Data set on sedimentology, palaeoecology and chronology of Middle to Late Pleistocene deposits on the Taimyr Peninsula, Arctic Russia

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This Data in Brief paper contains data (including images) from Quaternary sedimentary successions investigated along the Bol’shaya Balakhnya River and the Luktakh—Upper Taimyr—Logata river system on southern Taimyr Peninsula, NW Siberia (Russia). Marine foraminifera and mollusc fauna composition, extracted from sediment samples, is presented. The chronology (time of deposition) of the sediment successions is reconstructed from three dating methods; (i) radiocarbon dating of organic detritus (from lacustrine/fluvial sediment) and molluscs (marine sediment) as finite ages (usually <42 000 years) or as non-finite ages (>42 000–48 000 years) on samples/sediments beyond the radiocarbon
ESR dating
TCN dating
dating limit; (ii) Electron Spin Resonance (ESR) dating on marine molluscs (up to ages >400 000 years); (iii) Optically Stimulated Luminescence (OSL) dating, usually effective up to 100—150 0000 years. Terrestrial Cosmogenic Nuclide (TCN) exposure dating has been applied to boulders resting on top of moraine ridges (Ice Marginal Zones). See (Möller et al., 2019) (doi.org/10.1016/j.earscirev.2019.04.004) for interpretation and discussion of all data.

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1. Data

The data presented here and in Möller et al. [1] come from studies of sediment exposures along the Bol’shaya Balaknya and the Luktakh — Upper Taimyr — Logata river systems on the southern part of the Taimyr Peninsula, NW Siberia (Fig. 1), and from a complex of sites situated on the southern shore of

Specifications table

| Subject area | Geology |
|--------------|---------|
| More specific subject area | Quaternary palaeo-environmental reconstruction |
| Type of data | Photo documentation of sediment successions. Marine and terrestrial fauna and flora lists from the sediments. Lists of Optically Stimulated Luminescence (OSL), Electron Spin Resonance (ESR), AMS radiocarbon (14C) and Terrestrial Cosmogenic Nuclide (TCN) exposure ages. Tables and figures. |
| How data was acquired | The logging and photographing of excavated sedimentary successions (see logs in [1]), as well as sampling for palaeontological analyses and dating (all sampling points shown in sediment logs in [1]), took place during boat cruises along the Bol’shaya Balaknya River and the Luktakh — Upper Taimyr — Logata river systems on the Taimyr Peninsula, NW Siberia, in 2010 and 2012. Field sampling procedures are described in text, as well as laboratory procedures. |
| Data format | Raw and analysed |
| Experimental factors | Sediment successions in river-cut bluffs and solifluction scars were cleaned in vertical sections close to the permafrost table and logged to their lithofacies (Table 1), and sampled for palaeontological analysis (Tables 2—4) and dating (14C, ESR, OSL; Tables 5—7). Erratic boulders on Ice Marginal Zones were sampled for TCN dating (Tables 8—10). |
| Experimental features | Sediment succession logging provide basis for palaeoenvironmental interpretation for discerned sediment units at the specific site and retrieved chronological data (14C, ESR, OSL, TCN ages) form a base for temporal environmental reconstructions on a regional scale. |
| Data source location | Taimyr Peninsula, northwest Siberia, Russia, c. between coordinates N71°5–74°15–106°0 (see Fig. 1) |
| Data accessibility | Data is within this article |
| Related research article | Möller, P., Benediktsson, I.O., Anjar, J., Bennike, O., Bernhardsson, M., Funder, S., Håkansson, L., Lemdahl, G., Licciardi, J.M., Murray, A.S., Seidenkrantz, M-S., 2019. Glacial history and palaeo-environmental change of southern Taimyr Peninsula, Arctic Russia, during the Middle and Late Pleistocene. Earth-Science Reviews 193 (2019), doi.org/10.1016/j.earscirev.2019.04.004. |

Value of the data

- The comprehensive set of photographs of sediments and their structures provides a reference for interpretation of depositional settings/environments across the Arctic.
- The multi-disciplinary approach, combining a large chronometric database from radiocarbon, OSL, ESR, and terrestrial cosmogenic nuclide dating with “classical” palaeontological analyses of flora and fauna sets an example for deciphering the complex succession of glaciations and ice free periods.
- Presented data can be used to constrain palaeo-glaciological modelling of the Kara Sea Ice Sheet as part of the Eurasian Ice Sheet for described temporal phases.
- The study adds new evidence to ongoing studies of the decisive roles both of this ocean and of the Arctic from a global change perspective.

1. Data

The data presented here and in Möller et al. [1] come from studies of sediment exposures along the Bol’shaya Balaknya and the Luktakh — Upper Taimyr — Logata river systems on the southern part of the Taimyr Peninsula, NW Siberia (Fig. 1), and from a complex of sites situated on the southern shore of
the Khatanga River close to the small settlement of Novorybnoye (site 8, Fig. 1). Figs. 2–11 illustrate the
general morphology and typical examples of sediments found at our sites. Tables 2–4 contain results of
analysis of foraminifera, mollusc faunas and plant and animal remains. Tables 5–7 contain chrono-
logical data (radiocarbon ages, Electron Spin Resonance (ESR) ages, Optically Stimulated Luminescence
(OSL) ages) on logged sedimentary units, and Tables 8–10 contain data on terrestrial cosmogenic
nuclide (TNC) 36Cl exposure ages on erratic boulders sampled from the top of mapped Ice Marginal
Zones (IMZs) (see Fig. 12).

2. Experimental design, materials and methods

2.1. Sedimentology and stratigraphy

We focused on laterally extensive river bluff sections for sedimentological and lithostratigraphical
descriptions, and targeted geochronological sampling. The sections were dug out in a stair-case
manner (see Fig. 5B in [1]) in which sediment composition and structures were logged mostly at
1:10 scale (all site logs are in [1]). A number of images are presented below as examples of sediment
composition and structures, and references to these are given in the site descriptions in [1]. Lithofacies
codes in photographs are according to Table 1.

2.2. Foraminiferal analyses

Selected sites with marine or possibly marine strata were sampled for foraminiferal analyses. A total
of 129 samples from eight sections (sections BBR 6, 8, 12, 15, 16, 17, Nov 1 and LuR 6; Fig. 1) were
collected. The samples were processed at the Dept. of Geoscience, Aarhus University, Denmark, using
40–160 g of dry sediment (most commonly 90–140 g). The samples were wet-sieved using tap-water
and sieve sizes with mesh diameters of 63, 100 and 1000 μm, cf. [8], and dried in an oven at 40 °C. The
foraminifera in the 100–1000 μm fraction were subsequently concentrated using the heavy liquid C2Cl4
density of 1.6 g/cm3, collected and taxonomically identified. Unfortunately, most samples proved
barren; only very few foraminiferal specimens were found in only two of the sections and only benthic
foraminifera were present (Table 2).

2.3. Marine mollusc faunas

Molluscs were collected during stratigraphic work, both for dating purposes (14C, ESR) and, when
encountered in larger numbers, for determination of the marine mollusc fauna for the relevant
stratigraphic units (Table 3). The analyses were carried out at the Geological Museum, University of
Copenhagen, Denmark. The biostratigraphy of Siberian raised marine sediments based on mollusc
faunas has traditionally played an important role in the construction of a Pleistocene stratigraphy and
reconstruction of palaeoenvironments, based on the species’ present distribution, e.g. [9]. The species
are classified according to their present distribution into Subarctic (SA), Arctic (A), and non-indicative
(N/A). This is based on oceanographical parameters, notably the inflow of Atlantic water into the Arctic,
a decisive factor in the distribution of near-shore marine ecosystems, and absence/duration of sea ice
[10]. Subarctic species occur in the zone where Atlantic and Arctic water masses mix and seasonal sea
ice occurs, such as today in the southern and eastern Barents Sea and western part of the Kara Sea,
while Arctic species thrive in Arctic water masses with long lasting sea ice cover. A third biogeo-
graphical group, the Boreal species, is restricted to permanently ice free coasts. None of these species
have been observed in the present material, although they occur in interglacial sediments in the
Yenissei River basin to the south [9]. At present the eastern Kara Sea is dominated by Arctic water
masses, but with a high inflow of fresh river water in the southern part [11].

2.4. Terrestrial and limnic macrofossil analyses

Organic debris in fluvial ripple-laminated successions was analysed from one site (LoR 3, Fig. 1), five
samples in total, for their macrofossil content (Table 4). The samples were wet-sieved (mesh ≥0.1 mm)
Fig. 1. (A) Location map of the Taimyr Peninsula and the Severnaya Zemlya islands. The St. Anna, Voronin and Vilkitsky troughs at the Kara Sea shelf break are marked by blue arrows. (B) Ice-marginal complexes (zones; IMZ) on the Taimyr Peninsula, named according to Kind and Leonov [3], but drawn from Landsat image interpretation by Møller et al. [4]: U = Urdakh, Sa = Sampsela, K = Severokokorsky, J = Jangoda, S = Syntabul, M = Mokoritto, UT = Upper Taimyra and B = Baikuronymora ice marginal zones (IMZ). NTZ
and the residue left on the sieves was analysed using a Leica Wild dissecting microscope (analysed at Geological Survey of Denmark and Greenland (GEUS), Denmark (macrofossils)). The plant names are according to http://www.theplantlist.org/. Leaves, seeds and fruits were well preserved and come from local sources. The plant residue includes numerous remains of mosses; a few tentative identifications are included, but most moss remains were not identified. The remains of mosses usually preserve well and often dominate Quaternary macro-floras from the Arctic, reflecting that mosses are important constituents of Arctic plant communities. Some animal remains, especially Coleoptera fragments, were also identified to genera or species level (analysed at the Dept. of Biology and Environmental Science, Linnaeus University, Sweden (insects)).

2.5. Geochronology

Four dating methods were employed: Accelerator Mass Spectrometer radiocarbon dating (AMS 14C; molluscs, terrestrial organic material), Electron Spin Resonance (ESR; molluscs), Optically Stimulated

Fig. 2. Sediments at site BBR 13 (Fig. 1; sediment log is Fig. 7 in [1]). (A) Overview over the lower part of the section (fluvial sediment unit A). A slumped diamict (unit B) is visible in the upper part. Note large ~1 m boulder (arrow). (B) At 13–14 m; large-scale trough cross-laminated sand beds (Stc) interbedded with ripple-laminated bedsets (Sr(A)). (C) At ~17 m; small-scale trough cross-lamination in ripple bedsets (Sr(A)). Note organic debris in ripple sets. (D) At ~33.8 m; contact between glaciomarine unit C clay and shallow marine unit D sand. Note pebbles and cobbles in contact. (E) At ~35.4 m; unit D planar parallel-laminated sand. Note two sets of load casts, S(def), associated with thin silt beds interbedded with the sand.

= North Taimyr ice marginal zone according to Alexanderson et al. [5]. Lines marked P south and west of the Urdakh IMZ are piedmont glacier moraines, deposited by ice from the Putorana Plateau. Yellow circles, numbered 1–15, mark the position of sites/site areas described stratigraphically in [1] and below in this paper. Small circles color-coded in green, red, purple, yellow and white (chronostratigraphic division) mark positions of stratigraphic sites described in [2]. The base map is from the International Bathymetric Chart of the Arctic Ocean (IBCAO) [6].
Luminescence (OSL; sediment) and in situ Terrestrial Cosmogenic Nuclide surface exposure dating (TCN; boulders).

Radiocarbon dating. – A total of 66 AMS $^{14}$C ages were determined at the AMS Radiocarbon Dating Laboratory, Department of Geology at Lund University, Sweden (Table 5). Pre-treatment of mollusc shells included leaching to ~70% of their original mass. Finite ages from terrestrial material (wood, organic detritus, plant macrofossils, bone) are given as conventional radiocarbon years ($^{14}$C age BP) with $1\sigma$ age deviation, as well as calibrated calendar years (cal yr BP or cal ka BP), calculated with the software package Oxcal 4.3.2[12] and with use of IntCal 13 (mean age $\pm 1\sigma$).

ESR dating. – A total of 39 marine mollusc samples were dated by Electron Spin Resonance (ESR) at the Research Laboratory for Quaternary Geochronology at Tallinn Technical University, Estonia (Anatoly Molodkov) (Table 6). Unexposed shells were retrieved from within cleaned sections, followed by sampling of sediments enclosing the sampled shell for later measurements of background dose rates. The method is based on direct measurements of the amount of radiation-induced paramagnetic centres, trapped in the fossil shell substance and created by the natural radiation resulting from radioactivity in the shell itself and from the enclosing sediment. Standard analytical procedures were used according to Molodkov [13] and Molodkov et al. [14] and ESR age were calculated from the measured total radiation dose that the shell received during its burial versus dose rate [15]. In some sediment sections where sediment logs indicate the presence of molluscs it was unfortunately not possible to retrieve molluscs for ESR dating, either because they were too low in concentration, very friable and/or partly dissolved in situ. Although their presence was confirmed by weathered-out and hardened shells lying on exposed sediment surfaces, such shells are unsuitable for ESR dating because of prolonged daylight exposure and the difficulty of unambiguous identification of samples of the relevant burial sediment.

OSL dating. – A total of 76 sediment samples were dated by Optically Stimulated Luminescence (OSL) (Table 7). Sediment samples were taken by means of hammering 20 cm long PVC tubes into cleaned pit walls of suitable sediment (see Fig. 5C in [1]). Samples marked with an OSL laboratory code R-xxxxxx (Table 7) were processed at Aarhus University’s Nordic Laboratory for Luminescence (NLL) Dating located at the Risø Campus, Roskilde, Denmark, while samples marked S-xxxxxx were handled at SCIDR Luminescence Laboratory, Sheffield University, UK. After conventional grain-size
Fig. 4. Site Bol’shaya Balaknya 16. (A) The 35 m high river-cut cliff at BBR 16 (Fig. 1; sediment log is Fig. 9 in [1]). Undeformed unit A fluvial sediments are indicated, over which is ~15 m of glaciotectonically deformed fluvial and marine sediment. (B) Bar cross-laminated sand (unit A), deposited in a shallow marine setting. (C) Climbing type-B ripple lamination, Sr(B), with silt draping, on top of which is sand with planar parallel-lamination and massive, normally graded sand (unit A), deposited in a shallow marine setting. The arrow indicates an interbedded ripple form set. (D–E) Stacked successions of interbedded ripple-laminated sand, Sr(A), often with draping silt, and massive, normally graded sand beds (unit A), deposited in a shallow marine setting. (F) Undeformed ripple-laminated sand (unit A), which above a decollement surface (red arrows) are strongly deformed with a stress transfer from SE. (G) Marine clay (unit B). (H) At ~38–39 m; unit C diamict with a prominent sand wedge (unit D), that is aeolian sediment infill into a polygonal frost wedge. (I) Large-scale tectonics into unit A sediment (~31 m).
and density separation and subsequent chemical purification, the single aliquot regenerative (SAR) dose protocol was applied to multi-grain (180–250 μm) quartz aliquots (8 mm diameter, typically >18 per sample) to estimate the equivalent dose, $D_e$ [16,17]), using blue (470 ± 30 nm) light stimulation, 260 °C preheating for 10 s, and a cut heat of 220 °C. Photon detection was through a U-340 glass filter, and the signal used for $D_e$ determination was based on the first 0.8 s of OSL, less a
background based on the signal detected between 1.6 and 2.4 s of stimulation. To test the applicability of this chosen protocol to the measurement of the dose recoded by the quartz OSL signal, we applied a dose recovery test ([18]) to at least 3 aliquots from each sample dated at the NLL, after initial bleaching with blue light for 100s, followed by a 10 ks pause and a further 100s bleach. The average measured/given dose ratio is $0.999 \pm 0.011$ ($n = 168$) demonstrating that our protocol is able to accurately measure a dose given to a sample prior to any laboratory heating. The equivalent doses ($D_e$), measured for each sample are given in Table 7.

Because feldspar infra-red stimulated luminescence (IRSL) signals are more difficult to reset by daylight than the OSL signals from quartz [19,20], the apparent quartz and feldspar deposition ages of a particular sediment give information on the probability that the most light sensitive signal (quartz OSL) was fully reset prior to deposition. Accordingly, multi-grain (180–250 μm) feldspar aliquots (3 mm diameter, at least 3 aliquots per sample) extracted from the samples processed by NLL were measured using a post IR-IR SAR protocol, with a preheat temperature of 250 °C for 1 minute, and stimulation with IR (870 nm) for 100 s while the aliquot was held at 50 °C (IR$_{50}$), followed by a further 100 s with the sample held at 225 °C (pIRIR$_{225}$) [21] ([22]. Detection was through BG-39 and 7–59 filters. Signals used for dose estimation were based on the first 4 s of stimulation, less a background based on the signal between 95 and 100 s of stimulation. Multi-grain quartz and feldspar aliquots were employed because this study aims to identify well-bleached samples; the average dose is then the most

![Fig. 6.](image)

(B) Lower part of unit A with interbedded laminated silt and fine sand, cross laminated sand with organic debris layers and overlain by a thick bed of planar parallel-laminated sand (−37.6–40 m). (C) Interbedded laminated silt and thin sand beds, some of them as ripple form sets (starved ripples) (−45–46 m). (D) Contact (−48.7 m) between massive sand (unit A1) and laminated clay (unit A2). (E) Silty peat with intraformational ground-ice wedges (ice complex), unit B.

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appropriate dose estimate [23], and for a given number of measurements, this is most precisely measured using large aliquots.

The samples were analysed for natural radionuclide concentrations in the laboratory, using high-resolution gamma spectrometry [24,25]. These concentrations were converted into dose rates using conversion factors listed by Olley [26]; a cosmic ray contribution was calculated according to [27], assuming the modern burial depth has applied throughout the lifetime of the site. Both field and laboratory saturated water contents were measured. The resulting total dose rates to quartz are summarised in Table 7; the dose rates to feldspar can be derived by adding 0.81 Gy/ka to these values (based on an assumed concentration of 12 %K in feldspar extracts [28].
Fig. 8. (A) Solifluction ravines at site LuR 6 (Fig. 1; sediment log is Fig. 17 in [1]). Sediment thickness above river is ~30 m. (B) LuR 6a, unit A: planar laminated sand, glaciotectonically imbricated and thrust from northeast. (C) LuR 6a, unit B1 glaciotectonite: deformed silt with folded inclusion bodies (boudinage). (D) LuR 6a, unit B2: massive silty clayey diamict (traction till). (E) LuR 6a, unit C2: faintly laminated glacio-marine silt. (F) Mammoth remains eroded at Luktakh river side (site LuR 7) out of soliflucted ‘ice complex’ sediment. (G) Unit A sand at LuR 9a (Fig. 1; sediment log is Fig. 17 in [1]). Vertically standing sand displays at its top an overturned fold with vergence towards SSW (logs in Fig. 17 in [1]). (H) Unit B marine sand and cobble gravel beds at LuR 9b (Fig. 17 in [1]). Note the high abundance of mollusc shells visible at the base of the section.
The quartz ages resulting from the measurements described above are summarised in Table 7, together with the ratios of the feldspar IR50 and pIRIR225 ages to quartz OSL ages (for the NLL-measured samples). The quartz ages are then characterised as ‘probably well bleached’, ‘well bleached’ or unknown based on these age ratios, following Möller and Murray [29].

**Terrestrial Cosmogenic Nuclide (TCN) (36Cl) exposure dating.**—Erratic boulders on top of the major ice-marginal zone ridges were scouted by means of Mi8 helicopter transport, with flights over the ridges at 150 km/hr at 100 m height. We flew for a total of 2 days and covered ~1500 km in total distance, but large boulders suitable for 36Cl exposure dating proved difficult to find. Unfortunately, the Urdakh IMZ (‘U’ on Fig. 1) is covered with a sparse larch forest, and this prevented landing at potentially suitable boulders. Sampling was, however, possible at 11 sites along the Sampsesa, the Syntabule Severokokorsky and the Upper Taimyra – Baikuronyora ice marginal zones (Fig. 1), and with double sampling at a few sites, 16 boulders were sampled in total.

Samples were collected from the top surface of the largest available boulders in the vicinity, using an angle grinder and sawing the boulder in a cross-hatched pattern (see Fig 5D and E in [1]), enabling an exact estimate of the sample thickness. All sampled boulders were basalt and rested on flat surfaces on the crest of the IMZs. Sample coordinates and altitudes were obtained in the field using a handheld GPS. Topographic shielding was negligible for all sampled boulders. The dry bulk density was measured before crushing and sieving to the 250-125 µm fraction at Lund University, and averaged 3.0 g/cm³ (Table 8). From each sample, c. 10 g was retained for whole rock elemental analyses at SGS Minerals Services, Canada, where major and trace elements were measured using X-ray fluorescence (XRF) and inductively coupled plasma – optical emission spectrometry (ICP-OES), respectively (Tables 9 and 10).
Fig. 10. (A) North bank of the Logata River at site LoR 5 (Fig. 1; sediment log is Fig. 15B in Fig. 17 in [1]). Four sediment units (A–D) were identified from shallow test pits in the ~15 m high slope above the river. (B) Boulder and cobble armour of the river beach below the high-water mark at site LoR 5; the clasts result from erosion into the unit B diamict. (C) Close-up of the glacio-tectonically laminated diamict (unit B) at site LoR 6 (Fig. 1; sediment log is Fig. 18 in Fig. 17 in [1]). Note lenticular sand intraclast (boudin) and the more angular, finely intra-laminated clay intraclasts (marked by small white arrows). (D) Sand intraclast (boudin) with internal primary lamination conforming to its outer shape; unit B diamict at site LoR 6. (E) Close-up of one of the clay intraclasts with preserved intra-lamination (2–5 mm) found in the unit B diamict at site LoR 6.
Fig. 11. Site Logata River 3 (Fig. 1; sediment logs are in Fig. 19 in [1]). (A) The 2 km long river cliff with sediments documented at four sites LoR 3a-d. (B) Topmost unit D (LoR 3d) which is ‘ice-complex’ silt, rich in organic debris and with syngenetic ice wedges. An arrow indicates the skull of step bison (C) together with a high number of other bison skeleton parts, suggesting that a mostly intact animal body is present in the sediments. (C) Partly melted-out step bison (Bison priscus) skull; age is c. 43 cal ka BP. (D) Megafauna remains (mammoth tusks and scapulas), sampled on the river beach below outcropping ice-complex sediment at site LoR 3. (E) LoR 3a, ~32–33 m (unit D); syndepositionally block-slumped ripple laminated sand, with post-slump erosion (CoGlg), followed by alternating Spp and Sr(A) beds. (F) LoR 3, ~27.4–28.8 m (unit D); interbedded planar cross-bedded, planar parallel-laminated and ripple laminated sand. Note the high content of organic debris in some beds, seen up-scaled in panel H. (G) LoR 3a, ~33–34.4 m (unit D); planar parallel-laminated sand interbedded with ripple trough cross-laminated sand. (H) Up-scaled upper part of (F) with Sr(B) sand with a high organic debris content in ripple troughs and foresets. (I) LoR 3b, ~24.5–25 m (unit C); marine, rhythmically laminated clay.
Fig. 11. (continued).
Fig. 12. The Novorybnoye site (Fig. 1, sediment logs are in Fig. 20 in Fig. 17 in [1]). (A) Overview of the river cliff at Novorybnoye (looking east). The boundary between the Cretaceous sand (unit A) and overlying Quaternary sediment succession (unit B) is marked by hatched line, as well as position of logged sub-sections (Nov 1a-e) and main sections (Nov 2 and Nov 3). (B) Glaciomarine unit B (Nov 1b, ~13.5 m); massive, mollusc-bearing clayey silt with ice-rafted drop stones. (C) Unit C (Nov 1c, 14−15 m); shear laminated sand with intraclasts (boudins) from the unit B sediments; a glaciotectonite. (D) Unit E and F at site Nov 2; marine clayey silt overlain by shallow marine sand, in turn overlain by glaciomarine clayey silt with ice-rafted drop stones.
Six samples (UT_B-1, UT_B-2, NK-2, NK-8, SA-1, SA-4) were chemically prepared at PRIME Lab, Purdue University, USA, for AMS measurement following standard protocols at this facility. Chemical preparation of the remaining six samples (UT_B-4, NK-1, NK-5, NK-7, SA-2, SA-3) was performed in the Cosmogenic Isotope Clean Lab at the University of New Hampshire, USA, following methods developed
Foraminiferal counts provided as raw count data in the actual sample. Only samples from the parts of the sections, where foraminifera are present, are included. Author names of taxa are also given. Of seven sections along the Bol’shaya Balaknya River, sampled for foraminiferal analyses (sections BBR 6, 8, 12, 13, 15, 16, 17), and the Novorybnoye 1 section (Fig. 1), all but two were found barren. Section LuR 6 along the Luktakh River (Fig. 1) was only analysed for foraminifera in its lowermost unit A, but not in marine sediments further up (unit C) in the sediment succession. Section logs are found in Figs. 7, 8, 9, 12, 13, 14 and 17 in Möller et al. [1].

### Table 2

| Site                                | BBR 6 (Fig. 13) | BBR 15 (Fig. 8) | LuR 6 (Fig. 17) |
|-------------------------------------|-----------------|-----------------|-----------------|
| **Sample height (m a.s.l.)**        | 38.5 39.0 39.5 40.0 40.5 41.0 41.5 42.0 42.5 43.0 43.5 21.0 21.5 24.3 | A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 D D A | 1 |
| **Sediment unit**                   | A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 A1 D D A | 1 | 3 |
| **Sample size (gram dry sediment)** | 114 105 118 134 115 125 137 127 141 122 123 128 146 c. 1200 | 2 | 2 |

### Benthic foraminiferal taxa

- **Astrononion gallowayi** Loeblich & Tappan, 1953
- **Buccella frigida** (Cushman, 1922)
- **Cassidulina reniforme** Nørvang, 1945
- **Cibicides lobatulus** (Walker & Jacob, 1798)
- **Cibicides scaldisiensis** Ten Dam & Reinhold, 1941
- **Elphidium albiumbilicatum** (Weiss, 1954)
- **Elphidium asklundi** Brotzen, 1943
- **Elphidium bartetti** Cushman, 1933
- **Elphidium clavatum** Cushman, 1930
- **Elphidium hallandense** Brotzen 1943
- **Elphidium usutlutunum** Todd, 1957
- **Ephidiella hannai** (Cushman & Grant, 1927)
- **Eliohedra vitrea** (Parker, 1953)
- **Glabratella** sp.
- **Haynesina orbiculare** (Brady, 1881)
- **Islandiella inflata** (Gudina, 1966)
- **Stainforthia loeblichii** (Feyling-Hanssen, 1954)
- **Polymerophrinae**
- **Indeterminate**
- **Planktonic foraminiferal taxa**
  - **Neogloboquadrina dutertrei**
  - **Neogloboquadrina pachyderma (sinistral)**
  - **Other**
  - **Ostracod valves**

The foraminiferal species were identified and counted using a microscope. The counts were made in the actual sample (Table 2).

by Stone et al. [30] and modified by Licciardi et al. [31]. Milled samples were ultrasonically cleaned in deionized water, pre-treated with 2% HNO₃, and spiked with an enriched ³⁵Cl tracer supplied by PRIME Lab, then dissolved in HF–HNO₃ solution. Upon complete digestion, insoluble fluoride compounds were removed by centrifuging and Cl was precipitated as AgCl with the addition of AgNO₃. The precipitate was further purified by re-dissolution in NH₄OH and the addition of Ba(NO₃)₂ to precipitate sulphate as BaSO₄. AgCl was then re-precipitated by addition of 2M HNO₃ and AgNO₃, washed repeatedly in deionized water, and dried in an oven.

All ³⁵Cl/³⁷Cl and ³⁶Cl/Cl ratios were measured at the PRIME Lab facility. Appropriate corrections for a procedural blank (CLBLK-20) were made prior to age calculations and accounted for 0.1–1.6% adjustments to the ³⁶Cl concentrations in the unknowns. Ages were calculated with the online CRONUScalc ³⁶Cl exposure age calculator using the LSDn scaling scheme [32–34]. Sensitivity analyses were conducted using the CRONUScalc calculator [33,34] to evaluate the potential impact of a rock surface erosion rate of 1 mm/kyr on the apparent exposure ages (Table 8).
Table 3
Mollusc faunas from sites BBR 6, 8, 13, 14, 15, 17, LuR 1–3, LuR 5, 6 and LoR 2. Section logs for these sites are found in Figs. 7, 8, 11, 13, 14, 16, 17 and 18 in Möller et al. [1].

| Species: Bio-geography class | BBR 6 | BBR 8 | BBR 8:10 | BBR 13:10 | BBR 14:10 | BBR 15A:10 | BBR 15A:4 | BBR 17:8 | BBR 17:8:1:1 | BBR 22:2 | LuR 23:5:3 | LuR 5:5:1 | LuR 6a:2:2 | LuR 6a:3 | LuR 6a:4 | LuR 6b:3:3 | LuR 6b:4 | Logata |
|-----------------------------|-------|-------|----------|-----------|-----------|------------|----------|----------|----------------|--------|-------------|-----------|-------------|--------|-----------|--------|----------|--------|---------|
| Gastropods                  |       |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| Solariella obscura          | N/A   |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| (Couthouy, 1838)            |       |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| Tachyrhynchus erosus        | N/A   |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| (Couthouy, 1838)            |       |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| Euspira pallida             | N/A   |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| (Broderip & Sowerby, 1829)  |       |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| Amauropsis islandica        | N/A   |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| (Gmelin, 1791)              |       |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| Boreotrophon clathratus     | N/A   |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| (Linné, 1767)               |       |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| Buccinum undatum            | SA    |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| (Linné, 1758)               |       |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| Oenopota sp.                | N/A   |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| Buccinum sp.                | A     |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| Neptunea despecta           | A     |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| (Linné, 1758)               |       |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| Admete viridula             | N/A   |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| (Fabricius, 1780)           |       |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| Retusa obtusa               | ?     |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |
| (Montagu, 1803)             |       |       |          |           |           |            |          |          |                |       |             |           |              |        |          |        |         |        |

(continued on next page)
### Table 3 (continued)

| Species: Bivalves | Bio-geography class | BBR 6:0; 8:5; 8:8; 13:31 14:0; 15A:0; 15A:2; 15A:4; | BBR 17; 8 1:1; 2:2; 20.1 ± 0.1 | BBR 12; 51 52 m 58 | LuR 3:3; 5:3; | LuR 6a:2; 6a:3; 6a:4; | LuR 6b:3; 6b:4; | Logata LuR 1:1; 53 | LuR 2:2; 54 m | LuR 3:3; 59 ± 0.5 m | LuR 4:2; 48–49 46–47 44 m | LuR 6a:2; 6a:3; 6a:4; 31 30 ± 0.5 m |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cylichna alba* (Brown, 1827) | | | | | | | | | | | | |
| *Eunucula tenuis* (Montagu, 1808) | N/A | | | | | | | | | | | |
| *Nuculana pernula* Müller, 1779 | N/A | | | | | | | | | | | |
| *Portlandia arctica* (Gray, 1824) | A | + | | | | | | | | | | |
| *Mytilus edulis* (Linné, 1758) | SA | | | | | | | | | | | |
| *Musculus sp.* | | | | | | | | | | | | |
| *Similpecten greenlandicum* (Sowerby, 1842) | A | | | | | | | | | | | |
| *Chlamys islandica* (Müller, 1776) | SA | | | | | | | | | | | |
| *Astarte borealis* (Schumacher, 1817) | A | | | | | | | | | | | |
| *Astarte crenata* (Gray, 1824) | A | | | | | | | | | | | |
| *Astarte elliptica* (Brown, 1827) | N/A | | | | | | | | | | | |
| *Astarte montagui* (Dillwyn, 1817) | N/A | | | | | | | | | | | |
| *Ciliatocardium ciliatum* (Fabricius, 1780) | N/A | | | | | | | | | | | |
| Taxon                          | Biogeography | No. of valves/fragments: | Note                  |
|-------------------------------|--------------|--------------------------|-----------------------|
| Serripes groenlandicus        | N/A          | ...                     |                       |
| Macoma balthica               | SA           | ...                     |                       |
| Macoma calcarea               | A            | ...                     |                       |
| Mya truncata                  | N/A          | ...                     |                       |
| Hiattella arctica             | N/A          | ...                     |                       |
| Cyrtodaria angusta            | EXT          | ...                     |                       |
| Barnacles                     |              |                         |                       |
| Balanus balanus               | N/A          |                         |                       |
| Balanus crenatus              | A            |                         |                       |
| Balanus hameri                | SA           |                         |                       |
| Semibalanus balanoides        | SA           |                         |                       |
| Balanoidea                    |              |                         |                       |
| Polychaetes                   |              |                         |                       |
| Polydora ciliata              | SA           |                         |                       |
| Spirorbis spirorbis           | SA           |                         |                       |
| Bryozoans                     |              |                         |                       |
| Algae                         |              |                         |                       |
| Lithothamnion sp              | N/A          |                         |                       |

No. of valves/fragments: ...: >20; ●●: 10–19; ●: 4–9; ●: 1–3; ? dubious identification.
Biogeography classes; SA: subarctic, not present in the area today (grey shaded), A: present in several biogeographic zones, but only dominating in the Arctic. EXT: Extinct. N/A: widespread in several zones, present in the area today.
Table 4
Plants and animals remains from fluvial sediments at site Logata River 3 (LoR 3b and 3d), sediment unit D. Section logs for sites LoR 3 are found in Fig. 19 in Möller et al. [1].

| Site/sample: | 3b:3 | 3b:2 | 3d:3 | 3d:2 | 3d:1 |
|-------------|------|------|------|------|------|
| m a.s.l.    | 28.0 | 31.0 | 31.6 | 33.7 | 34.1 |

**PLANTS**

|                |      |      |      |      |      |
|----------------|------|------|------|------|------|
| **Terrestrial** |      |      |      |      |      |
| Dryas octopetala s.l. (L.) | 45 | 2 | 1 | 7 | 1 |
| Salix herbacea (L.) | 7 | - | - | 1 | 1 |
| Salix cf. phylicifolia (L.) | - | - | - | 1 | - |
| Salix sp. | - | 2 | - | - | - |
| Ranunculus sp. | 4 | - | 1 | 2 | - |
| Polygonum viviparum (L.) | - | 2 | - | - | 1 |
| Rumex acetosa (L.) | - | - | - | - | 1 |
| Cerastium sp. | 1 | - | - | - | - |
| Stellaria sp. | - | - | - | 1 | 3 |
| Minuartia sp. | - | - | - | 1 | 3 |
| Myosotis alpestris (F W. Schmidt) | - | - | - | - | 1 |
| Draba sp. | - | - | - | - | 2 |
| Papaver sect. Scapiflora | 1 | - | - | 3 | 2 |
| Potentilla sp. | 1 | - | - | - | 1 |
| Armeria sp. | 1 | - | - | - | - |
| Poaceae indet. | 2 | - | - | 4 | - |
| Distichium sp. | 1 | - | - | 7 | 1 |
| Ditrichium sp. | r | - | - | 2 | - |
| Polytrichium s. l. sp. | 1 | - | - | - | - |
| Cenococcum geophilum (Fries) | - | 6 | 12 | 14 | - |

|                |      |      |      |      |      |
|----------------|------|------|------|------|------|
| **Wetland**    |      |      |      |      |      |
| Carex sp. | 3 | - | - | - | 5 |
| Juncus sp. | - | - | 1 | - | 3 |
| Drepanocladus s.l. sp. | c | a | - | a | c |
| Calliergon sp. | 1 | - | - | - | - |
| Scorpidium sp. | r | - | c | - | - |
| Tomentypnum nitens (Hedw.) (Loeske) | c | c | - | - | - |

**ANIMALS (except Coleoptera)**

|                |      |      |      |      |      |
|----------------|------|------|------|------|------|
| Daphnia pulex s.l. (Leydig) | - | - | 1 | 3 | - |
| Chydrorus cf. sphaericus (O. F. Müller) | - | - | 2 | - | - |
| Lepidurus cf. arcticus (Pallas) | 1 | - | - | - | - |
| Chironomidae indet. | - | - | 3 | 2 | 1 |
| Rodentia indet. | 8 | 1 | - | - | - |

**Coleoptera**

|                |      |      |      |      |      |
|----------------|------|------|------|------|------|
| Carabus loschnikovi (Fischer v. W) | - | 1 | - | - | - |
| Nothophilius aquaticus (L.) | - | 1 | - | - | - |
| Pterostichus brevicornis (Kirby) | - | 2 | - | - | 1 |
| Pterostichus ventricosus Esch. | - | 1 | - | - | - |
| Amara alpina (Payk.) | - | - | - | - | 1 |
| Amara Cortonotus sp. | - | 1 | - | - | - |
| Amara sp. | - | 1 | - | - | - |
| Harpalus sp | - | 1 | - | - | - |
| Agabus confinis (Gyllh.) | - | 1 | - | - | - |
| Apion spp. | - | 2 | - | 1 | - |
| Sitona lineellus (Gyllh.) | - | 1 | - | - | - |
| Sitona lepidus (Gyllh.) | - | 1 | - | - | - |
| Dorytomus/Anthonomus sp. | - | - | - | 1 | - |

r: rare, c: common, a: abundant.
Table 5

Radiocarbon ages (n = 69) from stratigraphic sections at sites along the Bol’shaya Balaknya River and the Luktakh – Upper Taimyra – Logata river system (Fig. 1). More exact site locations are seen on Fig. 6 and Fig. 15 in Møller et al. [1], and stratigraphic positions of samples are indicated in sediment logs in Møller et al. [1], Figs. 8, 10 11, 14, 16, 18 and 19. Sites with sediment units marked with (*) are not described in [1], but will be used in a forthcoming paper. Finite radiocarbon ages on terrestrial material have been recalculated to calibrated 14C years by software package Oxcal v4.3.2 [12] with use of IntCal 13. LuS datings were conducted at the Radiocarbon Dating Laboratory, Department of Geology, Lund University, Sweden, while the \( ^{14} \)C–labelled datings (BBR 8) were conducted at the Geomorphology and paleogeography of Polar regions and World Ocean Laboratory, St. Petersburg State University, Russia.

| Sites         | Coordinates Site area | Sample no. | Sediment unit | Dated material          | Sample m a.s.l. | Lab no. | Conv. 14C age \((\pm 1\sigma)\) | Cal. yr BP \((\pm 1\sigma)\) | Context         |
|---------------|------------------------|------------|---------------|-------------------------|-----------------|---------|-----------------------------|-----------------------------|----------------|
| Bol’shaya     | N72° 32,384' 1         | BBR 1:2    | *             | organic detritus        | 49.5            | LuS_9344| 8675 ± 60                   | 9638 ± 88                   | fluvial/ice complex |
| Balaknya River| E100° 25,876'          | BBR 1:3    | *             | organic detritus        | 48.8            | LuS_9345| 8175 ± 60                   | 9130 ± 89                   | fluvial/ice complex |
| Bol’shaya     | N73° 38,030' 2         | BBR 2:1    | unit B2       | organic detritus        | 54.9            | LuS_9346| >46,000                     | –                           | off-shore marine    |
| Balaknya River| E100° 24, 914'         | BBR 2:2    | unit B1       | mollusc fragments       | 53.9            | LuS_9347| >48,000                     | –                           | off-shore marine    |
| Bol’shaya     | N73° 36,775'           | BBR 4:3    | unit A1       | mollusc fragments       | 56.5            | LuS_9348| >47,000                     | –                           | marine delta        |
| Balaknya River| 4 E100° 20,693'        | (Astarte borealis) |                |                         |                 |         |                              |                             |                  |
| Bol’shaya     | N73° 31,572' 3         | BBR 6:1    | unit A1       | organic detritus        | 35.6            | LuS_9349| >48,000                     | –                           | glaciomarine        |
| Balaknya River| 6 E101° 0,610'         | BBR 6:3    | unit A1       | *                        | 39.4            | LuS_9350| >47,000                     | –                           | glaciomarine        |
| Bol’shaya     | N73° 31,008' 3         | BBR 6:5    | unit A1       | wood (twig)             | 43.3            | LuS_9351| >48,000                     | –                           | glaciomarine        |
| Balaknya River| 7 E101° 0,352'         | BBR 6:7    | unit A1       | organic detritus        | 45.4            | LuS_9352| >48,000                     | –                           | glaciomarine        |
| Bol’shaya     | N73° 31,008' 3         | BBR 6:10   | unit A2       | Macoma calcaria         | 49.5            | LuS_12509| >48,000                     | –                           | glaciomarine        |
| Balaknya River| 7 E101° 0,352'         | BBR 6:11   | unit A2       | wood (twig)             | 48.9            | LuS_9354| >48,000                     | –                           | glaciomarine        |
| Bol’shaya     | N73° 31,008' 3         | BBR 6:17   | unit B        | mammoth tusk            | 56.5            | LuS_12759| >48,000                     | –                           | fluvial             |
| Balaknya River| 7 E101° 0,352'         | BBR 7:1    | *             | wood, macrofossil       | 37.95           | LuS_10135| 7115 ± 55                   | 7943 ± 54                   | fluvial/ice complex |
| Balaknya River| 7 E101° 0,352'         | BBR 7:2    | *             | macrofossil             | 38.05           | LuS_10136| 7190 ± 55                   | 8005 ± 62                   | fluvial/ice complex |
| Bol’shaya     | N73° 31,008' 3         | BBR 7:3    | *             | wood (twig)             | 38.45           | LuS_10137| 7335 ± 55                   | 8135 ± 76                   | fluvial/ice complex |
| Balaknya River| 7 E101° 0,352'         | BBR 7:4    | *             | macrofossil             | 38.55           | LuS_10138| 5110 ± 55                   | 5831 ± 68                   | fluvial/ice complex |
| Bol’shaya     | N73° 31,008' 3         | BBR 7:5    | *             | wood                    | 39.05           | LuS_10140| 6690 ± 50                   | 7560 ± 44                   | fluvial/ice complex |
| Balaknya River| 7 E101° 0,352'         | BBR 7:6    | *             | macrofossil             | 39.95           | LuS_10141| 6720 ± 55                   | 7587 ± 48                   | fluvial/ice complex |
| Bol’shaya     | N73° 31,008' 3         | BBR 7:7    | *             | macrofossil             | 40.50           | LuS_10142| 6500 ± 50                   | 7414 ± 55                   | fluvial/ice complex |
| Balaknya River| 1 E101° 0,352'         | BBR 7:8    | *             | mammoth (tusk)          | 35.0            | LuS_13604| >42,000                     | –                           | redeposited beach finds close to section |
| Bol’shaya     | N73° 39,224' 4         | BBR 8:3    | unit A1       | wood (twig)             | 40.5            | LuS_9355| >48,000                     | –                           | marine             |
| Bol’shaya     | N73° 39,224' 4         | BBR 8:5    | unit A1       | Macoma balthica         | 43.1            | LuS_9356| >47,000                     | –                           | marine             |

(continued on next page)
| Sites                  | Coordinates | Site area | Sample no. | Sediment unit | Dated material | Sample m a.s.l. | Lab no. | Conv. 14C age (± 1σ) | Cal. yr BP (± 1σ) | Context          |
|-----------------------|-------------|-----------|------------|---------------|----------------|----------------|---------|----------------------|-------------------|------------------|
| Balaknya River 8      | E102° 10,223' |           | BBR 8:11   | unit A        | *Macoma bathica* | 47.0           | LuS_9357 | >48,000              | –                 | marine           |
|                       |             |           | BBR 8:12   | unit B        | organic detritus | 54.2           | .YY-6679 | 7680 ± 100          | 8483 ± 103        | ice complex      |
|                       |             |           | BBR 8:13   | unit B        | organic detritus | 59.3           | .YY-6662 | 750 ± 50            | 691 ± 41          | ice complex      |
| Bol'shaya             | N73° 38,887' | 4         | BBR 9:1    | *wood         | *              | 51.6           | LuS_10143 | 15,310 ± 85         | 18,578 ± 100      | ice complex      |
| Balaknya River 9       | E102° 6,467' |           | BBR 9:2    | *wood         | *              | 52.0           | LuS_10144 | 14,640 ± 75         | 18,021 ± 107      | ice complex      |
|                       |             |           | BBR 9:3    | *wood         | *              | 52.5           | LuS_10145 | 13,620 ± 75         | 16,428 ± 136      | ice complex      |
|                       |             |           | BBR 9:4    | *wood         | *              | 52.8           | LuS_10146 | 4655 ± 50           | 5411 ± 74         | ice complex      |
|                       |             |           | BBR 9:5    | *wood         | *              | 53.1           | LuS_10147 | 13,940 ± 75         | 16,897 ± 148      | ice complex      |
|                       |             |           | BBR 9:6    | *wood         | *              | 53.5           | LuS_10148 | 13,810 ± 70         | 16,708 ± 145      | ice complex      |
|                       |             |           | BBR 9:7    | *wood         | *              | 53.6           | LuS_10149 | 13,960 ± 75         | 16,928 ± 149      | ice complex      |
|                       |             |           | BBR 9:8    | *wood         | *              | 53.9           | LuS_10150 | 13,160 ± 7          | 15,807 ± 128      | ice complex      |
|                       |             |           | BBR 9:9    | *wood         | *              | 54.2           | LuS_10151 | 12,460 ± 70         | 14,614 ± 217      | ice complex      |
|                       |             |           | BBR 9:10   | *wood         | *              | 54.5           | LuS_10152 | 12,310 ± 65         | 14,322 ± 174      | ice complex      |
|                       |             |           | BBR 9:11   | *wood         | *              | 54.8           | LuS_10153 | 9330 ± 65           | 11,397 ± 124      | ice complex      |
|                       |             |           | BBR 9:12   | *wood         | *              | 55.4           | LuS_10154 | 6250 ± 55           | 7464 ± 53         | ice complex      |
|                       |             |           | BBR 9:13   | *wood         | *              | 55.4           | LuS_10155 | 14370 ± 70          | 17514 ± 118       | ice complex      |
|                       |             |           | BBR 9:14   | *wood         | *              | 55.4           | LuS_10156 | 13301 ± 75          | 15996 ± 121       | ice complex      |
|                       |             |           | BBR 9:15   | *wood         | *              | 55.4           | LuS_10157 | 13590 ± 75          | 16378 ± 133       | ice complex      |
|                       |             |           | BBR 10:1   | *wood         | *              | 52.7           | LuS_10158 | 13280 ± 70          | 15968 ± 125       | ice complex      |
|                       |             |           | BBR 10:2   | *wood         | *              | 53.5           | LuS_10159 | 12845 ± 65          | 15321 ± 123       | ice complex      |
|                       |             |           | BBR 10:3   | *wood         | *              | 53.8           | LuS_10160 | 12845 ± 65          | 15321 ± 123       | ice complex      |
|                       |             |           | BBR 10:4   | *wood         | *              | 54.1           | LuS_10161 | 12845 ± 65          | 15321 ± 123       | ice complex      |
|                       |             |           | BBR 10:5   | *wood         | *              | 54.7           | LuS_10162 | 12845 ± 65          | 15321 ± 123       | ice complex      |
|                       |             |           | BBR 11:1   | unit C        | peat           | 23.8           | LuS_9358 | >48,000              | –                 | fluvial point bar |
|                       |             |           | BBR 11:2   | unit C        | organic detritus | 31.6           | LuS_9359 | 15,370 ± 80         | 18,644 ± 89       | fluvial point bar |
|                       |             |           | BBR 12:3   | unit A        | *Hiatella arctica* | 26.5           | LuS_9360 | >48,000              | –                 | marine           |
|                       |             |           | BBR 12:4   | unit B        | *Astarte montagui* | 22.0           | LuS_9363 | >48,000              | –                 | glaciomarine      |
|                       |             |           | BBR 15:1   | unit D        | *Hiatella arctica* | 20.1           | LuS_9364 | >48,000              | –                 | glaciomarine      |
|                       |             |           | BBR 15:2   | unit D        | *Astarte montagui* | 22.0           | LuS_9363 | >48,000              | –                 | glaciomarine      |
| Luktakh River 2        | N72° 9,585'  | 9         | LuR 2:1    | unit A        | *Hiatella arctica* | 54.2           | LuS_10377 | >48000               | –                 | glaciomarine      |
|                       | E92° 0,711' |           | LuR 10:1   | *plant        | macrofossils    | 23.2           | LuS_10963 | 180 ± 40             | 175 ± 89          | aeolian           |
|                       | E93° 2,429' |           | LuR 10:8   | *plant        | macrofossils    | 18.9           | LuS_10964 | 3615 ± 45            | 3927 ± 67         | fluvial point bar |
| Logata River 1         | N73° 0,677'  | 14        | LoR 1:1    | unit A        | *Hiatella arctica* | 20.2           | LuS_10377 | >48,000              | –                 | glaciomarine      |
|                       | E96° 0,937' |           | LoR 2:3    | unit A        | *Hiatella arctica* | 16.8           | LuS_10378 | >48,000              | –                 | glaciomarine      |
| Location     | Latitude | Longitude | Interval | Unit | Time Range       | Depth or Age | Notes               |
|--------------|----------|-----------|----------|------|------------------|--------------|---------------------|
| Logata River 3a | N73° 21,015' | E96° 20,492' | 15       | LoR 3a:1 | unit C | shell, undiff | 24.4 | 47,000 ± 1275 | ice complex, resedimented |
|              |          |           |          | LoR 3a:2 | unit E | Hiattella arctica | 21.8 | 45,000 ± 2000 | glaciomarine |
|              | E96° 58,462' |            |          | LoR 3a:3 | unit E | plant | 34.7 | 43,100 ± 2000 | ice complex |
|              |          |           |          | LoR 3a:4 | unit E | plant | 34.7 | 42,000 ± 2000 | ice complex |
|              | Logata River 3b | N73° 20,723' | 15       | LoR 3b:1 | unit D | twig, 2–5 mm | 31.9 | 48,000 ± 2000 | fluvial point bar |
|              | E97° 00,462' |            |          | LoR 3b:2 | unit D | twig, 2–4 mm | 31.1 | 48,000 ± 2000 | fluvial point bar |
|              | Logata River 3c | N73° 20,278' | 15       | LoR 3c:1 | unit D | Salix, Dryas | 34.1 | 48,200–3000/ +4000 | fluvial point bar |
|              | E97° 01,290' |            |          | LoR 3c:2 | unit C | Hiattella arctica | 25.3 | 46,500 ± 1500 | marine |
|              | Logata River 3d | N73° 19,956' | 15       | LoR 3d:1 | unit D | Salix, Dryas | 34.1 | 48,200–3000/ +4000 | fluvial point bar |
|              | E97° 00,866' |            |          | LoR 3d:2 | unit D | Salix leaves | 33.6 | 48,000 ± 2000 | fluvial point bar |
|              |          |           |          | LoR 3d:3 | unit D | plant det. | 31.6 | 48,000 ± 2000 | fluvial point bar |
|              | Logata River 6 | N73° 19,139' | 16       | LoR 6:1 | unit B | shell undiff | 54.8 | 48,000 ± 2000 | shell in till |
|              | E97° 32,471' |            |          | LoR 6:2 | unit B | shell undiff | 54.8 | 48,000 ± 2000 | shell in till |
|              | Logata River 6 | N73° 19,139' | 16       | LoR 6:2 | unit B | shell undiff | 54.8 | 48,000 ± 2000 | shell in till |
| Site                  | Coordinates | Site area | Sample no. | Sediment unit | Lab no. | Dated mollusc | m a.s.l. | Uin (ppm) | U (ppm) | Th (ppm) | K (%) | ΔΣ (mGy/ a) | Ps (Gy) | ESR-age (ka) | Context          |
|----------------------|-------------|-----------|------------|---------------|---------|---------------|---------|-----------|---------|----------|-------|-------------|---------|--------------|----------------|----------------|
| Bol'shaya            | N73°31.572' | 3         | BBR 6:13   | unit A2       | 435–061 | Macoma baltica | 51.0    | 0.18      | 1.04    | 5.56     | 1.75  | 153.2        | 153.2   | 89.2 ± 7.6   | glaciomarine     |
| Balaknya River 6     | E101°0.610' |           |            |               |         |               |         |           |         |          |       |             |         |              |                 |
| Bol'shaya            | N73°39.224' | 4         | BBR 8:5    | unit A1       | 436–061 | Macoma baltica | 43.1    | 0.10      | 1.08    | 5.14     | 1.75  | 1947        | 165.1   | 85.1 ± 7.3   | marine           |
| Balaknya River 8     | E102°10.223' |        |            |               |         |               |         |           |         |          |       |             |         |              |                 |
| Bol'shaya            | N73°27.236' | 6         | BBR 13:4   | unit C        | 439–061 | Astarte borealis | 34.2    | 0.31      | 0.93    | 5.76     | 1.95  | 1724        | 153.2   | 89.2 ± 7.6   | shallow marine   |
| Balaknya River 13    | E104°8.580' | 6         | BBR 14:3   | unit A2       | 440–061 | Macoma baltica | 28.7    | 0.18      | 0.49    | 1.72     | 1.91  | 1924        | 155.0   | 80.8 ± 8.6   | shallow marine   |
| Bol'shaya            | N73°29.873' | 6         | BBR 14:5   | unit A2       | 441–061 | Macoma baltica | 29.4    | 0.10      | 0.13    | 1.57     | 1.89  | 1824        | 148.4   | 81.5 ± 7.0   | shallow marine   |
| Balaknya River 14    | E104°13.599' |       |            |               |         |               |         |           |         |          |       |             |         |              |                 |
| Bol'shaya            | N73°25.832' | 6         | BBR 15:1   | unit D        | 442–061B | Macoma calcaria | 22.0    | 0.42      | 0.65    | 3.23     | 1.68  | 1677        | 386.8   | 228.0 ± 14.0 | glaciomarine     |
| Balaknya River 15    | E104°21.352' |      |            |               |         | Astarte montagui |       |           |         |          |       |             |         |              |                 |
| Bol'shaya            | N73°30.977' | 6         | BBR 15:3   | unit D        | 443–061 | Hiatella arctica | 20.2    | 0.65      | 0.89    | 4.18     | 1.65  | 1614        | 371.4   | 232.0 ± 19.1 | glaciomarine     |
| Balaknya River 16A   | E104°33.069' |      |            |               |         | Hiatella arctica | 35.2    | 0.24      | 0.79    | 6.39     | 1.87  | 1795        | 304.0   | 170.6 ± 14.5 | glaciomarine     |
| Bol'shaya            | N73°37.084' | 7         | BBR 17A:1  | unit A        | 444–061 | Portlandia arctica | 8.4     | 0.22      | 0.72    | 5.76     | 1.74  | 1919        | 199.2   | 104.5 ± 8.9  | marine           |
| Balaknya River 17A   | E105°38.178' |       |            |               |         | Portlandia arctica | 7.9     | 0.14      | 0.74    | 6.45     | 1.76  | 1771        | 178.3   | 101.0 ± 8.7  | marine           |
| Bol'shaya            | N73°37.314' | 7         | BBR 17A:3  | unit A        | 446–061 | Portlandia arctica | 12.4    | 0.16      | 0.64    | 5.53     | 1.63  | 1802        | 180.2   | 100.5 ± 12.0 | marine           |
| Balaknya River 17B   | E105°39.092' |       |            |               |         | Portlandia arctica | 4.0     | 0.19      | 0.20    | 0.90     | 1.79  | 1761        | 214.3   | 223.2 ± 14.5 | redeposited marine |
| Novorybnoye I        | N72°49.742' | 8         | BBR 17B:2a | unit B        | 447–061 | Portlandia arctica | 4.0     | 0.14      | 0.20    | 0.90     | 1.79  | 1753        | 214.3   | 232.0 ± 14.6 | redeposited marine |
|                      |             |           | BBR 17B:2b | unit B        | 447–061-OS(2) | Portlandia arctica | 4.0     | 0.14      | 0.20    | 0.90     | 1.79  | 1753        | 214.3   | 232.0 ± 14.6 | marine           |
|                      |             |           | Nov 1c:4   | unit B        | 461–033 | undif fragm | 12.9    | 1.70      | 1.35    | 6.06     | 1.93  | 741.0        | 1.93    | 311.7 ± 24.8 | glaciomarine     |
|                      |             |           | Nov 1c:7   | unit D        | 481–103 | undif fragm | 19.0    | 0.95      | 1.38    | 6.93     | 1.88  | 2101        | 421.0   | 202.0 ± 19.1 | glaciomarine     |
| Location             | Date     | Unit | Code | Age (kya) | Carbon     | Oxygen     | Depth     | Environment       | Notes                           |
|----------------------|----------|------|------|-----------|------------|------------|-----------|-------------------|---------------------------------|
| Novorybnoye 2        | Nov 2:1  | E2   | E105 | 12.7      | 67.56      | 117.84     | 113.7     | 131.0 ± 11.0      | shoreface marine                |
| Luktakh River 1-3    | LuR 2:1  | A    | E92' 59.58' | 110.3 | 80.5 ± 6.8 | 103.6 ± 6.8 | 106.0 | 86.8 ± 7.5 | glaciomarine            |
|                      | LuR 3:1  | A    | E92' 47.07' | 113.7 | 71.7 ± 5.9 | 135.7 ± 6.2 | 126.3 | 80.8 ± 6.5 | glaciomarine            |
|                      | LuR 3:2  | A    | E92' 32.1 | 131.5 | 118.5 ± 10.1 | 171.5 | 118.5 ± 10.1 | shallow marine        |
| Luktakh River 4      | LuR 4:1  | A    | E92' 59.08' | 193.5 | 78.0 ± 8.0 | 180.2 | 85.5 ± 7.3 | glaciomarine            |
|                      | LuR 4:2  | A    | E92' 51.16' | 193.5 | 78.0 ± 8.0 | 179.5 | 85.5 ± 7.3 | glaciomarine            |
|                      | LuR 6a:5 | C2   | E92' 28.95' | 193.5 | 78.0 ± 8.0 | 179.5 | 85.5 ± 7.3 | glaciomarine            |
| Luktakh River 8b     | LuR 6b:1 | C2   | E92' 28.79' | 193.5 | 78.0 ± 8.0 | 179.5 | 85.5 ± 7.3 | glaciomarine            |
|                      | LuR 6b:2 | C2   | E92' 31.3 | 193.5 | 78.0 ± 8.0 | 179.5 | 85.5 ± 7.3 | glaciomarine            |
|                      | LuR 6b:5 | C2   | E92' 27.6 | 193.5 | 78.0 ± 8.0 | 179.5 | 85.5 ± 7.3 | glaciomarine            |
|                      | LuR 6b:6 | C1   | E92' 27.6 | 193.5 | 78.0 ± 8.0 | 179.5 | 85.5 ± 7.3 | glaciomarine            |
|                      | LuR 8:1  | A    | E92' 27.6 | 193.5 | 78.0 ± 8.0 | 179.5 | 85.5 ± 7.3 | glaciomarine            |
|                      | LuR 9b:1 | B    | E92' 31.3 | 193.5 | 78.0 ± 8.0 | 179.5 | 85.5 ± 7.3 | glaciomarine            |
|                      | LuR 9b:2 | B    | E92' 27.6 | 193.5 | 78.0 ± 8.0 | 179.5 | 85.5 ± 7.3 | glaciomarine            |
| Logata River 1       | LoR 1:1  | A    | E96' 20.2 | 193.5 | 78.0 ± 8.0 | 179.5 | 85.5 ± 7.3 | glaciomarine            |
|                      | LoR 2:1  | A    | E96' 20.2 | 193.5 | 78.0 ± 8.0 | 179.5 | 85.5 ± 7.3 | glaciomarine            |
|                      | LoR 2:2  | A    | E96' 20.2 | 193.5 | 78.0 ± 8.0 | 179.5 | 85.5 ± 7.3 | glaciomarine            |

All ESR dates were carried out by Dr. A. Molodkov at the Research Laboratory for Quaternary Geochronology, Institute of Geology, Tallin Technical University, Estonia.

Notes: U, Th, K are the uranium, thorium and potassium content in sediments; D is the total dose rate; P is the palaeodose.

1) Two shells of different species from the same sample were analyzed, and mean age taken.

2) The sample was dated by the ESR open system (ESR-OS) method (Molodkov, 1988).
Table 7: Optically Stimulated Luminescence (OSL) ages from stratigraphic sections at sites along the Bol’shaya Balaknya River, the Luktakh – Upper Taimyra – Logata river system and the Novorybnoye site (Fig. 1). More exact site locations are seen on Fig. 6 and Fig. 15 in [1], and stratigraphic positions of samples are indicated in sediment logs in [1], Figs. 7, 8, 9, 12, 13, 14, 16, 17, 18, 19 and 20.

| Site          | Coordinates | Site code | Sample code | Sediment unit | OSL lab. code | Quartz OSL De Gy m a.s.l. | Age ratio IR50/OSL | Age ratio pIRIR290/OSL | Quartz OSL age, ka | prob. well reset | Context          |
|---------------|-------------|-----------|-------------|---------------|---------------|---------------------------|-------------------|------------------------|-------------------|------------------|------------------|
| Bol’shaya     | N72° 32.384’ | 1         | BBR         | no log        | R-111003      | 420 35.0 ± 2              | 26.038 ± 0.04     | 1.10 ± 0.12             | 30.0 ± 2          | ✓                | fluvial/ice complex |
| Balaknya River 1 | E100° 25.876’ | 2         | BBR 1:1a    | no log        | R-121001      | 490 31.8 ± 1.1             | 31.68 ± 0.10     | 1.9 ± 0.4               | 16.5 ± 1.0        | ✓                | fluvial/ice complex |
| Bol’shaya     | N73° 38.030’ | 2         | BBR 2:1b    | no log        | R-111004      | 54.6 >250                  | 40 <0.5           | <1.2                   | >75               | ✓                | off-shore marine   |
| Balaknya River 2 | E100° 24.914’ | 2         | BBR 2:3     | unit B1       | R-111005      | 53.5 >250                  | 21 <0.8           | <1.6                   | >117              | ✓                | off-shore marine   |
| Bol’shaya     | N73° 36.775’ | 2         | BBR 4:1a    | unit A1       | R-111007      | 58.2 >250                  | 38 <0.54          | <0.98                  | >119              | ✓                | marine delta       |
| Balaknya River 4 | E100° 20.693’ | 2         | BBR 4:2     | unit A1       | R-111008      | 57.8 202 ± 8               | 17.62 ± 0.06     | 1.5 ± 0.2              | 85 ± 5            | ✓                | marine delta       |
| Bol’shaya     | N73° 31.572’ | 3         | BBR 6:2a    | unit A        | S-11077       | 37.2 >152                  | 22 n/a            | n/a                    | >49               |                  | glaciomarine       |
| Balaknya River 6 | E101° 0.610’ | 4         | BBR 6:6     | unit A        | S-11078       | 43.7 264 ± 6               | 18 n/a            | n/a                    | 83 ± 6            |                  | glaciomarine       |
| Bol’shaya     | N73° 39.224’ | 4         | BBR 8:1     | unit A1       | S-11080       | 36.0 210 ± 3               | 24 n/a            | n/a                    | 97 ± 7            |                  | marine            |
| Balaknya River 8 | E102° 10.223’ | 4         | BBR 8:2     | unit A1       | S-11081       | 39.5 156 ± 10              | 32.71 ± 0.07     | 1.40 ± 0.16             | 87 ± 6            | ✓                | marine            |

P. Møller et al. / Data in brief 25 (2019) 104267
| Location | Date | Unit | Depth (m) | Age (ka) | Error (% of Age) | Width (m) | Description |
|----------|------|------|-----------|----------|-----------------|-----------|-------------|
| Bol'shaya N73° 26,525' | 26,525 | 0 | BBR 11:2 | 24.5 | 76 ± 3 | 30 0.58 ± 0.08 1.01 ± 0.12 | 46 ± 3 | ✓ ✓ | fluvial |
| Balaknya River 11 | 26,525 | 0 | BBR 11:3 | 28.4 | 37.5 ± 1.4 | 26 0.37 ± 0.03 0.84 ± 0.07 | 19.3 ± 1.2 | ✓ ✓ | fluvial |
| Bol'shaya N73° 26,747' | 26,747 | 0 | BBR 11:4 | 30.7 | 42.1 ± 1.2 | 32 0.63 ± 0.08 1.27 ± 0.14 | 19.2 ± 1.0 | ✓ ✓ | fluvial |
| Balaknya River 12 | 26,747 | 0 | BBR 12:1 | 300 | >250 | 21 <1.20 | – | >131 | – | marine |
| Bol'shaya N73° 27,584' | 27,584 | 0 | BBR 12:2 | 150 | >250 | 36 <1.7 | – | >100 | – | marine |
| Balaknya River 13 | 9,881 | 0 | BBR 13:6 | 14.1 | >250 | 32 <0.72 | <1.7 | >157 | ✓ | fluvial |
| Bol'shaya N73° 29,873' | 29,873 | 0 | BBR 14:1 | 25.7 | >250 | 18 <1.1 | – | >124 | ✓ | fluvial |
| Balaknya River 14 | 13,599 | 0 | BBR 14:2 | 28.8 | >250 | 18 <1.2 | – | >118 | ✓ | fluvial |
| Bol'shaya N73° 25,832' | 25,832 | 0 | BBR 15:2 | 25.0 | >250 | 29 <0.42 | <0.9 | >124 | ✓ ✓ | fluvial |
| Balaknya River 15 | 21,352 | 0 | BBR 15:7 | 15.0 | >250 | 21 <0.23 | <0.6 | >131 | ✓ ✓ | fluvial |
| Bol'shaya N73° 30,964' | 30,964 | 0 | BBR 15:1 | 12.5 | >415 | 12 <0.9 | <2 | >167 | ✓ | fluvial |

(continued on next page)
| Site               | Coordinates   | Site code | Sample code | Sediment unit | OSL lab. code | m a.s.L. | Quartz OSL Age, ka | prob. well reset | Context       |
|-------------------|---------------|-----------|-------------|---------------|---------------|----------|-------------------|-----------------|---------------|
| Balaknya River 16A |               | BBR 16A:2 | unit A      | S-11073       | 18.8 >486     | 26 n/a   | n/a               | >163            | shallow marine |
|                   |               | BBR 16A:3 | unit A      | S-11074       | 20.8 >449     | 18 n/a   | n/a               | >153            | shallow marine |
|                   |               | BBR 16A:4 | unit A      | S-11075       | 38.8 127 ± 8  | 26 0.85 ± 0.20 1.21 ± 0.16 | 60 ± 5 | ✓ ✓ | aeolian          |
|                   |               | BBR 16A:5 | unit D      | R-121017      | 40.8 85.3 ± 1.2 | 26      | 32 ± 2           |                 |               |
|                   |               | BBR 16A:6 | unit D      | S-11076       |               |          |                   |                 |               |
|                    |               |           |             |               |               |          |                   |                 |               |
| Bol'shaya         | N73° 31,004'  | BBR 16C:1 | unit A      | S-110109      | 10.1 >250     | 15 <0.5 | <1.4             | >137            | shallow marine |
|                   |               | BBR 16C:2 | unit A      | S-121018      | 12.5 132 ± 10 | 21 1.30 ± 0.14 3.4 ± 0.5 | 100 ± 9         | shallow marine |
|                   |               | BBR 17B:1 | unit B      | S-11083       | 8.0 103 ± 5   | 20 n/a   | n/a               | 42 ± 4          | fluvial        |
|                   |               | BBR 17B:3 | unit B      | S-111020      | 9.0 71 ± 4    | 23 0.54 ± 0.06 1.16 ± 0.16 | 45 ± 3 | ✓ ✓ | fluvial          |
| Bol'shaya         | N73° 37,314'  | Nov 1a:3  | unit A      | S-131001      | 11.0 >250     | 15 <1.9 | –                 | >117            | fluvial        |
|                   |               | Nov 1c:5  | unit D      | S-131002      | 15.0 >250     | 18 <0.9 | <6                | >129            | fluvial        |
| Novorybnoye 1a    | N72° 49,742'  | Nov 1c:6  | unit D      | S-131003      | 15.5 >250     | 27 <1.0 | <5                | >119            | glaciomarine   |
|                   | E105° 47,142' |           |             |               |               |          |                   |                 |               |
| Novorybnoye 1c    |               | Nov 1c:6  | unit D      | S-131003      |               |          |                   |                 |               |
| Novorybnoye 1e    | N72° 49,771'  | Nov 1c:8  | unit F      | S-131004      | 26.5 26.3 ± 0.6 | 29 0.63 ± 0.05 1.17 ± 0.09 | 143 ± 0.7       | aeolian        |
|                   | E105° 47,233' | Nov 1c:9  | unit F      | S-131005      | 27.0 26.5 ± 0.8 | 33 0.66 ± 0.05 0.97 ± 0.07 | 144 ± 0.8       | aeolian        |
| Novorybnoye 2     | N72° 49,650'  | Nov 2:2   | unit E2     | S-131006      | 17.0 236 ± 16 | 18 0.56 ± 0.10 1.5 ± 0.3 | 124 ± 10        | shallow marine |
|                   | E105° 47,073' | Nov 2:3   | unit E2     | S-131007      | 16.0 >250     | 7 <0.8  | <5                | >182            | shallow marine |
| Novorybnoye 3     | N72° 49,483'  | Nov 3:1   | unit E2     | S-131008      | 22.0 229 ± 12 | 15 0.70 ± 0.07 1.89 ± 0.30 | 101 ± 7         | shallow marine |
|                   | E105° 47,002' | Nov 3:2   | unit E2     | S-131009      | 21.6 >250     | 28 <0.6 | <5                | >121            | shallow marine |
| Luktakh River 4   | N72° 59,084'  | LuR 4:3   | unit A3     | S-13002       | 57.8 240 ± 9  | 29 n/a   | n/a               | 90 ± 6          | shallow marine |
|                   | E12° 12,187'  |           |             |               |               |          |                   |                 |               |
|                   | N72° 51,1322' | 9        |             |               |               |          |                   |                 |               |
| Location     | Elevation | Unit   | Age (ka) | Width (m) | Depth (m) | Indicator (Ma) | Description                  |
|--------------|-----------|--------|----------|-----------|-----------|----------------|-----------------------------|
| Luktakh River 6b | 28,797    | 6b     |          |           |           | 33 ± 2        | fluvial                     |
| Luktakh River 8 | 51,910    | 8      | 23.4     | 87 ± 2    |           | 56 n/a        |                             |
|              | 27,623     |        | 25.9     | 82 ± 45   |           | 25 n/a        |                             |
| Luktakh River 9 | 48,826    | 9      | 39.1     | 279 ± 19  | >84       | ✓ ✓           | glaciotechnic               |
|              | 22,093     |        | 38.6     | 306 ± 11  | >99       | ✓ ✓           | glaciotechnic               |
| Luktakh River 10 | 9,387     | 10     | 39.1     | 279 ± 19  | >84       | ✓ ✓           | aeolian                     |
|              | 24,429     |        | 18.2     | 8.5 ± 1   | 19.0 ± 2  | ✓             | fluvial point bar           |
| Logata River 3b | 20,723    | 3b     | 33.0     | 83 ± 4    | 24.0 ± 5  | ✓ ✓           | fluvial point bar           |
|              | 00,462     |        | 14.5     | 9.7 ± 1   | 17.0 ± 7  | ✓             | fluvial point bar           |
| Logata River 3c | 20,278    | 3c     | 30.0     | 105 ± 3   | 22.0 ± 5  | ✓             | fluvial point bar           |
| Logata River 3d | 19,956    | 3d     | 27.7     | 99 ± 1    | 24.0 ± 7  | ✓             | fluvial point bar           |
|              | 00,866     |        | 29.1     | 61 ± 2    | 28.0 ± 9  | ✓             | fluvial                     |
| Logata River 6 | 19,139     | 6      | 33.0     | 95 ± 5    | 27.0 ± 8  | ✓             | fluvial point bar           |
|              | 32,471     |        | 29.1     | 61 ± 2    | 28.0 ± 9  | ✓             | fluvial                     |
|              | 27,623     |        | 18.2     | 8.5 ± 1   | 19.0 ± 2  | ✓             | fluvial point bar           |
|              | 00,462     |        | 14.5     | 9.7 ± 1   | 17.0 ± 7  | ✓             | fluvial point bar           |
|              | 22,093     |        | 38.6     | 306 ± 11  | >99       | ✓ ✓           | marine sed?                 |

Note: E = Eastern, W = Western, N = Northern, S = Southern.
Table 8

Properties and analytical data for boulders on the Sampsas (SA), Syntabul – Severokokorsky (NK) and Upper Taimyr – Baikuryonyora (UBT_B) Ice Marginal Zones (IMZ) analysed for cosmogenic $^{36}$Cl (TCN exposure dating). Altitudes, latitudes, and longitudes were determined with GPS. For all samples, measured bulk rock density is 3.0 g/cm$^3$, thickness is 5.0 cm, and topographic shielding is negligible. The rock dissolved indicates the amount processed for AgCl extraction chemistry. The Cl carrier is from PRIME Lab and has a $^{35}$Cl/$^{37}$Cl ratio of 273. Uncertainties on $^{35}$Cl/$^{37}$Cl and $^{36}$Cl/Cl ratios and exposure ages represent propagated 1 analytical/internal uncertainties only. Sample $^{36}$Cl concentrations are corrected for procedural blanks. Exposure age uncertainties in parentheses incorporate external uncertainties, including production rate uncertainties; comparisons of the $^{36}$Cl ages with those derived from independent chronometers (e.g., radiocarbon, OSL) must account for these external uncertainties. Ages “$w$/erosion” are calculated with a prescribed rock surface erosion rate of 1 mm/kyr. See Fig. 21 in [1] for site locations on map (*).

| Sample PRIME ID | Lat. (°N) | Lon. (°E) | Elev. (m) | Site # | Boulder size (m) | Rock diss. (mg) | $^{35}$Cl/$^{37}$Cl (±1σ) | $^{36}$Cl/Cl (e$^{-15}$, ±1σ) | $^{36}$Cl conc. (e$^4$ at/g, ±1σ) | Exposure Age (ka, ±1σ) | Age w/erosion (ka, ±1σ) |
|-----------------|-----------|-----------|----------|--------|-----------------|-----------------|----------------|------------------|----------------|----------------|---------------- |
| **Upper Taimyr – Baikuryonyora IMZ** |
| UT_B-1 | 73.96507 | 102.69740 | 134 | 1 | 0.7 x 0.7 | 31.1458 | 1.0550 | 5.951 ± 0.001 | 135.18 ± 9.45 | 17.73 ± 1.24 | 22.1 ± 1.7 (2.4) | 22.0 ± 1.6 (2.3) |
| UT_B-2 | 73.79550 | 101.17040 | 123 | 2 | 2.6 x 2.0 | 30.3340 | 1.0406 | 3.437 ± 0.005 | 57.66 ± 8.18 | 39.96 ± 5.67 | 15.6 ± 2.4 (3.5) | 15.1 ± 2.2 (3.4) |
| UT_B-3 | 73.99403 | 99.54113 | 163 | 3 | 2.3 x 1.6 | – | – | – | – | – | – | – |
| UT_B-4 | 73.99402 | 99.54150 | 236 | 4 | 2.4 x 1.5 | 20.2981 | 1.0303 | 3.295 ± 0.021 | 79.30 ± 2.99 | 174.01 ± 21.97 | 26.9 ± 4.1 (6.8) | 25.2 ± 3.6 (6.1) |
| **Syntabul – Severokokorsky IMZ** |
| NK-1 | 73.98318 | 104.87208 | 130 | 5 | 2.0 x 2.0 | 20.1047 | 1.0281 | 6.825 ± 0.026 | 364.05 ± 8.95 | 72.32 ± 1.82 | 84.1 ± 2.5 (7.8) | 83.0 ± 2.9 (8.7) |
| NK-2 | 73.96920 | 103.47693 | 137 | 6 | 1.5 x 1.3 | 21.4587 | 1.0955 | 3.666 ± 0.009 | 291.41 ± 10.69 | 146.35 ± 5.37 | 81.0 ± 3.8 (13) | 73.0 ± 3.9 (12) |
| NK-3 | 73.96918 | 103.47695 | 143 | 7 | 1.2 x 1.2 | – | – | – | – | – | – | – |
| NK-4 | 73.04255 | 101.33038 | 155 | 8 | 0.8 x 0.6 | – | – | – | – | – | – | – |
| NK-5 | 73.04275 | 101.33110 | 156 | 9 | 0.7 x 0.6 | 20.1122 | 1.0276 | 4.740 ± 0.019 | 327.81 ± 6.82 | 100.57 ± 2.27 | 79.5 ± 2.8 (9.9) | 74.8 ± 2.8 (9.9) |
| NK-6 | 73.73607 | 98.38002 | 189 | 10 | 1.7 x 1.5 | – | – | – | – | – | – | – |
| NK-7 | 72.20930 | 101.63160 | 175 | 11 | 2.7 x 2.5 | 20.0517 | 1.0284 | 6.237 ± 0.034 | 499.23 ± 10.96 | 100.54 ± 2.31 | 109 ± 3.1 (9.5) | 110 ± 3.6 (11) |
| NK-8 | 73.10332 | 73.44448 | 102.80570 | 137 | 12 | 0.7 x 0.6 | 30.4033 | 1.0197 | 3.504 ± 0.200 | 281.91 ± 11.88 | 185.85 ± 7.83 | 92.0 ± 4.6 (17) | 82.0 ± 4.3 (15) |
| **Sampsas IMZ** |
| SA-1 | 72.01557 | 97.55150 | 131 | 13 | 1.0 x 0.9 | 30.7504 | 1.0578 | 7.276 ± 0.035 | 776.30 ± 28.52 | 89.30 ± 3.28 | 131 ± 5.8 (11) | 139 ± 7.1 (14) |
| SA-2 | 72.01587 | 97.55788 | 121 | 14 | 0.8 x 0.8 | 20.1556 | 1.0283 | 3.351 ± 0.015 | 322.60 ± 7.77 | 541.72 ± 36.83 | 120 ± 11 (29) | 98.0 ± 8.4 (22) |
| SA-3 | 72.02662 | 98.45890 | 65 | 15 | 0.7 x 0.7 | 20.2505 | 1.0264 | 10.145 ± 0.104 | 310.07 ± 8.30 | 41.81 ± 1.16 | 54.5 ± 1.7 (3.8) | 55.4 ± 1.8 (4.2) |
| SA-4 | 73.10332 | 72.20757 | 98.45793 | 78 | 16 | 0.7 x 0.7 | 3.6667 | 1.0757 | 7.308 ± 0.001 | 359.88 ± 13.12 | 346.22 ± 12.62 | 249 ± 15 (51) | 215 ± 15 (49) |
| **Procedural blank** |
| CLBLK-201900696 | – | – | – | – | – | 1.0285 | 167.1 ± 22.2 | 5.86 ± 0.90 | – | – | – |

Samples are sorted beneath their respective Ice Marginal Zones (IMZ), named in bold.
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Table 9
Major element chemistry of boulder samples analysed for cosmogenic 36Cl. All major element chemistry and LOI is listed in weight percent and was performed with XRF with 0.01% detection limit. H2O and CO2 are each assumed to account for half the LOI signal.

| Sample | SiO2 | TiO2 | Al2O3 | Fe2O3 | MnO | MgO | CaO | Na2O | K2O | P2O5 | Cr2O3 | LOI  |
|--------|------|------|-------|-------|-----|-----|-----|------|-----|------|-------|------|
| UT_B-1 | 48.90| 0.74 | 14.50 | 11.50 | 0.18| 10.50| 10.90| 2.15 | 0.42| 0.08 | 0.08  | 0.12 |
| UT_B-2 | 49.00| 0.92 | 14.60 | 11.30 | 0.18| 9.06 | 11.60| 2.18 | 0.46| 0.09 | 0.06  | 0.59 |
| UT_B-4 | 53.40| 2.62 | 14.00 | 12.30 | 0.18| 3.94 | 6.95 | 3.89 | 2.25| 0.15 | 0.01  | 0.00 |
| NK-1  | 50.00| 0.80 | 15.70 | 9.87  | 0.17| 8.52 | 11.20| 2.39 | 0.60| 0.03 | 0.06  | 0.28 |
| NK-2  | 51.60| 0.81 | 14.60 | 10.20 | 0.18| 7.43 | 10.90| 2.19 | 1.01| 0.10 | 0.03  | 1.16 |
| NK-5  | 51.00| 0.94 | 14.10 | 11.10 | 0.18| 7.81 | 12.00| 2.08 | 0.75| 0.03 | 0.01  | 0.03 |
| NK-7  | 52.80| 2.73 | 14.00 | 12.80 | 0.19| 4.13 | 7.16 | 3.84 | 2.17| 0.04 | 0.02  | 0.00 |
| NK-8  | 50.90| 0.94 | 14.20 | 10.90 | 0.18| 7.68 | 10.80| 2.31 | 0.88| 0.12 | 0.07  | 0.78 |
| SA-1  | 49.50| 0.93 | 15.00 | 11.30 | 0.18| 9.03 | 11.20| 2.21 | 0.52| 0.10 | 0.07  | 0.15 |
| SA-2  | 51.80| 0.95 | 13.90 | 10.70 | 0.18| 6.98 | 11.50| 2.24 | 0.91| 0.02 | 0.01  | 0.90 |
| SA-3  | 51.80| 0.94 | 14.00 | 11.00 | 0.18| 7.22 | 11.70| 2.22 | 0.87| 0.02 | 0.01  | 0.04 |
| SA-4  | 52.20| 0.86 | 14.00 | 11.60 | 0.18| 7.83 | 10.40| 2.08 | 1.00| 0.10 | 0.04  | 0.28 |

Table 10
Trace element chemistry of boulder samples analysed for cosmogenic 36Cl, expressed in ppm. Cl is calculated using isotope dilution based on AMS data from PRIME Lab. Trace elements were analysed by ICP-OES with detection limits (ppm) as follows: 10 for B, Cr, Li; 0.1 for Sm, Th; 0.05 for Gd, U.

| Sample | Cl (±1σ) | B | Sm | Gd | U | Th | Cr | Li |
|--------|-----------|---|----|----|---|----|----|----|
| UT_B-1 | 48.9 ± 4.2| <10| 2.0| 2.53| 0.17| 0.7| 521 | <10|
| UT_B-2 | 458.7 ± 92.3| <10| 2.5| 3.07| 0.18| 0.8| 419 | <10|
| UT_B-4 | 1243.6 ± 155.6| <10| 5.4| 5.29| 1.31| 4.6| 51  | 15 |
| NK-1  | 65.4 ± 0.6 | <10| 1.7| 2.02| 0.22| 0.8| 395 | <10|
| NK-2  | 270.3 ± 11.3| <10| 3.6| 3.52| 0.69| 2.7| 188 | 15 |
| NK-5  | 129.2 ± 1.5 | <10| 2.4| 2.92| 0.59| 1.8| 63  | <10|
| NK-7  | 66.7 ± 0.8 | <10| 4.6| 4.70| 1.31| 4.2| 53  | 12 |
| NK-8  | 368.2 ± 17.4| <10| 3.5| 3.79| 0.47| 2.0| 422 | 17 |
| SA-1  | 33.6 ± 1.3 | <10| 2.6| 3.09| 0.26| 1.1| 441 | <10|
| SA-2  | 937.2 ± 62.8| <10| 2.5| 2.76| 0.69| 2.0| 46  | 11 |
| SA-3  | 28.5 ± 0.5 | <10| 2.8| 3.22| 0.65| 2.0| 47  | 11 |
| SA-4  | 284.2 ± 11.4| <10| 3.9| 4.21| 0.82| 3.1| 236 | 12 |
Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] P. Möller, I.O. Benediktsdóttir, J. Anjar, O. Bennike, M. Bernhardsson, S. Funder, L. Hákansson, G. Lemdahl, J.M. Licciardi, A.S. Murray, M.-S. Seidenkrantz, Glacial history and palaeo-environmental change of southern Taimyr Peninsula, arctic Russia, during the middle and late Pleistocene, Earth Sci. Rev. 196 (2019) (2019) xx-xx, https://doi.org/10.1016/j.earscirev.2019.04.004.

[2] P. Möller, H. Alexanderson, S. Funder, C. Hjort, The Taimyr Peninsula and the Severnaya Zemlya archipelago, Arctic Russia: a synthesis of glacial history and palaeo-environmental change during the last glacial cycle (MIS 5e-2), Quat. Sci. Rev. 107 (2015) 149–181, https://doi.org/10.1016/j.quascirev.2014.10.018.

[3] N. V Kind, B.N. Leonov (Eds.), Antropogen Taimyra (The Antropogen of the Taimyr Peninsula), Nauka, Moscow, 1982, p. 184 pp (in Russian).

[4] P. Möller, H. Hjort, H. Alexanderson, F. Sallaba, Glacialization history of the Taymyr Peninsula and the Severnaya Zemlya archipelago, Arctic Russia. Quaternary Glaciations - Extent and Chronology - a closer look, in: J. Ehlers, P.L. Gibbard, P.H. Hughes (Eds.), Developments in Quaternary Science, vol. 15, Elsevier, ebook, 2011, pp. 373–384. ISBN: 978044453537520.

[5] H. Alexanderson, C. Hjort, P. Möller, O. Antonov, M. Pavlov, The North Taymyr ice-marginal zone, Arctic Siberia - a preliminary overview and dating, Glob. Planet. Chang. 31 (2001) 427–445. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.465.3599&rep=1&type=pdf.

[6] M. Jakobsson, L. Mayer, B. Coakley, J.A. Dowdeswell, S. Forbes, B. Fridman, H. Hodnesdal, R. Noormets, R. Pedersen, M. Rebescio, H.W. Schenke, Y. Zarayskaya, D. Accetella, A. Armstrong, R.M. Anderson, P. Bienhoff, A. Camerlenghi, I. Church, M. Edwards, J.V. Gardner, J.K. Hall, B. Hell, O. Hestvik, Y. Kristoffersen, C. Marcussen, R. Mohammad, D. Mosher, S.V. Nghiem, M.T. Pedrosa, P.G. Travaglini, F. Weatherall, The international bathymetric Chart of the Arctic Ocean (IBCAO) version 3.0, Geophys. Res. Lett. 39 (2012) L12605. https://doi.org/10.1029/2012GL053520.

[7] N. Eyles, C.H. Eyles, A.D. Miall, Lithofacies types and vertical profile models; an alternative approach to the description and environmental interpretation of glacial diamict and diamicrite sequences, Sedimentology 30 (1983) 393–410.

[8] R.W. Feyling-Hanssen, Quantitative methods in micropaleontology, in: L.I. Costa (Ed.), Palynology - Micropalaeontology: Laboratories, Equipment and Methods, vol. 2, Norwegian Petroleum Directorate Research Bulletin, 1983, pp. 109–128.

[9] S.L. Troitsky, Quaternary Deposits and Relief of the Low Coastslands of the Yenisei Estuary and Adjacent Byrranga Mountains (In Russian), Nauka, Moscow, 1966, p. 207.

[10] S. Funder, I. Demidov, Y. Yelovicheva, Y. Hydrography and mollusc faunas of the baltic and the white-north sea seaway in the eemian, Palaeogeography, Palaeoclimatology, Palaeoecology 184 (2002) 275–304. http://dx.doi.org/10.1016/S0031-0120(02)00256-0.

[11] M.Y. Kulakov, V.B. Pogrebov, S.F. Timofeyev, N.V. Chernova, O.A. Kiyko, Ecosystem of the Barents and Kara seas, coastal segment, in: A.R. Robinson, K.H. Brink (Eds.), The Sea, Volume 14B: the Global Coastal Ocean, Harvard University Press, 2004, pp. 1135–1172.

[12] C. Bronk Ramsey, Methods for summarizing radiocarbon data sets, Radiocarbon 59 (2) (2017) 1809–1933. https://doi.org/10.1017/RDC.2017.108.

[13] A.N. Molodkov, ESR dating of Quaternary shells: recent advances, Quat. Sci. Rev. 7 (1988) 477–484. https://doi.org/10.1016/0277-3791(88)90049-2.

[14] A.N. Molodkov, A. Dreimanis, O. Antonov, M. Pavlov, The North Taymyr ice-marginal zone, Arctic Siberia - a preliminary overview and dating, Glob. Planet. Chang. 31 (2001) 427–445. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.465.3599&rep=1&type=pdf.

[15] A.N. Molodkov, N.S. Bolikhovskaya, Eustatic sea-level and climate changes over the last 600 ka as derived from mollusc-based ESR chronostratigraphy and pollen evidence in Northern Eurasia, Sediment. Geol. 150 (2002) 185–201. https://doi.org/10.1016/S0037-0738(01)00275-5.

[16] A.S. Murray, A.G. Wintle, Luminesence dating of quartz using an improved single-aliquot regenerative-dose protocol, Radiat. Meas. 32 (2000) 57–73. https://doi.org/10.1016/S1350-4487(99)00253-X.

[17] A.S. Murray, A.G. Wintle, The single aliquot regenerative-dose protocol: potential for improvements in reliability, Radiocarbon Measurements 37 (2003) 377–381. https://doi.org/10.1016/S1350-4487(03)00053-2.

[18] A.S. Murray, Incomplete stimulation of luminescence in young quartz sediments and its effect on the regenerated signal, Radiat. Meas. 26 (1996) 221–231.

[19] D.L. Godfrey-Smith, D.J. Huntley, W.H. Chen, Optically dating studies of quartz and feldspar sediment extracts, Quat. Sci. Rev. 7 (1988) 273–380.

[20] A.S. Murray, K.J. Thomsen, N. Masuda, J.P. Buylaert, M. Jain, Identifying well-bleached quartz using the different bleaching rates of quartz and feldspar luminescence signals, Radiat. Meas. 47 (2012) 688–695. https://doi.org/10.1016/j.radmeas.2012.05.

[21] K.J. Thomsen, A.S. Murray, M. Jain, Laboratory dating of the single-grain quartz in well-sorted sand samples: the dispersion arising from the presence of potassium feldspars and implications for single grain OSL dating, Quat. Geochronol. 27 (2015) 52–65. https://doi.org/10.1016/j.quageo.2014.12.006.
[24] A.S. Murray, R. Marten, P. Johnston, A.J. Martin, Analysis for naturally occurring radionuclides at environmental concentrations by gamma spectrometry, J. Radioanal. Nucl. Chem. 115 (1987) 263–288.

[25] A.S. Murray, L.M. Helsted, M. Autzen, M. Jain, J.P. Buylaert, Measurement of natural radioactivity: calibration and performance of a high-resolution gamma spectrometry facility, Radiat. Meas. 120 (2018) 215–220. https://doi.org/10.1016/j.radmeas.2018.04.006.

[26] J.M. Olley, A.S. Murray, R.G. Roberts, The effects of disequilibria in uranium and thorium decay chains on burial dose rates in fluvial sediments, Quat. Geochronol. 15 (1996) 751–760. https://doi.org/10.1016/S1350-4487(96)00114-X.

[27] J.R. Prescott, J.T. Hutton, Cosmic-ray contributions to dose-rates for luminescence and ESR dating - large depths and long-term variations, Radiat. Meas. 23 (1994) 497–500. https://doi.org/10.1016/1350-4487(94)90086-8.

[28] D.J. Huntley, M.R. Baril, The K content of the K-feldspars being measured in optical dating or in thermoluminescence dating, Ancient TL 15 (1997) 11–13.

[29] P. Møller, A.S. Murray, Drumlinised glaciofluvial and glaciolacustrine sediments on the Småland peneplain, South Sweden – new evidence on the growth and decay history of the Fennoscandian Ice Sheets during MIS 3, Quat. Sci. Rev. 122 (2015) 1–29. https://doi.org/10.1016/j.quascirev.2015.04.025.

[30] J.O. Stone, L.K. Fifield, G.L. Allan, R.G. Cresswell, Cosmogenic chlorine-36 from calcium spallation, Geochem. Cosmochim. Acta 60 (1996) 679–692.

[31] J.M. Licciardi, C.L. Denoncourt, R.C. Finkel, Cosmogenic 36Cl production rates from Ca spallation in Iceland, Earth Planet. Sci. Lett. 267 (2008) 365–377. https://doi.org/10.1016/j.epsl.2007.11.036.

[32] N. Lifton, T. Sato, T. J Dunai, Scaling in situ cosmogenic nuclide production rates using analytical approximations to atmospheric cosmic-ray fluxes, Earth Planet. Sci. Lett. 386 (2014) 149–160. https://doi.org/10.1016/j.epsl.2013.10.052.

[33] S.M. Marrero, F.M. Phillips, B. Borchers, N. Lifton, R. Aumer, G. Balco, Cosmogenic nuclide systematics and the CRONUScalc program, Quat. Geochronol. 31 (2016) 160–187. https://doi.org/10.1016/j.quageo.2015.09.005.

[34] S.M. Marrero, F.M. Phillips, M.W. Caffee, J.C. Gosse, CRONUS-Earth cosmogenic 36Cl calibration, Quat. Geochronol. 31 (2016) 199–219. https://doi.org/10.1016/j.quageo.2015.10.002.