, built up towards the marine limit by meltwater-transported sediment from outlet glaciers from a residual ice cap on Edgeøya after the main break-down of the Svalbard-Barents Sea Ice Sheet (see review by Möller et al. 1995). As the configuration of the "Murnau-riegel" in Iladalen is concave towards the east (Fig. 1c), it does not fit with an ice tongue retreating westwards in that valley. Nagy (1984) therefore excluded this ridge from the "Riegelserie".

An in-depth investigation into the sediment stratigraphy in the outer part of Visdalen on north-western

Edgeøya and the sedimentological architecture of its prominent valley-blocking "riegel" (Möller et al. 1995) completely ruled out that this morphological feature originated as an ice-contact delta. Büdel's (1968) long-shore sediment transport and deposition explanation was in principle confirmed: the "riegel" was built from sediment entrained by long-shore currents and wave action along the steep coastline with alluvial fans as sediment feeders. Such sediments were deposited across valley mouths as prograding spit-platforms, with a thick basal cross-bedded unit (≥23 m in Visdalen) overlain by topset beds deposited in the foreshore swash-backwash zone, eventually draped by beachface sediment forming low-relief beach ridges at gradual isostatic uplift.

The "Murnau-riegel" in Iladalen does not have the same proportions as that in Visdalen; it is much shallower, with no cross-bedded unit on top of the more fine-grained nearshore sediments (Unit A), thus lacking the spit-platform sediment architecture. It seemingly was deposited on a cross-valley bedrock ridge over which more flat-bedded upper shoreface sediment (Unit B) formed a subaqueous cross-valley spit, eventually draped by low-relief beachface ridges during shore regression over the eastward-sloping terrace. The maximum sea level after deglaciation is indicated from the proximal slope of the beach terrace which is 88 m a.s.l. (Fig. 1d). This falls well within the marine limits presented by Bondevik et al. (1995) for the eastern Svalbard islands: 87 m a.s.l. at Humla on the north-eastern part of Edgeøya (about 29 km towards the east–south-east) and 89 m a.s.l. at Kapp Ziehen, on the north-eastern tip of Barentsøya (ca. 30 km northward). The marine limit is suggested to have formed about 11 000 years ago, in connection with the breakup of the Svalbard-Barents Sea ice dome over Barentsøya-Edgeøya (Bondevik et al. 1995). This scenario has been more recently confirmed in the deglaciation chronology compilations by Hormes et al. (2013), Hughes et al. (2016) and Farnworth et al. (2020).

I therefore conclude that the cross-valley beach terrace in Iladalen, in the south-eastern corner of Barentsøya, was built by long-shore sediment transport and deposition, with its maximum height at ca. 88 m a.s.l., marking the marine limit at deglaciation. The terrace was built on top of deeper-water marine sediments, unfortunately barren of marine molluscs that could have revealed an age close to the more exact deglaciation age of this specific area. However, the vertebra—most probably from a bowhead whale (*Balaena mysticetus*)—embedded in the upper part of the littoral sediments at a height of about 80 m a.s.l., is not much below the marine limit. At 10 762 ± 137 cal yr BP, the whale carcass seemingly stranded in the emerging beach zone of the time-transgressively built cross-valley marine terrace, only a few hundred years after the generally accepted deglaciation age of the coastal parts of Barentsøya, about 11 000 years ago. Applying an early-stage relative sea-level regression rate of about 1 m per 32 years, as suggested from the relative sea-level curve at Humla, on the north-eastern tip of Edgeøya (Bondevik et al. 1995), yields a date of about 10 700 years ago for a relative sea level at 80 m a.s.l., a close match to the age of the whale vertebra.

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Disclosure statement

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