ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

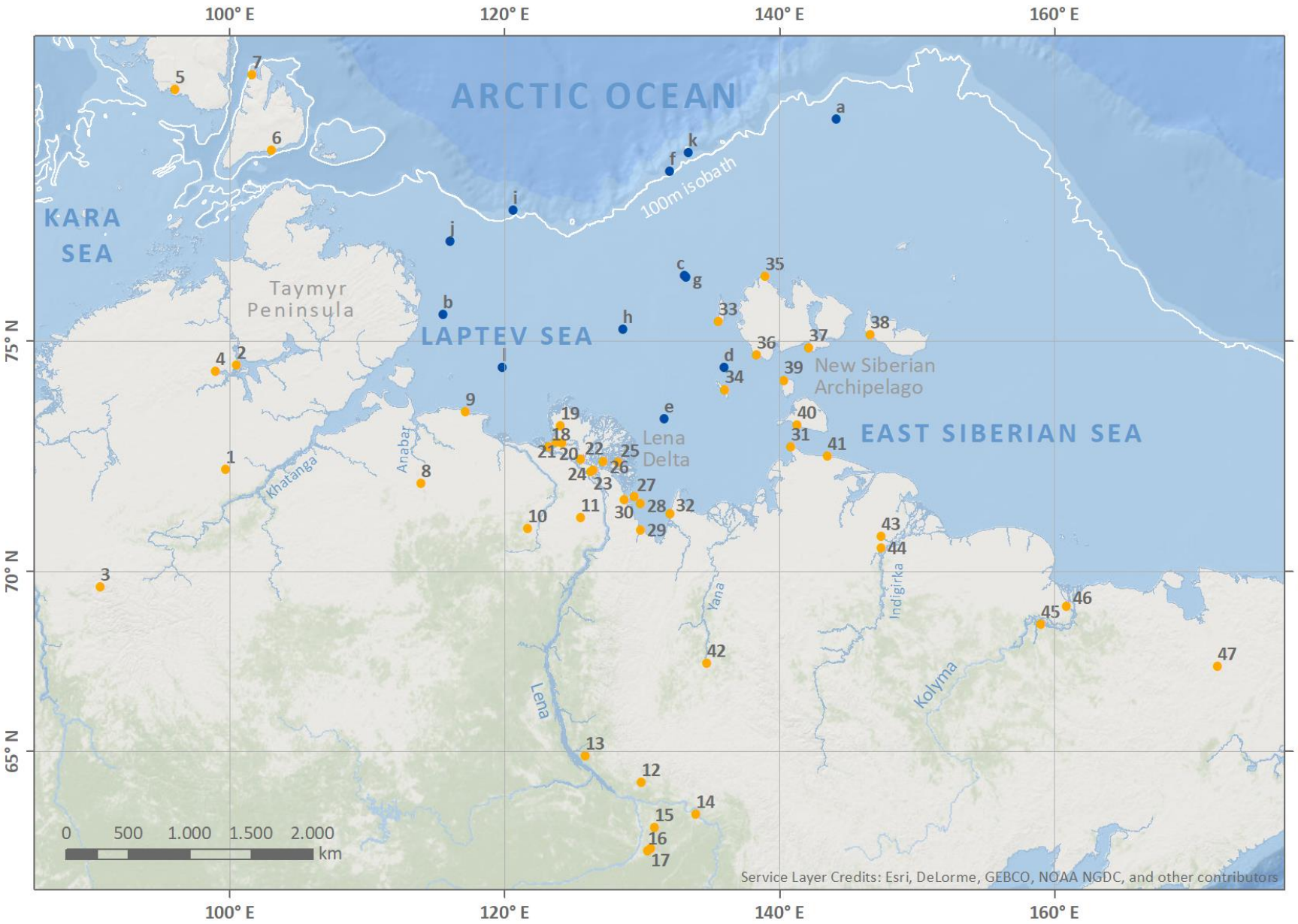
EUROPEAN CONFERENCE ON PERMAFROST
18-22 JUNE, 2023, PUIGCERDÀ

WESTERN BERINGIA AND BEYOND

THREE DECADES OF GERMAN-RUSSIAN PALEOENVIRONMENTAL RESEARCH ON SIBERIAN PERMAFROST

By Schirrmeister, L., Wetterich S., Grosse, G., Andreev, A., Dereviagyn, A., Kienast. F., Meyer, H., Opel, T., Ulrich, M., Strauss, J., Kunitzky, V., Tumskoy, V., Grigoriev, M., Kuznetsova, T., Kuzmina, S., Schwamborn, G., Siegert, C., Morgenstern, A., Bobrov, A., Rudaya, N., Pavlova, E., Nazarova, L., Frolova, L., Pestryakova, L., Palagushkina, O., Fedorov, A., Kizyakov, A., Hubberten, H.-W.

Study sites



Study sites between 1993 and 2019

- 47 terrestrial sites
- 11 sites with marine cores [1, 2, 3, 4, 5, 6]

(Map compiled by Sebastian Laboor, AWI Potsdam)

[1] *Bauch et al. (2001) GPC 31(1), 125-139, doi: 10.1016/S0921-8181(01)00116-3.*
[2] *Bauch et al. (2001) QR 55, 344-351, doi: 10.1006/qres.2000.2223.*
[3] *Müller-Lupp et al. (2000) Int J Earth Sci 89(3), 563-568, doi: 10.1007/s005310000128.*
[4] *Naidina et al. (2001)GPC 31(1), 141-153, doi: 10.1016/S0921-8181(01)00117-5.*
[5] *Rekant et al. (2015) arktos 1, 11, https://doi.org/10.1007/s41063-015-0011-y.*
[6] *Spielhagen et al. (2005) GPC 481-3), 187-2007, doi: 10.1016/j.gloplacha.2004.12.013.*

1 Labaz Lake
2 Cape Sabler, Taymyr Lake
3 Lama Lake
4 lower Ledyanaya River
5 October Revolution Island, Changeable Lake
6 Bolshevik Island, Solnechnaya Bay
7 Bolshevik Island, Prima Station
8 Anabar River flood plain
9 Cape Mamontov Klyk
10 Beenchime-Salaatinsky Crater
11 El'gene-Kyuele Lake
12 Tumara River
13 Dyanushka River
14 Mamontova Gora
15 Syrdakh Alas
16 Yukechi Alas
17 Khara Bulgunyakh Alas
18 Ebe Sise (Nagym)
19 Lake Nikolay (Arga Complex)
20 Turakh Island (Arga Complex)
21 Khardang Island
22 Dzhangylakh Island
23 Kurungnakh Island
24 Samoylov Island
25 Sobo Sise Island
26 Sardakh Island
27 Bykovsky Peninsula
28 Muostakh Island
29 Buor Khaya Bay, southern rim
30 Khorogor Valley
31 Cape Svyatoy Nos
32 Buor Khaya Peninsula
33 Bel'kovsky Island
34 Stolbovoy Island
35 Kotel'ny Island (Cap Anisii)
36 Kotel'ny Island (South)
37 Bunge Land
38 Novaya Sibir Island
39 Maly Lyakhovsky Island
40 Bol'shoy Lyakhovsky Island
41 Oyogos Yar
42 Batagay
43 Kytalyk
44 Achagy Alaykha
45 Duvanny Yar
46 Pokhodsk
47 Elgygytgyn Lake
a – l marine cores at the Laptev Sea shelf

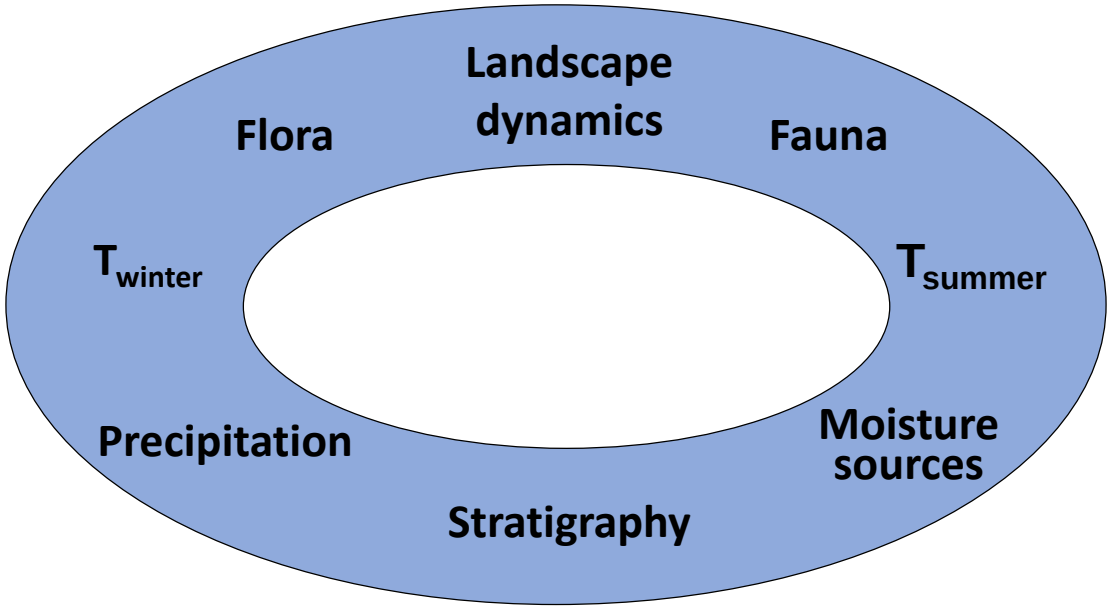
Multidisciplinary approach

Permafrost Proxies

Stable isotopes (δ^2H, $\delta^{18}O$, $\delta^{13}C$),
Ice content, cryo- and sediment structure,
Mass specific magnetic susceptibility,
Anorganic chemical composition,
Grain-size parameters,
Biogeochemistry (C, N, S), Biomarker,
Heavy mineral spectra

Fossil Bioindicators

Pollen, Plant macro-remains,
Ostracods, Beetles,
Diatoms, Testate amoebae,
Chironomids, Cladocera,
Mussel and snail shells,
Mammal bones,
Microorganisms,
Ancient DNA



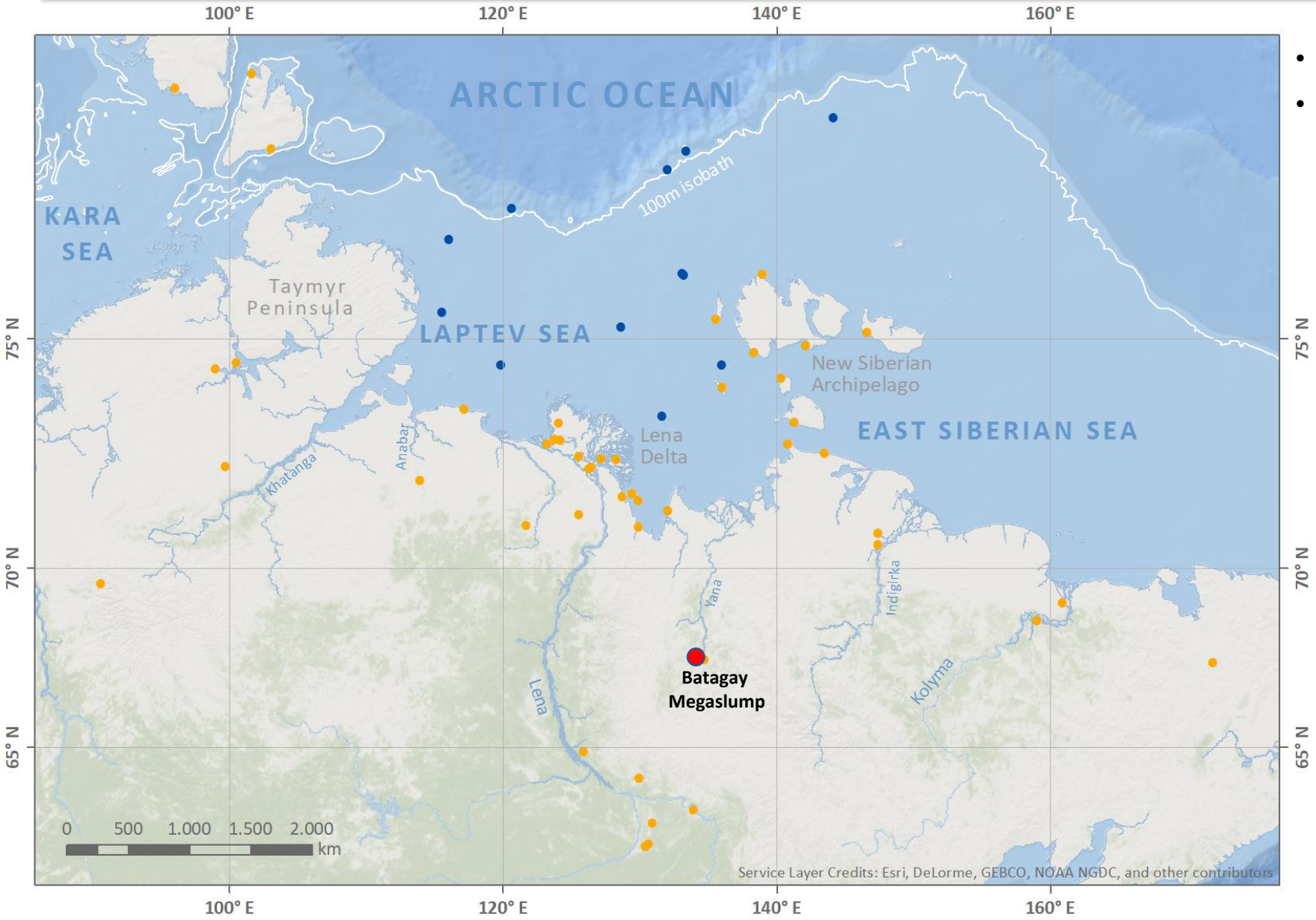
Methods

Geochronology,
Cryolithology,
Cryostratigraphy,
Geochemistry,
Sedimentology,
Paleontology,
Geophysics,
Geomorphology,
Remote sensing, GIS

Material (from outcrops and cores):

Permafrost deposits,
Ground ice,
Fossils

The oldest dated permafrost in Siberia: **Batagay Megaslump**



- 330 m above sea level, Yana Highlands
- Expeditions in 2011, 2014, 2017, 2019

Batagay Megaslump

Upper Ice Complex (MIS 4 to MIS 3)
- ^{14}C AMS, OSL, IRSL: 90.5 to 27.1 ka

Upper Sand (MIS 3 to MIS 2)
- ^{14}C AMS, OSL, IRSL: 61 to 22.5 ka

Lower Ice Complex (MIS 16)
- Luminescence K-feldspar (pIRIR):
  658 ± 74 ka
  693 ± 97 ka
- ^{36}Cl/Cl age: 624 ± 51 ka

Murton et al. (2022) QR 105, 1–22, doi:10.1017/qua.2021.27

Paleoenvironment

MIS 2 Meadow-steppe, scattered larch

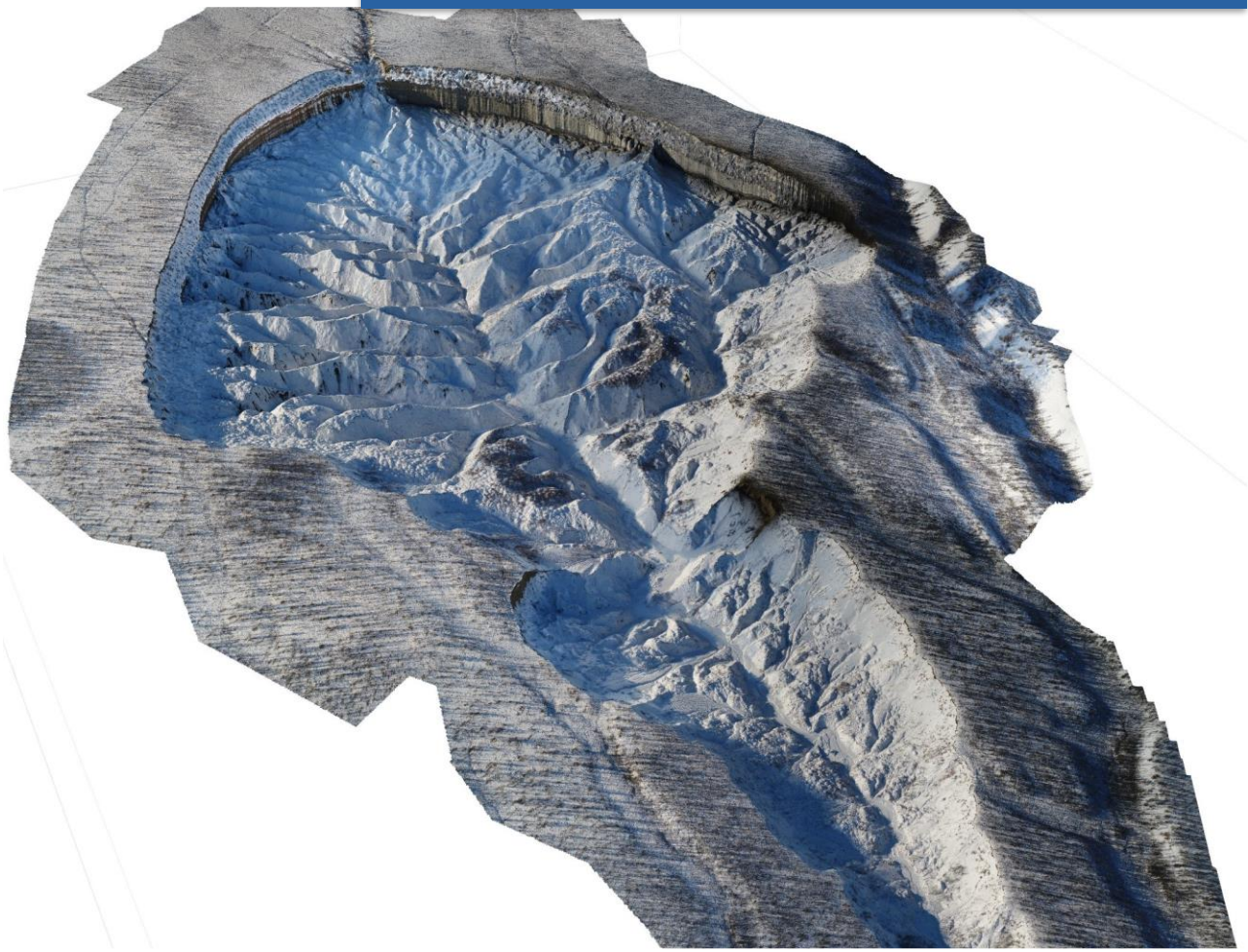
MIS 3 meadow-steppe with tundra-steppe inclusions

MIS 4 meadow-steppe with interlocked tundra-steppe

MIS 5e herb-rich light coniferous taiga

MIS 6 meadow-steppe, scattered woods

Ashastina et al. (2018) QSR 196, 38-61, doi: 10.1016/j.quascirev.2018.07.032



- Largest retrogressive thaw slump of the world (ca. 1.8 x 0.9 km)[1]
- Has been formed since the 1990s by combination of human activities (timber cutting, mining) and climate warming at the place of previously existed thermo-erosional gully. [2]

[1] *Kyzyakov et al (2023) Geomorphology 420 (2023) 108501, doi: 10.1016/j.geomorph.2022.108501*
[2] *Kunitzky et al. (2013) Krisfera Zemli (Earth Cryosphere) 17(1), 56-68.*

The lowermost permafrost deposits at Dmitry Laptev Strait

Luminescence (IRSL of K feldspar), old Ice Complex [5]
- 134 ± 22 ka (MIS 6)

Paleomagnetic, old Ice Complex, Bol'shoy Lyakhovsky Island [5]
- Biwa I reversal event 181-171 ka (MIS 6)

^{230}Th/U age of old peat, Bol'shoy Lyakhovsky Island
- 200.9 ± 3.4 ka (isochrone age) [3]
- 221 ± 27 ka (TSD model), 178 ± 14 ka (L/L model) [4] (MIS 7)

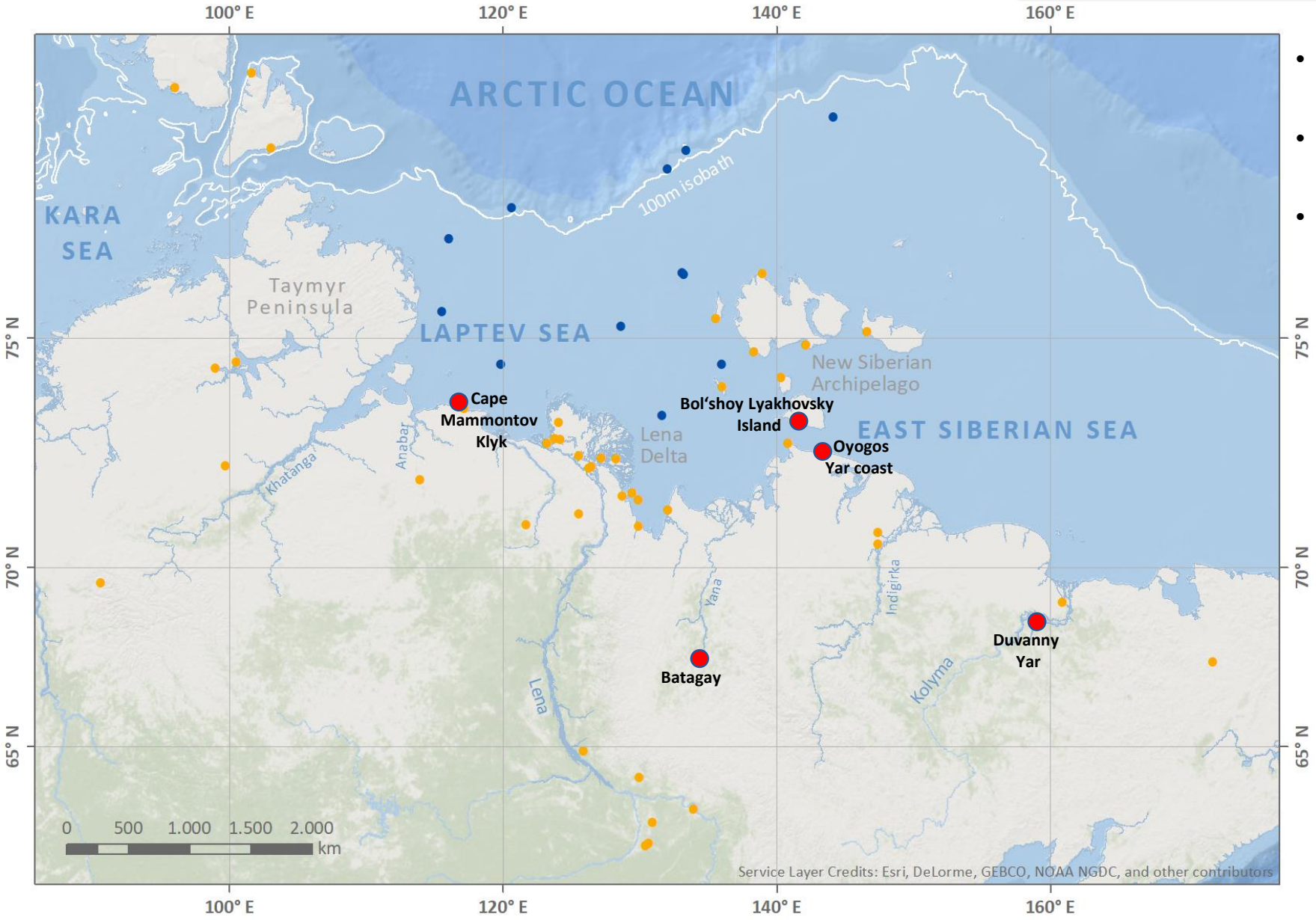
^{36}Cl/Cl age of old ice wedges, Bol'shoy Lyakhovsky Island [2]
- 309 ± 40 ka, 341 ± 43 ka (about MIS 9)

^{36}Cl/Cl age of old ice wedges, Cape Svyatoy Nos [1, 2]
- 484 ± 141 ka, 581 ± 166 ka (about MIS 13 to 12)

Paleoenvironment [6]
- MIS 6 stadial - sparse grass-sedge tundra steppe
- MIS 7 interstadial – dense grass dominated tundra
- MIS 7 stadial - sparse grass-sedge tundra steppe

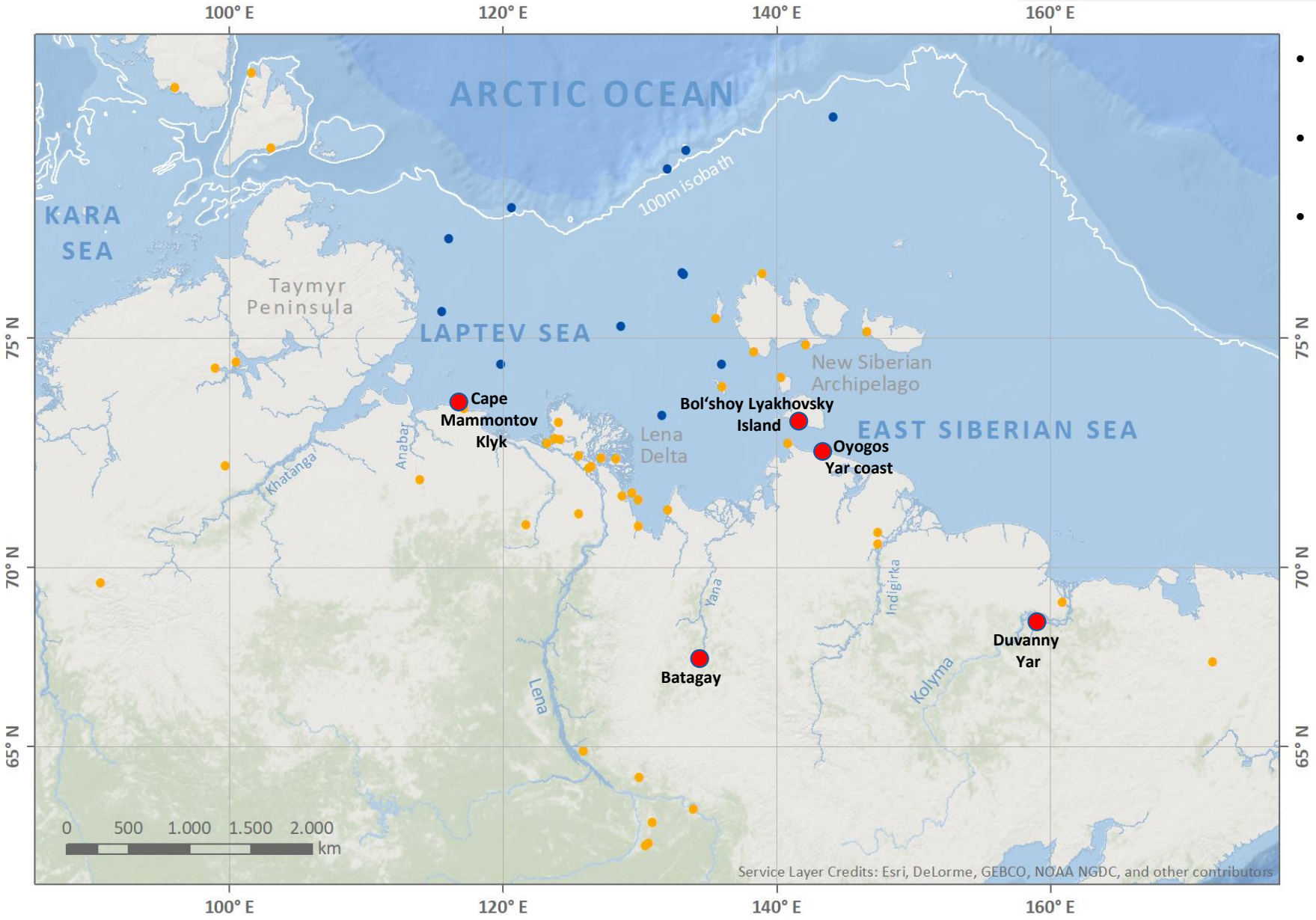
[1] *Glichinsky et al (2007) QSR 26, 1547-1556, doi: 10.1016/j.quascirev.2007.04.004*
[2] *Blinov et al. (2009) G^3 10, Q0AA03, doi:10.1029/2009GC002548*
[3] *Schirrmeister et al. ((2002) QR 57, 253-258, doi:10.1006/qres.2001.2306*
[4] *Wetterich et al. (2019) QR 92(2), 530-548, doi: 10.1017/qua.2019.6*
[5] *Andreev et al. (2004) Boreas 33, 319-348, doi: 10.1080/03009480410001974*
[6] *Andreev et al. (2011) QSR 39, 2182-2199, doi:10.1016/j.quascirev.2010.12.026*

The last Interglacial MIS 5e



- Coastal exposures, river outcrops, thaw slumps nearshore cores
- Cores between -65 and -75 m below sea level, exposures 0 to +10 m above sea level
- Expeditions in 1999, 2002, 2003, 2007, 2008, 2014, 2019

The last Interglacial MIS 5e



- Coastal exposures, river outcrops, thaw slumps nearshore cores
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The last Interglacial MIS 5e

Cape Mamontov Klyk (Interglacial lagoon) [1]

- High pore water salinity (12 – 30 ‰), fragments and single shells of marine and freshwater diatoms, some spongi spicula
- Tree pollen: *Pinus Haploxylon, P. Dyploxylon, Picea, Larix, Alnus fruticosa, Betula nanae*
- Indications of glacioisostatic movement (post MIS 6) and seismo-tectonic processes until now

Dmitry Laptev Strait (thermokarst lakes) [2, 3, 4, 5, 6]

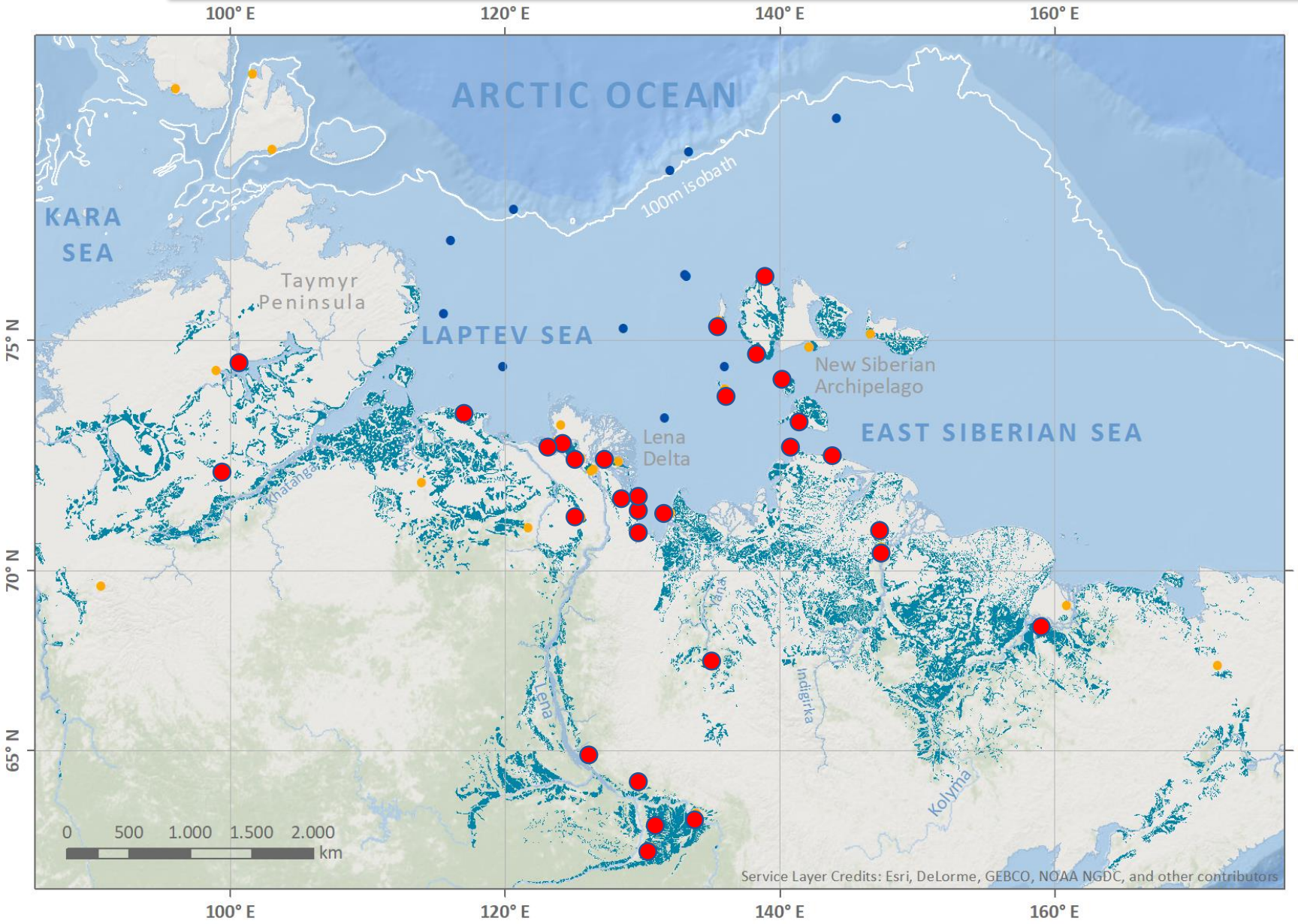
- Numerous ice wedge casts with laminated lake deposits
- IRSL dating of K feldspar 120.3 ± 14.4 ka, 117.3 ± 13.8 ka, 112.5 ± 9.6 ka
- Tree and shrub pollen and plant macrofossils of *Larix dahurica, Alnus incana, Duschekia fruticosa, Betula fruticosa, Betula divaricata, Betula nana*
- Aquatic freshwater organisms like ostracods, molluscs, chironomids, cladocerans, and hydrophytes
- Indicator of warmer environmental conditions: aquatic, steppe, tundra beetles, shrub and single forest or forest tundra indicators

Paleoenvironment during the MIS 5e Interglacial

- Terrestrial lowland with **thermokarst lakes on a dry Arctic shelf plain** and in the southern hinterland as well
- Permafrost degradation due to interglacial *climate warming of 10 to 14 °C (MTWA)*
- **Tree line** was located **at today's Dmitry Laptev Strait** area
- **Thermokarst lagoons** at the **west of the today Laptev Shelf** area
- Further east, probably **mainland up to the New Siberian Archipelago** → Global sea level was about 10 m higher than today

[1] *Winterfeld et al. (2011) Boreas 40, 697-713, doi: 10.1111/j.1502-3885.2011.00203.x.*
[2] *Andreev et al. (2004) Boreas 33, 319-348, doi: 10.1080/03009480410001974*
[3] *Kienast et al (2008) GPC 60, 535-562, doi:10.1016/j.gloplacha.2007.07.004.*
[4] *Kienast et al. (2011) QSR 30, 2134-2159, doi:10.1016/j.quascirev.2010.11.024.*
[5] *Ilyashuk et al. (2006) J. Paleolimnol. 35, 855-872, doi: 10.1007/s10933-005-5859-6.*
[6] *Wetterich et al. (2009) PALAEO 3 279, 73-95, doi:10.1016/j.palaeo.2009.05.002.*

Late Pleistocene ice-rich permafrost: **Yedoma Ice Complex**



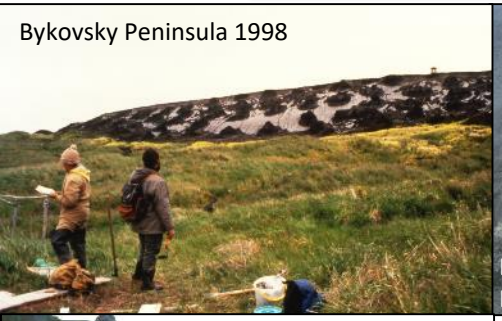
Yedoma Ice Complex (MIS 3 to MIS 2)

- 31 sites were studied between 1993 and 2019
- Yedoma domain about 480,000 km^2 of the PanArctic mainland [1]

Yedoma distribution in Arctic and sub-Arctic Siberia and Far East Russia and the Yedoma study sites *(Map compiled by Sebastian Laboor, AWI Potsdam)*

[1] *Strauss et al. (2021) Front. Earth Sci. 9:758360.doi: 10.3389/feart.2021.758360. Strauss et al. (2022) Database of Ice-Rich Yedoma Permafrost Version 2 (IRYP v2). doi: 10.1594/PANGAEA.940078*

Late Pleistocene ice-rich permafrost: **Yedoma Ice Complex**

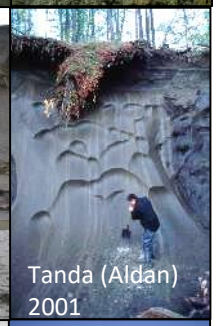

Bykovsky Peninsula 1998


Bol'shoy Lyakhovsky 1999


Stolbovoy Island 2002


Lena Delta 2000


Cape Mamontov Klyk 2003


Tanda (Aldan) 2001


Oyogos Yar 2007


Buor Khaya Peninsula 2010

Some important characteristics of Yedoma horizons

- Thickness 20 – 50 m: Vertical alternation of sediment columns and large syngenetic ice wedges, **very high ground ice content** (sediment + ice wedges) 65 to 90 Vol % [1]
- Radiocarbon dated between **57.2 +5.5/-3.2 kyr BP and 13.1 ± 0,07 kyr BP,** often with lacking of MIS 2 stadial deposits
- Rich in **fossil bioindicators** (e.g. pollen[2], large plant remains[3, 4], insects of various groups[5], ostracods[6], large[5] and small mammals, tecamoebaes[7]) indicate different paleoenvironmental conditions in stadial and interstadial periods
- **Tundra-steppe (mammoth-steppe) landscape** with numerous small ponds in ice wedge polygons
- **Polygenetic sedimentation processes**, from local to regional aeolian, alluvial, fluvial, nival, and ponding water accumulation, and additionally in situ frost weathering result in mean sediment grain sizes between 2.6 and 591 µm[8]
- Signature of **$\delta^{18}O$ isotopes of ice wedges** -35.7 to -29.3 ‰[9, 10, 11]
- **Late Pleistocene coastline** was **200-300 km further north** than today


Bol'shoy Lyakhovsky Island 2007

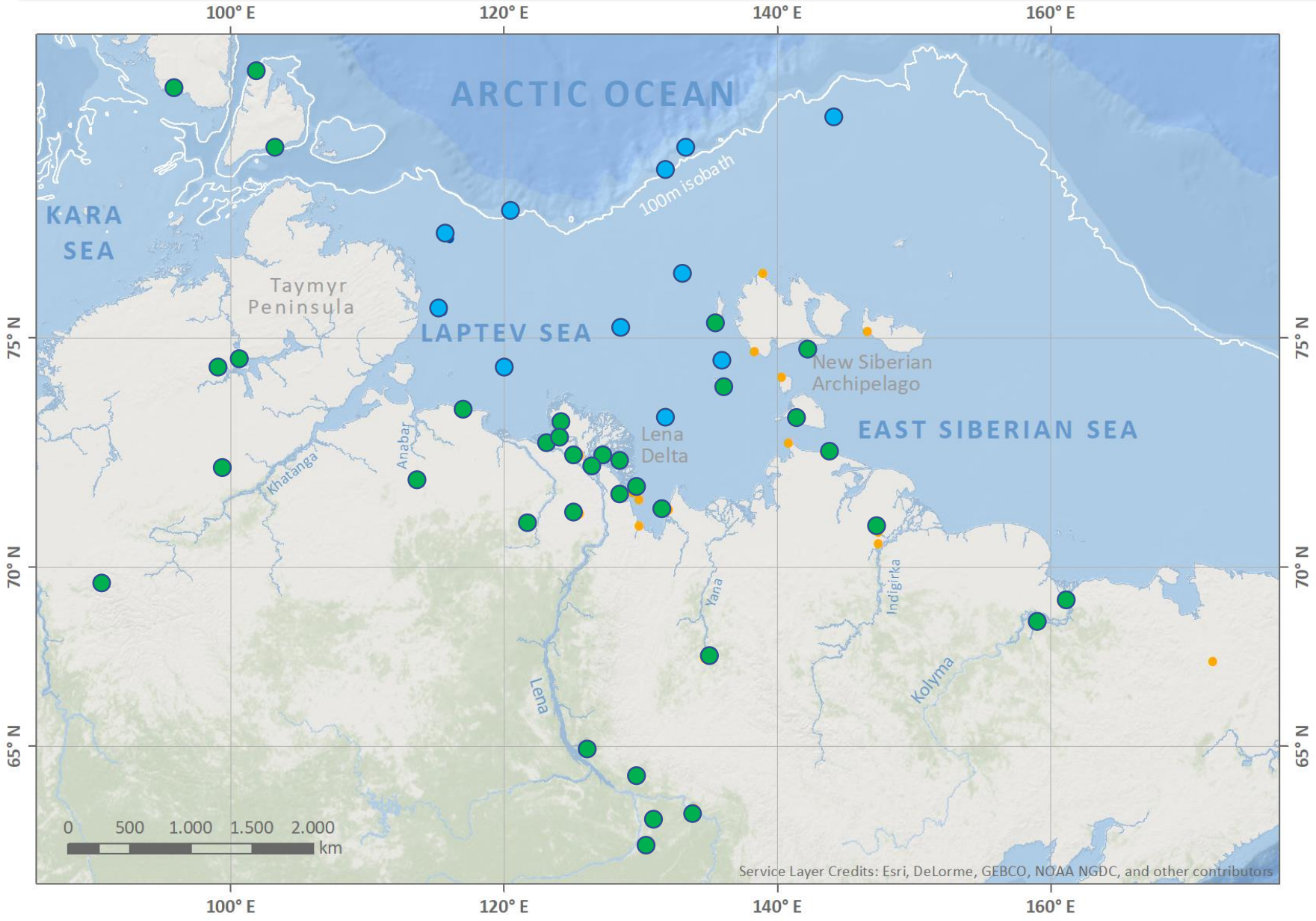

Duyanny Yar 2008


Tabaga 2013


Sobo Sise, Lena Delta 2018

[1] Schirrmeister et al. (2011) Encyclopedia of Quaternary Science, 542-552. doi: 10.1016/B978-0-444-53643-3.00106-0. [2] Andreev et al. (2009) Boreas 38(1), 72–110.,DOI 10.1111/j.1502-3885.2008.00039.x. [3] Kienast et al. (2001) GPC 31, 265-281, doi: 10.1016/S0921-8181(01)00124-2. [4] Kienast, et al. (2005). QR 63(3), 283-300..doi: 10.1016/j.yqres.2005.01.003.. [5] Sher et al. (2005) QSR 24, 533–569, doi:10.1016/j.quascirev.2004.09.007, [6] Wetterich et al. (2005) Journal of Paleolimnology, 34, 363-376. doi:10.1007/s10933-005-5801-y. [7] Bobrov et al. (2004) PALEO 3 209, 165-181. doi:10.1016/J.PALAEO.2004.02.012. [8] Schirrmeister et al. (2020) E&G Quaternary Sci. J., 69, 33–53, doi: 10.5194/egqsj-69-33-2020. [9] Meyer et al. (2002) Polarforschung, 70, 37-51, hdl:10013/epic.29857.d001. [10] Meyer et al.(2002) PPP 13, 91-105. Ddoi: 10.1002/ppp.416. [11] Opel et al. (2019) Clim. Past, 15, 1443–1461, doi: 10.5194/cp-15-1443-2019.

End of MIS 2 and transition to MIS 1 (Deglacial and early Holocene)



End of MIS 2 to MIS 1

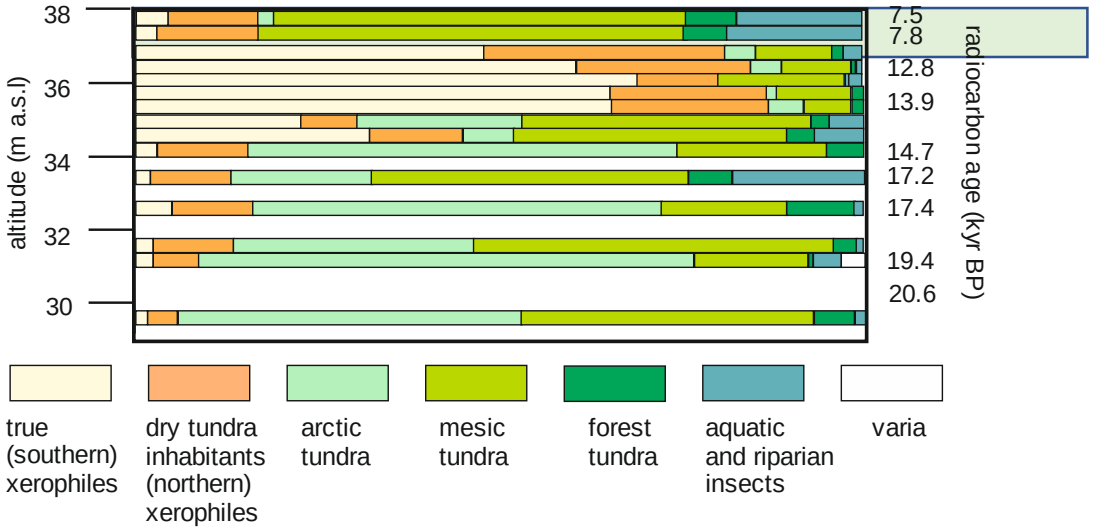
- Marine transgression of the Siberian shelf regions between 11.2 and 5.3 cal kyr BP [1]
- Large-scale permafrost degradation of late Pleistocene Yedoma landscapes [2]
- Formation of thermokarst depressions and thermokarst lakes up to far inland
- Formation of thermokarst lagoons on the Yedoma coasts
- Signature of $\delta^{18}O$ isotopes of ice wedges -29.0 to -19.4 ‰

Study sites of Lateglacial and Holocene deposits
- terrestrial exposures and cores
- marine cores

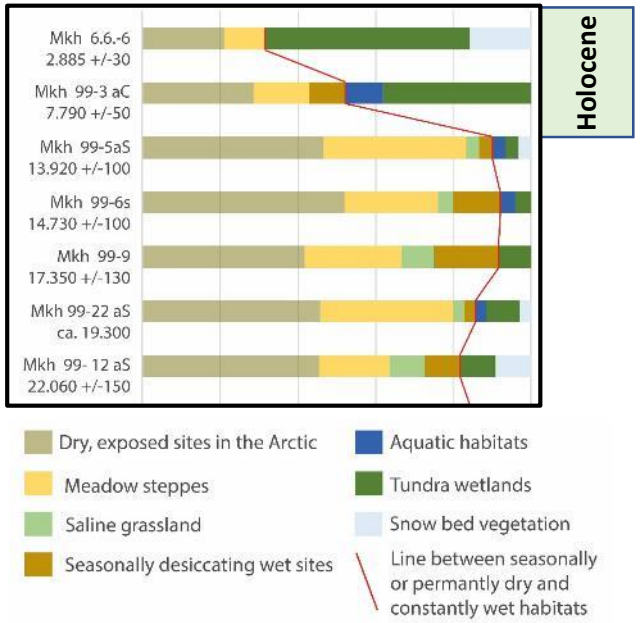
[1] *Bauch et al. (2002) GPC 31, 125-140, doi: 10.1016/S0921-8181(01)00116-3.*
[2] *Grosse et al. (2007) Geomorphology, 86, 25-51. doi:10.1016/j.geomorph.2006.08.005*
[3] *Angelopoulos et al. (2020) GPL 48, e2021GL093881, doi: 10.1029/2021GL093881*

End of MIS 2 and transition to MIS 1 (Deglacial and early Holocene)

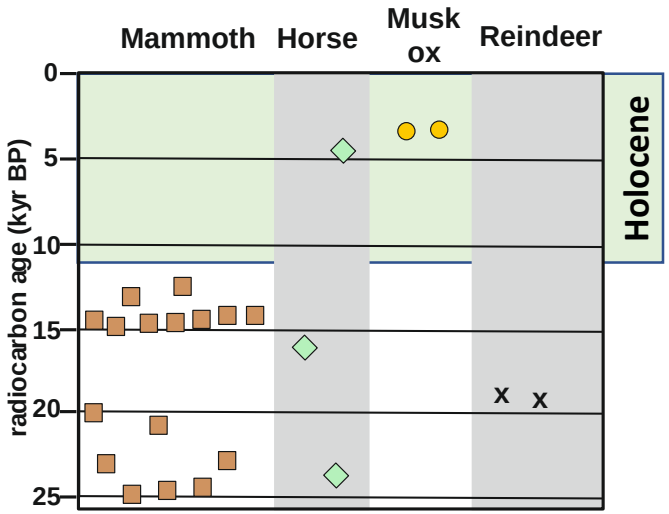
Thermokarst landscapes of Arctic NE Siberia with thermokarst lagoons , thermokarst depressions and lakes, pingos, thermo-erosional valleys, and retrogressive thaw slumps



Lateglacial to Holocene insect record of the Mamontovy Khayata site (Bykovsky Peninsula)[1]



Indicators of dry or wet habitats among plant macrofossil taxa detected at Mamontovy Khayata during the Lateglacial to Holocene period [1]



Large mammal distribution during the Lateglacial to Holocene period at the Mamontovy Khayata site (Bykovsky Peninsula) [2]

[1] *Sher et al. (2005) QSR 24, 533–569, doi:10.1016/j.quascirev.2004.09.007*
[2] *Schirrmeister et al. (2002) QI 89, 97-118, doi: 10.1016/S1040-6182(01)00083-0*

30 years of joint Russian-German expeditions: **Final remarks**


Tiksi 1998


Cape Mamontov Klyk 2003


Duvanny Yar 2008


Kytalyk 2011


Yukechi 2015


Bol'shoy Lyakhovsky 1999


COAST 2005


Elgygytgyn 2008


Pokhodsk 2013


Yukechi 2013


Yakutsk 2001


Lena Delta, Ebe Sise Island 2005


Buor Khaya Peninsula 2010


Bol'shoy Lyakhovsky 2014 spring


Sobo-Sise Island 2018


New Siberian Archipelago 2002


Oyogos Yar coast 2007


Buor Khaya Peninsula 2012


Bykovsky Peninsula 2017


Batagay 2019

ca. 50 expedition groups studied about 60 sites between 1993 and 2019

30 years of joint Russian-German expeditions: **Cooperation partners**

Germany (16)
→ Alfred Wegener Institute Potsdam (Section of Permafrost Research, Section of Polar Terrestrial Environmental Systems, Section of Marine Geochemistry),
→ University of Potsdam (Institute of Geosciences; Institute of Biochemistry and Biology), → German Research Centre for Geosciences (GFZ) Potsdam,
→ Christian-Albrecht University Kiel (Leibniz Laboratory), → Leibniz Institute for Applied Geoscience Hannover, → University Hamburg (Institute of Soil Sciences),
→ GEOMAR Helmholtz Centre for Ocean Research Kiel, → Free University of Berlin (Institute of Geological Sciences),
→ University of Cologne (Institute of Geology und Mineralogy),
→ Senckenberg Research Institute and Natural History Museum (Research Station of Quaternary Palaeontology, Weimar),
→ University of Leipzig (Institute for Geography), → Helmholtz Institute Freiberg for Resource Technology,
→ Greifswald University (Institute of Botany and Landscape Ecology), → German Aerospace Center (DLR) Berlin (Institute for Planetary Research),
→ Helmholtz Centre Hereon (Institute of Carbon Cycles), → Helmholtz-Centre for Environmental Research UFZ Leipzig (Department of Analytical Chemistry)

Russia (14)
→ Arctic and Antarctic Research Institute (AARI) St. Petersburg, → St. Petersburg State University (Institute of Earth Sciences),
→ Moscow State University (Faculty of Geology, Faculty of Soil Science, Faculty of Geography), → Herzen State Pedagogical University (Faculty of Geography),
→ Institute of Physical Chemical and Biological Problems in Soil Science, RAS Pushchino,
→ North-East Science Station Cherskiy, Pacific Geographical Institute FEB RAS, → Melnikov Permafrost Institute, SB RAS Yakutsk,
→ Kazan Federal University (Faculty of Biology and Soil), → Lena Delta Nature Reserve Tiksi,
→ North-Eastern Federal University of Yakutsk (Institute of Natural Sciences), → Institute of Geology of Diamond and Noble Metals (IGABM) SB RAS Yakutsk,
→ Institute of Archaeology and Ethnography SB RAS (Centre of Cenozoic Geochronology) Novosibirsk,
→ Institute for Biological Problems of the Cryolithozone Yakutsk SB RAS, → Palaeontological Institute RAS

International partners (7)
→ University of Alaska Fairbanks (Geophysical Institute, Institute of Northern Engineering), → US Geological Survey,
→ University of Sussex (Department of Geography), → University of Aarhus (Nordic Laboratory for Luminescence Dating),
→ Stockholm University (Department of Physical Geography and Quaternary Geology),
→ Northumbria University (Department of Geography and Environmental Sciences), → Université catholique de Louvain (Earth and Life Institute),
→ Istanbul Technical University (Eurasia Institute of Earth Sciences)

30 years of joint Russian-German expeditions: **Take home**

- ✓ About 200 English and Russian publications
- ✓ Countless diploma, bachelor and master theses; numerous PhD theses and theses for higher qualifications in Russia, in Germany and by international partners

- ❖ **Permafrost research in the Arctic and sub-Arctic has advanced by long-term studies and international collaborations including in the vast areas of Siberia, Far-East, and European Russia.**
- ❖ **Climate changes in global contexts are strongest in the Arctic and a very large part of the terrestrial Arctic is located in Russia. It is necessary to find ways to continue international data collection and analysis for such an important permafrost region**
- ❖ **For permafrost science, we hope that international collaboration on permafrost research will come back in the future.**

THANK YOU! QUESTIONS?

contact:
Lutz.Schirrmeister@awi.de