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ABSTRACT BOOK

June 28 – July 3, 2026, Łódź, Poland

International Field Symposium

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of the Middle and Upper Pleistocene in central Poland”

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Contents

Comparison of Finnish hard bed and Polish soft bed eskers based on GPR surveys 7
Elina Ahokangas[a], Anna Lejzerowicz[b], Joni Mäkinen[a], Małgorzata Frydrych[c] 7

Revision of the Lithuanian Quaternary stratigraphic scheme, based on the latest geochronological data 9
Albertas Bitinas[a], Michal Šujan[a,b], Aldona Damušytė[c], Vaida Šeirienė[a], Dalia Kiselienė[a] 9

Postglacial lake formation and permafrost evolution in the Central European Lowland at the end of the last glaciation 11
Mirosław Błaszkiewicz 11

Spatial and temporal reconstruction of an abandoned Vltava valley between Kralupy nad Vltavou and Roudnice nad Labem 12
Marie Brožová[a], Daniel Nývlt[a,b], Regis Braucher[c], ASTER Team[c] 12

Morphogenetic and lithological controls on the evolution of a paraglacial barrier spit: evidence from the Eidem Spit (Svalbard) 13
Oleksiy Davydov[a,b], Iliya Buynevich[c], Oleksiy Roskos[d] 13

Contemporary spatial differentiation of deglaciation of a polythermal glacier as a model for Late Pleistocene ice margin retreat (a case study of Eidembreen Glacier) 15
Oleksiy Davydov[a,b], Yuliia Shevchuk[a], Albertas Bitinas[c], Aldona Damušytė[d] 15

Relict sand wedge-like polygonal structures at the southern edge of the Late Pleistocene periglacial zone in Hungary 17
Szabolcs Ákos Fábián[a], Dárius Márk Szabadkai[b], György Sipos[c], Gábor Varga[a], Ákos Halmai[a], Éva Farics[a], Noémi Sarkadi[a], Beáta Farkas[a] 17

Sand wedges as important sedimentary archives in periglacial research 19
Beáta Farkas[a, b], Szabolcs Ákos Fábián[a] 19

Morphologically undetected kettle hole (MUKH) in a Saalian esker near Tosie (Central Poland) ... 20
Małgorzata Frydrych[a], Anna Lejzerowicz[b] 20

Surface exposure dating of Saalian erratic boulders with in-situ cosmogenic ^{10}Be and ^{26}Al at the southern periphery of the Fennoscandian Ice Sheet 21
Sanjaya Gurung[a], Karol Tylmann[a], Vincent Rinterknecht[b], Andreas Börner[c], Olaf Juschus[d], Henrik Rother[e], Konrad Schubert[e], Piotr P. Woźniak[a] 21

Glacial erratic mega-blocks on the bed of the Fennoscandian Ice Sheet: origins, transport, and significance 22
Adrian Halll[a], Ingmar Bergstrom[b], Lars-Gunnar Jarl[c] 22

Mobility of subglacial till: ring-shear experiments and microstructural constraints 23

Piotr Hermanowski[a], Jan A. Piotrowski[b,d], Gustav Jungdal-Olesen[b], Vivi K. Pedersen[b], Jutta Winsemann[c], Runa Fälber[c] 23

Origin of aeolian sand accumulations and evaluation of sediment fluxes in a meltwater-fed catchment on James Ross Island, Antarctica 24

Jakub Holuša[a, *], Martin Kadlec[a], Daniel Nývlt[a] 24

The latest news on cold-climate dunes dynamics in the Vienna Basin, Central Europe 26

Jakub Holuša[a, *], Joel Roskin[b], Daniel Nývlt[a] 26

Late Holocene storminess and shoreline changes in the Harilaid Peninsula, Eastern Baltic Sea 28

Triinu Jairus[a], Alar Rosentau[a], Annabel Eensoo[a], Tiit Hang[a], Hannes Tõnisson[b], Ülo Suursaar[c] 28

From Deflation to Deposition: Ice-Margin Retreat Drives Spatial Inversion of Loess Systems in Southwestern Poland 29

Zdzisław Jary[a], Marcin Krawczyk[a], Michał Łopuch[a], Jerzy Raczyk[a], Jacek Skurzyński[a], Zuzanna Sowińska[a] 29

Plateau-like hills in the Vištytis Upland, SW Lithuania 30

Asta Jusiene 30

Pleistocene and Holocene Sediments Comparison Based on Geochemistry, Lithuania 31

Donatas Kaminskas[a], Eugenija Rudnickaitė[b] 31

Modelling of the Quaternary Subsurface: Workflow and Initial Results for a Pilot Area in Northern Germany 32

Michael (Ede) Kenzler[a], Kay Krienke[a] 32

Cladocera-based reconstruction of Late-Glacial and Early Holocene environmental changes at Lake Velykoye (Belarus) 33

Gražyna Kluczynska 33

Groß Buchholz (Perleberg, Prignitz) — a remarkable series of Eemian to Early Weichselian sediments — first results 34

Sławomir Kowalski[a], Olaf Juschus[a], Andreas Börner[b], Jaqueline Strahl[a], Elisabeth Endtmann[c], Małgorzata (Gosia) Pisarska-Jamroży[d] 34

Quaternary calcareous sandstone from the Izbica profile (Central Poland) as a product of carbonate cementation in shallow groundwater under interglacial conditions 37

Bogusz Kulus 37

Reconstructing palaeo-ice lobe dynamics in Latvia from the glacial landform record 39

Kristaps Lamsters[a], Edijs Breijers[b], Hugo Huberts Puriņš[b], Normunds Stivriņš[a], Kristaps Rendinieks[a], Izolde Ivanova[a], Aleksis R. Larionovs[a], Katrīna Landratova[a] 39

Multiproxy analysis of biogenic cores from kettle holes and lake: case study from the Ostrowite archaeological complex (Northern Krajna Lakeland, N Poland)..... 41

Aleksandra Leszczyk[a], Dmitry Tsvirko[a], Piotr Kittel[b], Daniel Okupny[c], Marta Rudna[d], Mirosław Makohonienko[e], Olga Antczak-Orlewska[f], Mateusz Płóciennik[g], Dominika Łuców[h], Monika Rzodkiewicz[i], Izabela Zawiska[j], Joanna Rennwanz[k], Agnieszka Halaś[j], Michał Słowiński[m], Michał Gąsiorowski[l], Łukasz Trzciński[n], Jerzy Sikora[n] 41

High-resolution grain-size variability within a Late Glacial inland dune foreset at Przyłubie, Toruń Basin, Poland 44

Przemysław Mroczek[a], Robert J. Sokołowski[b], Paweł Zielińskia, Piotr Moska[c], Marcin Krawczyk[d], Michał Łopuch[d], Jacek Skurzyński[d], Jerzy Raczyk[d], Grzegorz Poręba[c], Natalia Piotrowska[c], Zdzisław Jary[d], Alicja Ustrzycka[c], Andrzej Wojtalak[c], Agnieszka Szymak[c], Konrad Tudyka[c], Grzegorz Adamiec[c] 44

Development and Disappearance of a Palaeolake in the Araxes River Valley: Evidence from the Argishtikhinili (Davti Blur) Archaeological Site, Armenia 46

Kajetan Ogłaza[a], Barbara Woronko[b], Barbara Rybak-Ostrowska[b], Mateusz Iskra[c], Piotr Moska[d], Arshavir Hovhannisyan[e], Ara Avagyan[e], Hasmik Simonyan[f] 46

A Quaternary sediment budget for the North Sea Basin 48

Dag Ottesen[a], Mikis van Boeckel[a], Adrian Hall[b], Christine Batchelor[c], Jorg Lang[d] 48

Reconstructing cold-stage ecosystems in a Warta Valley: 49

multi-proxy insights from Warenka site 49

Joanna Petera-Zganiacz[a], Dorota Brzozowicz-Strojna[a], Tymoteusz Matera[b], Dominik Pawłowski[c], Mateusz Płóciennik[b], Sylwia Skoczylas-Śniaz[d] 49

Lithodynamics and evolution of the sedimentary environment in the marginal zone of the last Fennoscandian (Valdai) Ice Sheet: The Serteyka River valley case study 51

Wiktor Piech[a], Małgorzata Frydrych[a], Piotr Kittel[b] 51

Intraplate seismicity triggered by ice-sheet loading and unloading: insights from the Peribaltic region 52

Małgorzata Pisarska-Jamroży[a], Szymon Belzyt[b], Albertas Bitina[c], Andreas Börner[d], Małgorzata Bronikowska[e], Aldona Damušytė[f], Tiit Hang[g], Heiko Hüneke[h], Asta Jusienė[f], Michael Kenzler[h], Māris Krievans[i], Kristaps Lamsters[i], Māris Nartišs[i], Karsten Obst[h], Niko Putkinen[j], Alar Rosentau[g], Henrik Rother[k], Anna Salwowska[l], Holger Steffen[m], Rebekka Steffen[m], Raimo Sutinen[n], Szymon Świątek[a], A.J. (Tom) van Loon[o], Barbara Woronko[p], Piotr P. Woźniak[r] 52

Warmth or chill? New insights into Late Weichselian summer conditions in the Polish Lowlands.. 54

Mateusz Płóciennik[a], Patrycja Jankowska[a], Violeta Berlajolli[b], Sylwia Łukawska[a], Jacek Forysiak[c] 54

Middle Pleistocene climate and lake ecology in Central Poland inferred from palaeobotanical and Chironomidae evidence 55

Mateusz Płóciennik[a], Agata Wasiak[a], Aleksandra Sławska[b], Małgorzata Malkiewicz[c], Aleksandra Majecka[d], Dariusz Krzyszkowski[e], Dariusz Wieczorek[f], Lucyna Wachecka-Kotkowska[g] 55

Cladocera communities from the Miocene (Bełchatów, Central Poland) 56

Agnieszka Pociecha[a], Edyta Zawisza[b], Elżbieta Worobiec[c], Grzegorz Worobiec[c] 56

Geological 3D modeling of the Quaternary in eastern central Germany (Saxony-Anhalt) using stacked lithofacies maps and borehole information 59

Henrik Rother[a], Jacob Wächter[a] 59

Reconstruction of abrupt climate changes at the Late Glacial–Holocene transition based on Cladocera from two peatlands in central Poland 61

Marta Rudna[a], Marta Wojewódka-Przybył[b], Jacek Forysiak[c] 61

Record of SIS dynamics in the relief of the Polish-Lithuanian border area in the Suwałki region (NE Poland) 63

Joanna Rychel[a], Robert J. Sokołowski[b], Weronika Danel[a] 63

Portable analysis method for analysing very low concentrations of gold 64

Pertti Sarala[a], Bolster, S.[b], Gupto, S.[a], Hietula, V.-A.[a], Keränen, S.a, Järvinen, J.[c], Lyytikäinen, J.[c] 64

Existence and environmental effect of black shales in glaciated terrain in the Oulu region, northern Finland 65

Pertti Sarala[a], Pauliina Liwata-Kenttälä[b], Tiina M. Nieminen[c], Liisa Ukonmaanaho[c] 65

Environmental changes during the Late Glacial and Early Holocene transition revealed by palaeolimnological record from southern Lithuania 66

Vaida Šeirienė[a], Gražyna Kluczynska[a], Neringa Gastevičienė[a] 66

Coleoptera-based MCR temperature reconstructions of the Last Glacial termination in Lithuania 68

Nick Schafstall[a], Mingle Stančikaitė[a], Vaida Šeirienė[a] 68

Spatial distribution and morphometry of polygonal crop marks in the lowlands of the Pannonian Basin, NW Hungary 70

Dárius Márk Szabadkai[a], Noémi Sarkadi[b], Beáta Farkas[c], Szabolcs Ákos Fábián[c] 70

Glacial geomporphological map of Verkhoyansk Mountains, NE Siberia 72

Izabela Szuman[a], Martin Margold[b], Jakub Z. Kalita[a] 72

3D microtomography of till from the Baltic Sea floor: record of subglacial and ice-marginal processes? 73

Karol Tylmann[a], Jan A. Piotrowski[b,c], Sarah L. Greenwood[d], Richard Gyllencreutz[d], Piotr Duda[e] 73

Directions of glacial transgression in the frontal zone of the ice sheet during the Saalian Glaciation (MIS 6) in the north-western foothills of the Holy Cross Mountains – preliminary results 75

Dominik Witkowski[a], Artur Teodorski[b] 75

^{14}C-OSL chronology of the Warta River oxbow lakes generations in the Śrem Basin – central-western Poland 77

Andrzej Wojtalak[a], Robert J. Sokołowski[b], Piotr Moska[a], Alicja Ustrzycka[a], Grzegorz Poręba[a], Mateusz Kramkowski[c] 77

Provenance of MIS 4 Loess Inferred from Microtextural Analysis of Silt Grains: Evidence from Poland and Ukraine 78

Barbara Woronko[a], Oleksandr Bonchkovskyi[b], Martyna E. Górska[c], Maria Łanczont[d], Maryna S. Komar[e] 78

New data on Weichselian ice advances in the Suwałki Lakeland, NE Poland 79

Wojciech Wysota[a], Edyta Kalińska[a], Helena Alexanderson[b], Piotr Weckwerth[a], Marek Chabowski[a], Arkadiusz Krawiec[a], Agnieszka Noryśkiewicz[c], Joanna Mirosław-Grabowska[d], Joanna Martewicz[e], Mateusz Suwiński[e] 79

Archaeological Layers as Archives of Human–Soil Interactions: A Multiproxy Study from Northern Poland 81

Margarita Zalinian [a], Jerzy Sikora [b], Sascha Scherer [c], Sabine Fiedler [c], Annemarie Susanne Bach [c], Karolina Leszczynska [d], Daniel Okupny [e], Alexandra Golyeva [f], Renata Stachowicz-Rybka [g], Magdalena Moskal-del Hoyo [g], Wojciech Toloczko [h], Daniel Makowiecki [i], Lukasz Trzcinski [j], Piotr Kittel [k] 81

Comparison of Finnish hard bed and Polish soft bed eskers based on GPR surveys

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The Fennoscandian Ice Sheet melted rapidly after the warming following the end of Younger Dryas period and extensive supraglacial, englacial and subglacial hydrological networks formed into it. This hydrological network consists of two main parts; a distributed and weakly connected and a channelized network. The most prominent signs of channelized network include eskers and tunnel valleys. In Finland, tunnel valleys are replaced by subglacial meltwater corridors and routes. These routes contain murtoos and murtoo-related landforms or dominant hummocky terrains, both often later occupied by eskers (Ahokangas et al., 2021).

Eskers form close to the ice margin in subglacial and englacial tunnels, crevasses or in supraglacial and ice-walled channels. Esker formation is influenced by the lithology of the underlying substrate of the moving ice sheet. Eskers on imperameable bedrock (hard bed) form in R-channels that erode into the bottom of the ice sheet due to the frictional heat of the flowing water. The eskers on soft bed form in N-channels that erode down to the substrate or in N-R channels that are a combination of R- and N-channels. Some research claims that eskers are unlikely to form on permeable, soft sediments or sedimentary rocks (so called soft bed) (Clark and Walder, 1994; Walder and Fowler, 1994) despite numerous studies on eskers on soft beds (e.g. Storrar et al., 2014; Salamon and Mendecki, 2021; Frydrych 2022).

Although morphological analysis of eskers on hard beds (R-channels) are abundant, the study by Frydrych (2022) in Poland was the first to analyse eskers of a wider area on a soft bed. The studied eskers were formed mostly during the Saalian Glaciation. To compare eskers of soft and hard bed, the morphology of eskers of Poland and Finland was studied (Frydrych et al., 2024). The study areas in Finland and Poland shared common characteristics that enabled comparison of esker morphologies. Both areas represented deglaciation of the Fennoscandian Ice Sheet (FIS) after the Last Glacial Maximum (LGM) with ice stream behavior connected to the eastern ice flow patterns along the Baltic Sea basin. The Finnish study area located in the supra-aquatic Tammela upland area in southern Finland, dating to just at the end of the Younger dryas cold period recorded by the II Salpausselkä end moraine (ca. 11.6-11.8 ka) in the southeastern margin of the study area. The Polish study area in northwestern Poland in vicinity of city of Stargard is within the Pomeranian ice-marginal belt dated to ca. 18-19 ka. The eskers in both study areas showed minor burial by glaciolacustine sediments and little influence of postglacial reworking.

Following the morphological analysis of eskers, the next step of esker study in Finland and Poland was to compare the internal esker characteristics and the relation of eskers to their substrate in more detail. This comparion was based on extensive GPR (ground penetrating radar) surveys in both Finland and Poland, with a total of ca. 35 km of GPR profiles.

The preliminary interpretation of GPR profiles revealed details on the esker characteristics, the relationship of the esker to their substrate and surroundings, including tunnel valleys and subglacial meltwater routes. In addition, the profiles revealed multiple channels that formed in several phases adjacent to eskers and meltwater routes, which implies the occurence of multiple meltwater flow events. The results highlight the complexity of the ice-marginal environment with eskers both joining and occurring with subglacial meltwater routes and tunnel valleys.

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Revision of the Lithuanian Quaternary stratigraphic scheme, based on the latest geochronological data

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One of the current challenges in the study of Lithuanian Quaternary deposits is the lack of a unified stratigraphy scheme. One of the country's main geological research institutions, the Lithuanian Geological Survey, follows the Quaternary stratigraphy scheme that was approved in 2009. However, researchers at other scientific institutions are developing and promoting their own schemes, which are not very compatible with each other. Different schemes have different numbers of stratigraphic units and different ranks, and the absolute ages assigned to these units vary. The schemes also correlate ambiguously with the stratigraphic schemes of neighbouring countries and international schemes.

In retrospect, during the second half of the 20th century, Quaternary researchers tended to favour a single, unified Quaternary stratigraphy scheme. This was partly due to the centralised, clearly hierarchical system of geological science and industry institutions that existed at the time. However, in recent decades, the status and subordination of geological institutions have changed radically, and there have been structural changes, a decrease in the number of active geologists, and a reduction in the amount of new geological information obtained. Consequently, the work of updating or unifying the Quaternary stratigraphy scheme has practically ceased.

Until now, Quaternary stratigraphic schemes have largely been based on climatostratigraphic principles, whereby sediments are divided into cold (glacial periods, stadials, cryomers) and warm (interglacial periods, interstadials, thermomers). The main criterion for this division has been the results of palaeobotanical studies; in their absence, lithostratigraphic criteria have been used instead. However, the rapid development of various absolute age determination methods means that the results of geochronological studies are now forming the basis for the compilation of stratigraphic schemes.

In 2024-2026, at the State Scientific Research Institute Nature Research Centre, implementing the postdoctoral project "CosmoLith", funded under the European Union's economic recovery and resilience facility NextGenerationEU "New Generation Lithuania" (No. 10-036-T-0008), absolute dating methods based on cosmogenic nuclide studies were used to date Lithuanian Quaternary deposits. The dating was performed using the $^{26}Al/^{10}Be$ and $^{10}Be/^{9}Be$ methods. The absolute age of sediments widespread in south-eastern Lithuania (in the Vilnius area, where a drill core was studied) and in eastern Lithuania (in the Anykščiai area, at the Daumantai, Šlavė and Vetygala outcrops, and in the operating Anykščiai quartz sand quarry) was established. Sediment dating and parallel lithological and microstructural studies suggest that the oldest glacial (Kalviai Glacial) moraine deposits found in the Vilnius area are not glacial origin, but are merely diamictites formed by mudflows. This raises doubts about the validity of the adjacent stratigraphic units known as the Daumantai Pre-glacial and the Vinžiūnai Interglacial. Cosmogenic nuclide dating methods estimate the absolute age of the latter

deposits to be approximately 1.00±0.06 million years. The average age of the pre-glacial deposits in the Anykščiai area outcrops and the sand layers of Anykščiai quartz sand quarry is estimated to be around 0.96±0.11 million years. However, until now, the Anykščiai quartz sand layers had been attributed to the Neogene period.

Over the past decade, studies of Quaternary deposits in western Lithuania — specifically, the Baltic coastal region — using the optically stimulated luminescence method, have made it possible to accurately determine the age of the widespread intermorainic deposits and distinguish the layer of glacial sediments associated with the MIS 4 glacial advance.

The results of the above-mentioned geochronological studies provide a solid basis for claiming that the time has come to fundamentally change the current approach to certain features of Lithuanian Quaternary stratigraphy. The authors of the thesis therefore propose a revised stratigraphic scheme as a possible foundation for developing a new, unified Lithuanian Quaternary stratigraphic scheme.

Postglacial lake formation and permafrost evolution in the Central European Lowland at the end of the last glaciation

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Lake basins containing existing or disappeared lakes are the most characteristic elements of young glacial landscapes associated within the reach of the last continental glaciation. While the Holocene past of lakes has been well investigated in palaeolimnological research, especially in the context of hydrological and trophic changes, some issues related to the genesis and postglacial evolution of lake basins are still unresolved and contain gaps. Generally, the genesis of lake basins is related to erosion and accumulation processes during the transgression and recession of the last (Upper Vistulian) Scandinavian ice sheet. The vast majority of large lake basins in the young glacial areas of the Central European Lowland are tunnel valleys/tunnel channels formed by the erosive activity of subglacial waters flowing under hydrostatic pressure and by glacial erosion (the depression formation phase). Immediately after their formation, these glacial depressions were filled with blocks of dead glacial/hydrogenic ice, which, in permafrost conditions and under mineral cover, could be preserved for long periods in some cases exceeding 5,000 years (the conservation phase). The melting of the buried dead ice was related to thermokarst conditions and depended on global climate changes in the Late Glacial and on local conditions, which included the decisive relationship between the future lakes and the emerging surface drainage network (the phase of buried ice melting and lake formation). The variedly progressive melting of buried dead-ice blocks was the main determinant of the differences in lake ages, from the pre-Allerød lakes through the lakes of the Bølling-Allerød complex to lakes that formed only at the beginning of the Holocene. A very interesting issue related to the functioning of the oldest generation of lakes is the relationship between glacial lakes, which were fed by ice meltwater, and postglacial lakes, which were and are fed by rain and groundwater. A detailed identification of the beginnings of lake formation also provides very important grounds for discussing permafrost evolution in young glacial areas at the end of the last glacial period.

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Spatial and temporal reconstruction of an abandoned Vltava valley between Kralupy nad Vltavou and Roudnice nad Labem

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Changes in flow direction during the Pleistocene are very important indicators of environmental changes and can be monitored by the presence of river terraces in abandoned valleys in a different position than expected nowadays. Tectonic activity, isostatic movements, and climate change have the biggest impact on the abandonment of valleys and changing flow direction. Data from boreholes can help determine the spatial extent of terrace accumulations. Dating of the environmental and flow direction changes can be done by determining the age of the river terraces, especially the ones that signal those changes. Cosmogenic nuclides ^{10}Be and ^{26}Al can date river terraces with a high share of quartz older than 0.5 Myr. Using dating with cosmogenic nuclides in depth profiles can determine not only the age but also surface denudation and nuclide concentrations from previous transport, allowing more precise results to be modelled.

The Vltava River in Czechia changed its flow direction between Kralupy nad Vltavou and Roudnice nad Labem during the Quaternary. The abandoned valley can be studied because fluvial sediments are well preserved there. Geological borehole documentation from the Geofond Archive of the Czech Republic, administered by the Czech Geological Survey, allowed the identification of a total of 5 terrace levels in the abandoned valley. These terraces indicate that the Vltava River changed its flow direction twice. First, it moved from the eastern side of Říp Hill into the palaeovalley on its western side and then into its current position. Cosmogenic radionuclides exposure dating, specifically ^{10}Be and ^{26}Al in depth profiles, was used to date terrace levels T_1 (highest), T_3, and T_5 (lowest). The ages of the dated terrace levels correspond to the Mid-Pleistocene revolution, during which a transition from short 41kyr cycles to long 100kyr climatic cycles occurred. The age of the oldest terrace level T_1 is 800 ± 59 ka (interpreted to occur during MIS 20), which matches the maximum age of the PalaeoVltava movement from the eastern side of Říp Hill to the palaeovalley on its western side. The results show that there were probably two terrace levels (T_2, T_3) accumulated during two cold fluctuations in MIS 18. The lowest terrace level T_5 is 673 ± 39 ka old, and its formation falls within MIS 16, which corresponds to the minimum age when the river Vltava left the palaeovalley west of Říp Hill and moved to its eastern side to its current position between Kralupy nad Vltavou and Mělník. This environmental change could have been triggered by isostatic changes connected to the first Scandinavian ice sheet front advance to Central Europe or river piracy. All terrace levels show a complex exposure history, and it is assumed that up to several meters of the originally deposited aeolian material was eroded above them. Compared to previous studies, a more precise temporal classification of individual terrace levels was obtained, and the earlier dating of these terrace levels exceeding 1 million years was not confirmed.

Morphogenetic and lithological controls on the evolution of a paraglacial barrier spit: evidence from the Eidem Spit (Svalbard)

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Under conditions of modern transgression and ongoing climate change, assessing the stability of coastal accumulative landforms has become particularly relevant, as these systems exhibit a wide range of evolutionary trends — from stabilization to destabilization.

The Eidem Spit, which formed over the past 90 years through the reworking of glacial and glaciofluvial deposits, represents a model example of rapid postglacial reorganization of a periglacial coastline. Its investigation makes it possible to assess the stability of young accumulative landforms under ongoing deglaciation and to consider contemporary processes as an analogue of coastal evolution during the Holocene.

The aim of the study is to identify the morphogenetic and litho-morphological patterns of the Eidem Spit structure and to interpret its evolution under conditions of postglacial deglaciation and transgressive coastal reorganization.

The Eidem Spit is located on the eastern coast of the Forlandsundet Strait in the Eidembukta Bay area (West Spitsbergen, Svalbard Archipelago). It extends for approximately 3.4 km from the mainland near Cape Eidempynten East (78°22'11.16" N; 12°45'41.47" E) toward the Eidem Strait (78°21'16.87" N; 12°52'34.56" E). In plan view, the spit has an arcuate shape (R ≈ 2.27 km); its width ranges from 60 to 200 m, reaching up to 500 m where it adjoins the bedrock promontory. The highest elevations are associated with the crest of the storm ridge (mean ~2.3 m; max 3.6 m; min 1.4 m) (Davydov et al., 2025).

The study is based on an integrated analysis of remote sensing and field data. Fieldwork conducted in 2023 included sediment sampling and measurements of the storm ridge crest parameters, with GPS-based recording of observation points. The spatial evolution of the spit was analyzed using Landsat satellite data (1984–2025, July–September) and archival aerial photographs from 1938, which allowed refinement of its formation conditions. Morphometric parameters were compared with altimetric survey data and the ArcticDEM digital elevation model (Porter et al., 2018).

Morphogenetic analysis of the Eidem Spit indicates that it formed through the reworking and redeposition of glacial and glaciofluvial sediments by coastal processes. The primary development of the spit from northwest to southeast is confirmed by archival aerial photographs from the 1930s, which show a clear connection between the proximal part of the spit and the delta of a glaciofluvial stream. The long-term dynamics of the frontal shoreline position of the spit (1938–2025) indicate a retrogradational trend, with retreat rates ranging from 0.7 to 2.1 m/year and increasing toward the southeast.

Morphologically, the spit represents an asymmetrical coastal ridge composed of distinct morphodynamic zones: the seaward slope, the crest, and the lagoon-facing slope. The seaward slope is steeper and progressively flattens toward the southeast (gradient 0.09–0.042), whereas the lagoon-facing slope, which is generally gentler, shows an opposite spatial trend (0.034–0.043). The development of a morphologically uniform subaqueous profile along the seaward slope reflects the adaptation of the landform to prevailing hydrodynamic conditions.

A clear lithological differentiation is also observed along the seaward slope of the spit: toward the southeast, the proportion of the gravel–pebble fraction decreases from 89% to 23%, while the content of sandy fractions correspondingly increases.

The upper part of the spit is represented by the crest of the storm ridge, which varies in elevation and degree of surface dissection. Longitudinally, it is most pronounced in the northwestern sector and gradually lowers and flattens toward the southeast, disappearing in the distal part of the spit. The crest is composed predominantly of coarse marine sediments, with the gravel–pebble fraction reaching 80–90%, while the content of sandy fractions varies irregularly along its extent.

No clear longitudinal differentiation of coarse-grained material is observed along the lagoon-facing slope; however, the progressive increase in the proportion of medium-grained sand toward the southeast indicates directed sediment transport by lagoonal currents. The absence of sorting within the coarse fraction is interpreted as the result of periodic storm overwash events, which lead to the formation of washover fans along much of the lagoon-facing slope.

The obtained results allow the Eidem Spit to be interpreted as a young postglacial accumulative landform formed through the reworking of glacial and glaciofluvial sediments under active coastal processes. Its primary development from northwest to southeast is confirmed by both historical records and present-day morphological and lithological characteristics.

The long-term dynamics of the frontal shoreline reflect retrogradational trends of the spit while preserving its longitudinal structural organization, indicating an adaptive transgressive reconfiguration of the landform. The longitudinal differentiation of sediments along the seaward slope points to the operation of directed longshore sediment transport toward the southeast.

The predominance of coarse-grained material (up to 80–90% gravel–pebble fraction in the crest and up to 89% on the seaward slope) indicates that the spit formed under conditions of high-energy ocean waves. It is precisely the dominance of coarse material that ensures the relative morphodynamic stability of the landform under ongoing transgression and intensified hydrodynamic activity.

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Contemporary spatial differentiation of deglaciation of a polythermal glacier as a model for Late Pleistocene ice margin retreat (a case study of Eidembreen Glacier)

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At present, the western sector of the Arctic is experiencing active deglaciation, accompanied by the exposure of extensive areas formerly covered by glacier ice (Hugonnet et al., 2021). Within Oscar II Land (Western Spitsbergen), the retreat of Eidembreen Glacier has led to the formation of a mosaic deglacial landscape comprising a glacial accumulation plain, a lagoonal depression, and a barrier spit (Davydov et al., 2025). The object of the study is Eidembreen Glacier and the adjacent periglacial surface, where the glacier front was located during the first half of the 20th century. The aim of the study is to investigate the long-term thermal regime of the periglacial surface as a factor controlling the spatial differentiation of the dynamics of Eidembreen Glacier.

Eidembreen Glacier is classified as polythermal, which determines the complex structure of its thermodynamic regime (Kotlyakov, 1984). Glacier dynamics are controlled not only by near-surface air temperature and the amount of solid precipitation, but also by the parameters of the surface energy balance, which govern the total energy input during the ablation season and the thermal state of the proglacial areas. Under polythermal conditions, contrasts in the adjacent surface may contribute to the spatial variability of glacier retreat rates. The periglacial surface adjacent to Eidembreen Glacier has an asymmetric fan-shaped configuration, widening from southeast to northwest, with a total area of approximately 29.5 km², of which 6.8 km² is occupied by the lagoon. The geological structure of the periglacial surface comprises areas composed of unconsolidated glacial, fluvioglacial, limnoglacial, and marine deposits (Davydov et al., 2025).

Standard Landsat Collection 2 Level-2 products (Landsat 5 TM, 7 ETM+, and 8/9 OLI/TIRS) were used for the spatial analysis of glacier retreat dynamics and for deriving land surface temperature (LST) of glacial and periglacial surfaces. The time series covers the warm season (July–September) for the period 1984–2025, corresponding to the phase of the most intensive glacier retreat. In addition, archival aerial photographs from 1938 (Norwegian Polar Institute, 1936–1938) were examined, allowing a comparison between present-day deglaciation rates and the historical position of the glacier front over a nearly 90-year interval.

The analysis of long-term mean retreat rates revealed a pronounced spatial differentiation along the glacier front, ranging from 19 to 42 m/yr. The highest deglaciation rates are observed in the western and northwestern sectors, where extensive areas of deglaciated land prevail. The lowest retreat rates were recorded in the southern and southeastern sectors, where the lagoon occupies a significant portion of the area. The results of the LST analysis indicate pronounced spatial variability in surface temperatures both across the glacier surface and within the adjacent deglaciated areas. The lowest land surface temperature values are recorded over the glacier and average −2 to −4 °C, with localized

episodic increases to +4 to +6 °C in areas covered by supraglacial moraine material. Within the lagoonal water area, LST values are characterized by relative stability (+2 to +6 °C), with lower temperatures observed in the zone adjacent to the glacier front and higher values recorded in shallow areas located near the barrier spit. The highest LST values (up to +20 °C) are associated with deglaciated terrestrial surfaces composed of unconsolidated glacial, fluvioglacial, and limnoglacial deposits. These values exhibit the greatest variability and reflect the intensity of heat accumulation within periglacial land areas.

The analysis of the LST time series revealed a three-phase pattern: a gradual increase in temperature during 1985–2000, a period of relative stabilization in 2000–2015, and a subsequent renewed increase after 2015, reaching maximum values in the most recent years. The obtained results indicate that the spatial differentiation of glacier retreat rates is directly related to the thermal heterogeneity of the adjacent surface. Contrasts in land surface temperature (LST) between glacial, aquatic, and deglaciated areas create differences in the thermal influence on the glacier front, thereby determining the uneven intensity of deglaciation within the study area.

Thus, the thermal regime of the proglacial zone acts as a key factor controlling the spatial heterogeneity of deglaciation in polythermal glaciers. Contemporary dynamics may serve as a model for interpreting the mechanisms of Late Pleistocene ice margin retreat and the formation of deglacial plains.

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Relict sand wedge-like polygonal structures at the southern edge of the Late Pleistocene periglacial zone in Hungary

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Relict sand wedge-like polygonal structures (SWLS) are widely recognised as significant indicators of periglacial processes and ground thermal regimes during the Late Pleistocene. In the Peri-Baltic lowlands and neighbouring areas of Central Europe, these features have been extensively utilised to reconstruct the spatial extent, internal variability, and temporal evolution of permafrost and seasonal frost environments during glacial-interglacial transitions (Fábián et al., 2014; Uxa et al., 2024). However, their palaeoenvironmental significance at the southern edge of the European periglacial zone remains less well understood. Similar polygonal forms may indicate a range of processes, from deep seasonal frost cracking to incipient or discontinuous permafrost, complicating traditional binary interpretations. This study examines SWLS in lowland Hungary and assesses their significance within a broader Peri-Baltic and Central European context.

The study area includes both lowland and hilly regions within the Pannonian Basin. These lowland areas are located well south of the reconstructed classical continuous permafrost zone for the Last Glacial Maximum (LGM). However, they contain extensive networks of buried polygonal features. The original surface expression of these structures is typically obscured by Holocene soil development. However, they can still be detected as cropmarks and subtle spectral anomalies in aerial and satellite imagery (Farkas et al., 2023). Similar lowland polygonal networks have been well documented from France to Poland, where they are often interpreted as indicators of permafrost or intense seasonal frost during the LGM (Bertran, 2022). Nevertheless, systematic comparisons of sedimentology, micromorphology, and provenance across this north–south transect remain limited.

Our study integrates remote sensing, field investigations, sediment analysis, and numerical dating to reevaluate the formation conditions and paleoclimatic significance of SWLS at the southern edge of the periglacial zone. We identified polygonal patterns using orthophotography, multispectral satellite imagery, and targeted drone surveys. We systematically measure various morphometric parameters, including polygon diameter, size and edge count. These measurements are compared with published datasets from the Peri-Baltic lowlands to identify latitudinal trends in polygon geometry and degradation states.

Field investigations focus on selected sites where sand-wedge infills and host sediments are accessible. The sedimentological analyses include measurements of grain-size distribution, paired with statistical end-member modelling to reconstruct sediment supply mechanisms and depositional environments during cold and arid phases. Special emphasis is placed on distinguishing aeolian-dominated infills from mixed or reworked sediments. Microscale investigations conducted using scanning electron

microscopy provide detailed insights into frost-related grain surface textures, cryogenic microstructures, and post-depositional disturbances (Farkas et al., 2025). This data allows for the differentiation between primary periglacial signatures and inherited or modified structures—an increasingly recognised challenge in both Peri-Baltic and Central European lowland studies.

Heavy-mineral analysis is applied to constrain the provenance of sand-wedge infill materials and to assess sediment-transport pathways within the Pannonian Basin. The results are discussed in relation to aeolian systems, palaeowind directions, and changes in vegetation cover during the Late Pleniglacial. Provenance signals indicate a complex interplay between local fluvial sources and long-distance aeolian transport, suggesting that southern-margin SWLS may record regionally integrated sedimentary processes rather than purely local frost-cracking phenomena.

Chronological control is achieved through optically stimulated luminescence (OSL) dating of sand-wedge infills. While incomplete bleaching poses a challenge in periglacial and fluvial-aeolian environments, the application of multiple aliquots and suitable statistical models enables the estimation of burial ages that indicate the end of active frost cracking. Preliminary results suggest that cracks formed and filled in an episodic manner during the later phases of the LGM, approx. between 22 and 15 ka ago. These ages coincide with established chronologies from southern Poland and the Czech lowlands, but also highlight significant spatial and temporal variability. This indicates that periglacial activity was neither synchronous nor uniform across Central Europe.

To improve regional-scale detection and comparability of lowland periglacial features, deep learning–based image analysis is tested using convolutional neural networks and transformer-based segmentation models. These approaches are applied to multispectral imagery to identify subtle polygonal patterns similar to those documented in European datasets. While automated detection substantially enhances spatial coverage and reproducibility, our results underscore the necessity of sedimentological and micromorphological validation when correlating polygonal landforms across different climatic and geomorphological settings.

Overall, the results demonstrate that relict SWLS at the southern edge of the Late Pleistocene periglacial zone record transitional environmental conditions rather than continuous permafrost. When evaluated alongside Peri-Baltic records, the Hungarian sites refine reconstructions of latitudinal gradients in periglacial processes and highlight the complexity of environmental transitions during and following the LGM.

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Sand wedges as important sedimentary archives in periglacial research

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One of the most common and spectacular macro-scale features of lowland periglacial environments are thermal contraction cracks (TCC). TCCs filled with allochthonous sand are called sand wedges. Initially, mm-wide sand veins are formed, which develop into sand wedges if followed by repeated lateral accretion. Sand wedges are called primary structures when they are filled exclusively with sand throughout their lifetime. However, secondary structures are filled with mineral material after the melting of wedge ice. Sand wedges tend to form polygonal networks from a plan view. The morphological (shape, diameter, angles etc.) and topographical properties (elevation, slope, microtopography) of these networks have been studied in different settings. These variables refer to local conditions which contribute to or limit sand wedge development. Sand wedge development is possible in areas where 1) vegetation cover is limited or absent, 2) snow is either deflated or winter precipitation is very low, and 3) sediment source is locally available for aeolian transport. Depending on the complexity of these factors, sand wedges can reach depths of up to 10 m, and widths of up to a few meters. Primary sand wedges are found today in the dry valleys of Antarctica, the polar deserts of Arctic Canada, and Northern Greenland.

The inherently supply-limited periglacial aeolian systems in which sand wedges might develop are further complicated by 1) hydrological factors, 2) active layer processes, and 3) the textural properties of the surface sediments. This means that, currently, sand wedge development is restricted to a few areas globally. Although sand wedges have been disregarded in modern periglacial research, it is clear that sand wedges have great preservation potential. They preserve sediments in a unique way by acting as a sediment trap, therefore their analysis can provide a sedimentological-geomorphological "window" into the past. The characteristics of their morphometry, their infilling sediments, as well as numerical dating possibilities (especially optically stimulated luminescence techniques) create a unique possibility to utilise sand wedges as valuable paleoenvironmental archives.

This work attempts to summarize relict and recent sand wedges across the globe and to give an overview about the main factors responsible for their development. Their main characteristics are discussed through geomorphological and sedimentological aspects. Since more than 25 years has passed since the last big summary paper on sand wedges, this presentation will focus on new results as well. Further inputs for a potential collaboration from the conference participants will be greatly appreciated.

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Morphologically undetected kettle hole (MUKH) in a Saalian esker near Tosie (Central Poland)

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Buried dead-ice melt-out structures are widely recognised in glacigenic environments; however, their subsurface expression within esker systems remains insufficiently documented. This study presents a detailed sedimentological and structural analysis of a morphologically undetected kettle hole (MUKH) developed within a Saalian (Wartanian) esker near Tosie in Central Poland. Unlike classical kettle holes, which are expressed as surface depressions, the investigated structure lacks a clear geomorphological manifestation and is identifiable only through internal deformation patterns.

The research integrates high-resolution sedimentological logging of gravel-pit exposures with ground penetrating radar (GPR) profiling, to reconstruct the deformation zone. The results reveal a spatially confined collapse structure restricted to the central part of the esker ridge. The deformation is characterised by large vertical displacements of gravelly, sandy, and fine-grained lithofacies, dense networks of high-angle normal faults (60–90°), marginal reverse faults, and internally developed horst-and-graben structures. The underlying massive gravel core remains undeformed, indicating that deformation postdates primary esker deposition.
The structural configuration, including deep marginal reverse faults and numerous central normal faults arranged in a step-like pattern, indicates progressive gravitational collapse above buried dead-ice blocks. The graben-like architecture closely corresponds to MUKH structures described from interlobate eskers in Finland (Ahokangas et al., 2020). The scale, stratigraphic position, and deformational confinement strongly support the interpretation as a buried ice-block melt-out structure formed beneath a thick sediment cover.
The structure's genesis is interpreted as the result of the gradual melt-out of large dead-ice blocks fromed by the collapse of the roof or walls of a subglacial tunnel during deglaciation. Progressive reduction in ice volume triggered gravitational subsidence of overlying sediments. Brittle deformation dominated, particularly within coarse-grained units, whereas fine-grained sands and silts display evidence of ductile behaviour and local fluidisation.

The Tosie structure represents the first detailed sedimentological documentation of a MUKH within a Saalian esker. The findings emphasise the importance of recognising subsurface dead-ice collapse structures in glaciofluvial systems, as they significantly influence internal heterogeneity and potentially hydrogeological properties of eskers. The study contributes to a broader understanding of subglacial tunnel evolution, post-depositional collapse processes, and the complexity of soft-bed esker architecture.

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Surface exposure dating of Saalian erratic boulders with in-situ cosmogenic ^{10}Be and ^{26}Al at the southern periphery of the Fennoscandian Ice Sheet

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This study presents new terrestrial cosmogenic nuclide exposure ages (^{10}Be and ^{26}Al) obtained from Saalian erratic boulders distributed across the southern margin of the Fennoscandian Ice Sheet (FIS) in three regions: eastern Germany, western Poland and eastern Poland. The objective was to refine the chronology of Saalian ice-marginal landforms along the latitudinal transect in the southern fringe if the FIS. A total of 53 erratic boulders were sampled: 21 from eastern Germany, 16 from western Poland, and 16 from eastern Poland. The resulting exposure ages exhibit substantial scatter within each region, indicating complex exposure–burial histories. In eastern Germany, ^{10}Be exposure ages range from 21.9 ± 1.8 ka to 101.9 ± 8.5 ka, whereas corresponding ^{26}Al ages range from 17.4 ± 1.7 ka to 78.5 ± 8.0 ka. Most of ^{26}Al ages cluster between 40 ka and 60 ka, while ^{10}Be ages predominantly fall between 40 ka and 80 ka. In western Poland ^{10}Be ages span from 8.8 ± 0.8 ka to 67.4 ± 5.6 ka, and ^{26}Al ages from 3.4 ± 0.7 ka to 53.2 ± 5.8 ka. The majority of ^{26}Al ages cluster between 15 ka and 45 ka, whereas ^{10}Be ages are concentrated mainly between 25 ka and 45 ka. In eastern Poland ^{26}Al ages range from 11.6 ± 1.5 ka to 87.8 ± 9.1 ka, with most ages falling between 10 ka and 40 ka.

Across all study area many exposure ages are significantly younger than the expected age of the Saalian termination (end of marine isotope stage 6). The wide dispersion and systematic ^{10}Be and ^{26}Al discrepancies indicate episodes of burial, exhumation, and surface reworking following initial deposition. These results highlight the complex post-depositional evolution of Saalian morainic landscapes at the southern periphery of the FIS and demonstrate that erratic boulders exposure ages do not necessarily always record the initiation of ice-margin retreat.

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Glacial erratic mega-blocks on the bed of the Fennoscandian Ice Sheet: origins, transport, and significance

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Observations of giant glacial erratics were pivotal in the birth of glacial theory in the 19th century. Yet outside of mountain areas, the origins of mega-block erratics have received limited recent attention. Here, we examine the sources, erosion mechanisms, and transport paths of large glacial erratics in the Precambrian basement terrain of lowland southern Sweden. We present Digital Elevations Models that show the regional distribution of boulder spreads and large erratics (Swedish: jätteblocks) using SGU data. We then use local case studies based on new UAV imagery and field mapping to link mega-blocks to sources and to establish glacial transport paths and distances. Angular mega-blocks > 10^3 m^3 in volume were sourced from smooth-topped rock knobs with exceptionally high (up to 10 m) vertical fracture spacing. Previous work has shown that such hills are highly resistant to glacial drag forces but that long fractures with high apertures make the hills susceptible to subglacial hydraulic damage by overpressured meltwater. Disruption of the hills generates new steps that allow application of glacitectonic forces across the hill mass, leading to further disintegration and block detachment. Most transport distances are short (<100 m and ≯20 km) and indicate that disruption and transport occurred late in the last deglaciation. Glacial mega-blocks are important not only for understanding the mechanisms of episodic erosion of rock knobs but also for wider public engagement with glacial geology.

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Mobility of subglacial till: ring-shear experiments and microstructural constraints

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Limited accessibility to the subglacial environment leaves processes operating therein poorly constrained. Understanding these processes is imperative for deciphering the dynamic behaviour of past ice sheets, in particular related to glacial erosion and sediment advection at the ice-bed interface. Their legacy is typically studied through investigating deposits left behind the ice sheets but conclusions often remain equivocal due to the scarcity of well constrained reference studies and modern analogues.

Here, we used a ring-shear apparatus to simulate the response of a subglacial traction till from northern Germany to stresses imposed on it by an overriding glacier. Bearing in mind all the simplifications and limitations inherent to *in-vitro* laboratory settings, these experiments intend to mimic as closely as possible the conditions beneath ice sheets. A homogenized natural water-saturated till was continuously sheared at effective normal pressure of 85 kPa and shearing velocity of 2 mm/min (i.e., parameters considered representative for ice sheets) to a total displacement of 80 cm. During and after the shearing, the till was sampled to (1) determine its Anisotropy of Magnetic Susceptibility (AMS), (2) analyse its microstructural characteristics using X-ray computed tomography (µCT) with a spatial resolution of 60 µm, and (3) constrain its micromorphological evolution during shearing based on thin section data. The results of AMS measurement show a high clustering degree of the elongated particles cluminating in the middle of the till. The µCT revealed a distinct relationship between the elongation of clasts (a/b axis ratio) and their orientation while the volume of pores steadily decreased suggesting progressive compaction. The thin sections indicate heterogeneous development of microfabrics, reflecting the partitioning of deformation and microfabric overprinting with increasing shear distance.

Our data show progressive evolution of till microfabrics with higher susceptibility to shear stress and thus higher mobility of smaller particles. The revealed processes point to a plastic rather than viscous mode of deformation.

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Origin of aeolian sand accumulations and evaluation of sediment fluxes in a meltwater-fed catchment on James Ross Island, Antarctica

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Aeolian sand accumulations and dunes are extremely rare in Antarctica, as only <0.5% (ca. 45,000–70,000 km^2) of its surface is ice-free (Vieira et al., 2010; Terauds and Lee, 2016; Lee et al., 2017; Brooks et al., 2019; Gerrish et al., 2020). The only Antarctic dunes can be found in McMurdo Dry Valleys (Speirs et al., 2008; Bourke et al., 2009; Bristow et al., 2010a, b) and only small aeolian sand accumulations were observed in other parts of this icy continent.

James Ross Island, located in the Weddel Sea east of the Antarctic Peninsula, represents one of such a places. A few aeolian sand accumulations are located in the Abernethy Flats, i.e. a place of confluence of many meltwater-fed rivers and creeks. James Ross Island is of great research interest because it is one the largest deglaciated areas in Antarctica (>300 km^2; Kavan et al., 2017), it is located in a precipitation shadow of Antarctic Peninsula mountain range (Láska et al., 2011), and the ongoing climate change impacts significantly on local terrestrial environments (Hrbáček et al., 2025). The dominant wind direction in the northernmost part of James Ross Island is south-westerly (Kavan et al., 2020). Regarding the climate change, some of the predictions suggest a rise in temperatures and evaporation, increasing thus the aridity of this place (Hrbáček et al., 2025). Furthermore, most of the precipitation is in a form of snow, which is distributed unequally over the landscape, as wind largely blow it out from the most convex parts of the surface (Nývlt et al., 2016; Kňažková et al., 2020). Therefore, the hypothesis is that the present small aeolian sand accumulations could develop into dunes in future, making the James Ross Island the second place in Antarctica with such landforms.

The main aim was to reveal the provenance of aeolian sand accumulations, map their extent, and examine sediments fluxes in a catchment, in which the studied accumulations are located. To do so, we collected samples from aeolian sand accumulations and from the presumed upwind sources and measured and compared their elemental composition using the portable XRF. Mapping was based on a UAV campaign over the study area.

Extent of the aeolian sand accumulations varies a lot, as the smallest forms are only up to 10 m^2 large, whereas the most prominent are spread over 50 m^2 or even 100 m^2. The geochemical results show that the Abernethy River, which is flowing next to the aeolian sand accumulations, is the most important feature controlling the distribution and development of the studied forms. First, the river carries the majority of source sediments coming from the nearby Triangular Glacier. Second, the river consist of two major channels close to the aeolian sand accumulations, while the more upwind channel blocks the sediment flux from the southwest. Most of the sediments transported by the southwest prevailing winds end their journey in this upwind channel or on an adjacent snowpatch. Only a small amount of sediments transported from southwest are able to cross both channels and get incorporated in the studied aeolian sand accumulations.

In future, we aim to keep monitoring by using the UAV the aeolian sand accumulations to asses whether their spatial extent is changing or not. The plan is also to re-collect the aeolian sand samples to evaluate if the sediment fluxed has changed in the catchment or not.

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The latest news on cold-climate dunes dynamics in the Vienna Basin, Central Europe

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The Vienna Basin is a ca. 50x200 km large tectonic burial and sedimentary basin in the seam area between the Alps, the Carpathians and the Pannonian Plain, which experienced profound landscape changes during the Last Glacial Period. Enormous amounts of loose sand brought to the basin by rivers, scarse vegetation, and strong winds led to sand accumulations, e.g. vast sand sheets and dunes that drape and hide a wide range of earlier morphologies. A recent systematic research led to palaeonvironmental reconstruction of the second largest (ca. 60 km^2) dunefield in the Vienna Basin, the Moravian Sahara (Holuša et al., 2022, 2024a, b; Holuša and Kadlec, 2025). The results show that two different atmospheric circulation systems met in the Vienna Basin during the Last Glacial Maximum. The northern part of the Vienna Basin was dominated by northern winds coming from the Scandinavian Ice Sheet (Holuša et al., 2024b), whereas the southern part was dominated by northwestern to western winds, similar to existing modern patterns (Sebe et al., 2015). This setting probably lasted until the Oldest Dryas, when the Scandinavian Ice Sheet retreated far north and the katabatic winds did not reach the Vienna Basin. In turn, westerlies penetrated the basin and gradually prevailed in the northernmost parts of the area (Holuša et al., 2024b).

Large parts of the Vienna Basin remain understudied with regard to past aeolian activity, leaving significant gaps in knowledge and understanding. The Borská nížina lowland hosts the largest dunefield (ca. 500 km^2) in the Vienna Basin, including up to 30 m high dunes. Previous research provides a general description of dunes with a few published OSL ages dated between 25.8 ± 1.7 ka and 12.2 ± 0.6 ka (Fordinál et al., 2013; Kadlec et al., 2015), 1:50,000 geological maps (Fordinál, 2012), and finds of unique neotectonic features within thick aeolian sand deposits (Šujan et al., 2022). Sporadically isolated floodplain dunes in the Vienna Basin (ca. 20 km SW from the Moravian Sahara) also remained understudied.

The main aim of our research is to map and evaluate all the possible factors controlling the development of cold-climate dunes located in the Vienna Basin. We also aim to find more evidences pointing to propagation of katabatic winds to the basin during the Last Glacial Maximum and, if possible, determine a place of contact between two atmospheric circulation systems prevaing of the study area during this period.

Here we present preliminary results of a research campaign on the Borská nížina and isolated dunes. To reach the research aims, we used sedimentological data (grain-size properties, lithofacies), LiDAR DTM, relative age port-OSL profiling and OSL dating, ground-penetrating radar surveys, geochemistry (elemental composition measured using the posrtable XRF), and quartz grain morphoscopy. We have also collected samples for port-OSL profiling from one trench dug through one of the dunes in the Moravian Sahara to compare the results.

Port-OSL dating profiles obtained from the Borská nížina dunefield, isolated dunes and the Moravian Sahara reveal usually continuous and occassionally rapid dune formation over time. Most of the sand grains from the Borská nížina lowland and isolated dunes fall in the classic dune grain-size range of 125–250 µm. Two groups of differently oriented transverse dunes were detected in the Borská nížina lowland dunefield, supporting the hypothesis of Late Glacial atmospheric circulation changes (Holuša et al., 2024b). Morphological classification (and thus wind reconstruction) of the isolated dunes is challenging, as their original geometry was largely reshaped during by Holocene floods. LiDAR data leans to morphologies resembling parabolic or barchans, meaning that the dunes were formed by NE or SW winds.

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Late Holocene storminess and shoreline changes in the Harilaid Peninsula, Eastern Baltic Sea

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Global warming, sea-level rise, and changes in storm activity require improved understanding of the Earth system. The non-tidal, uplifting eastern Baltic Sea coast preserves Holocene coastal formations suitable for reconstructing pre-instrumental shoreline changes and storminess. The Harilaid Peninsula (NW Saaremaa Island) is a low-lying (~4 km², up to 4.7 m a.s.l.) coastal landform that developed from a cluster of islets into a tombolo-connected peninsula. Its morphology includes sandy beach ridges and foredunes in the north, and pebbly–gravelly ridges in the south, including the Kelba spit complex. The coastline is exposed to the open Baltic Sea and subject to frequent storm impact. This study reconstructs Late Holocene shoreline displacement and storm activity using sediment records from isolated coastal lake basins at different elevations. The analysis combines cartographic data, high-resolution LiDAR, ground-penetrating radar (GPR), and multi-proxy sediment analyses, including loss-on-ignition (LOI), grain size, magnetic susceptibility, X-ray fluorescence (XRF) geochemistry, computed tomography (CT), and radiocarbon dating. The highest basin was isolated from the Baltic Sea around 1325 AD due to glacio-isostatic uplift and spit progradation. The transition from marine to lacustrine conditions is indicated by decreased Br/Ti ratios. The sediment record identifies two discrete storm phases at 1320–1370 AD and 1550–1610 AD, and a prolonged interval from 1730 to 1970 AD, consistent with historical data. Pre-isolation deposits consist of fine sands from reworked coastal bars, while post-isolation sediments are coarser and associated with barrier erosion and overwash. The results show that isolated coastal lake basins can be used to reconstruct centennial-scale storminess and shoreline development in non-tidal, uplifting coastal environments.

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From Deflation to Deposition: Ice-Margin Retreat Drives Spatial Inversion of Loess Systems in Southwestern Poland

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The North European Loess Belt (NELB) formed within the extraglacial domain of the Fennoscandian Ice Sheet, where loess accumulation was tightly coupled to spatiotemporal variations in ice-sheet margin dynamics. In southwestern Poland, the principal phase of loess deposition occurred during the Last Glacial Maximum (LGM) and subsequent deglaciation, a period marked by rapid reorganisation of foreland morphoclimatic zones driven by ice-margin oscillations.

New high-resolution luminescence chronologies from two regions in southwestern Poland—the Niemcza–Strzelin Hills (~140 km from the LGM limit) and the Trzebnica Hills (~70 km from the LGM limit)—demonstrate a clear diachroneity in loess accumulation. Loess deposition in the distal Niemcza–Strzelin region terminated at ~18 ka, whereas in the more proximal Trzebnica region it was initiated at that time, following an earlier phase of deflation and erosion.

We identify a pronounced, transient zonation of sedimentary environments in the ice-sheet foreland, structured primarily by distance from the ice margin and associated thermal gradients. Proximal zones were characterised by high sediment availability due to glacial comminution and periglacial weathering, but were dominated by deflation and sediment export under the influence of katabatic wind systems and high-energy fluvial reworking. In contrast, more distal zones functioned as net depositional sinks, where reduced wind competence and enhanced surface stability promoted sustained loess aggradation.

This spatial inversion provides direct evidence for the migration of morphoclimatic zones in response to ice-sheet retreat. As the ice margin receded, belts of dominant deflation and transport shifted poleward, while previously erosional domains transitioned into zones of loess accumulation. These findings highlight the primary control exerted by ice-sheet dynamics on the organisation of periglacial sedimentary systems and demonstrate that loess deposition in the NELB cannot be interpreted as a synchronous process, but rather as a time-transgressive response to the evolving position of the ice margin. Local geomorphological conditions further modulated this pattern, reinforcing spatial heterogeneity in loess thickness and preservation.

Plateau-like hills in the Vištytis Upland, SW Lithuania

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The spatial geological mapping of the Kalvarija area (879 km^2) was carried out at a scale 1:50 000 in the period 2024 – 2025. Geological and geomorphological maps of the Quaternary deposits were created at a scale 1:50 000 based on the material collected during the mapping process. The creation of maps was based on the airborne aerial photo interpretation, field observations and analysis of a high-resolution LiDAR digital elevation model (DEM). Plateau-like hills were mapped in the southern part of the study area within the Vištytis Regional Park, near the Lithuanian-Polish border approximately seven kilometers to the east of Lake Vištytis. These hills are characterized by irregular shapes and flat surface, extending over 1,4 kilometer in width and 2,8 kilometers in length. The surface altitude of the hills ranges from 270 meters to 283 meters. The relative height of the plateau-like hills reaches up to 33 meters. They are composed by clay, silty clay, silt and very fine-grained sand. The plateau-like hills stand significantly elevated above the surrounding relief of marginal formations. They were formed during the Late Nemunas period when glacier flows from the north covered previously formed morainic hills. These plateau-like hills are surrounded by a glaciolacustrine kame terraces that formed on their slopes. Additionally, the slopes of the plateau-like hills are extensively eroded by both old and young ravines and gullies.

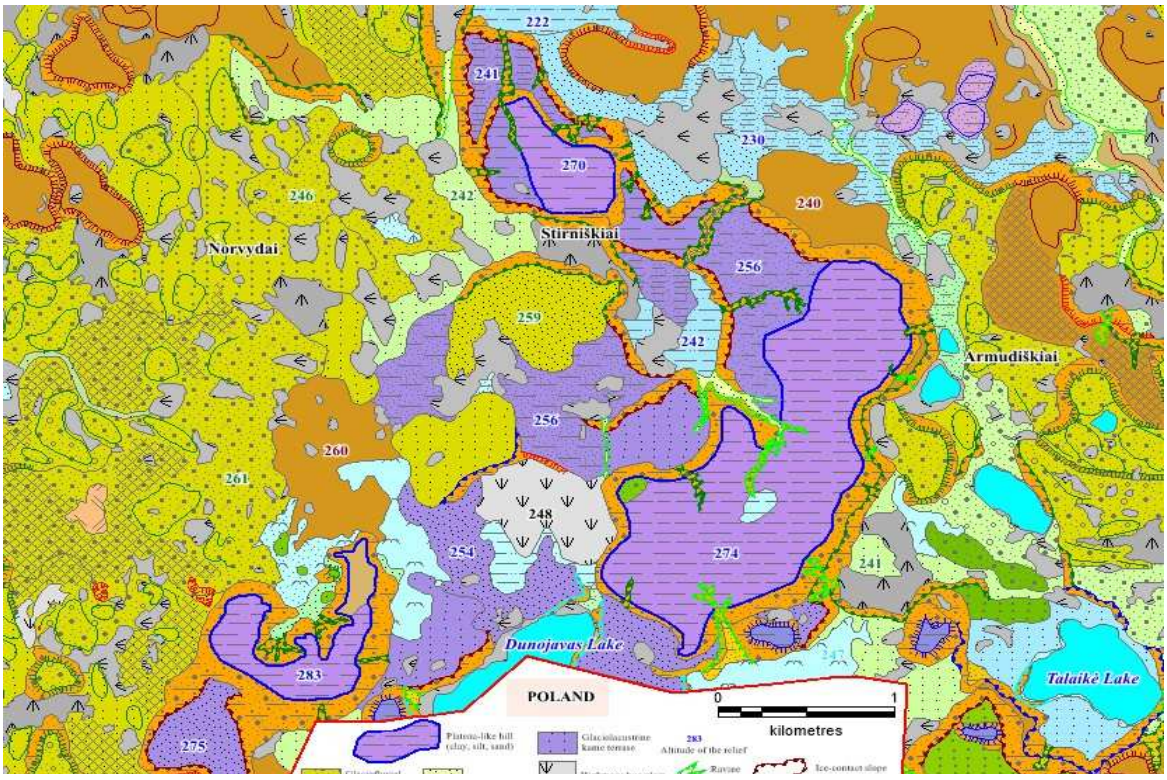

Fig.1. Fragment of a geological-geomorphological map.

Pleistocene and Holocene Sediments Comparison Based on Geochemistry, Lithuania

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The Quaternary period was characterized by repeated glaciations and interglacial periods, resulting in extensive sediment deposits with diverse compositions. Pleistocene glacial sediments underwent physical weathering and mechanical transport of material from various bedrock sources. Quaternary sediments in Lithuania were deposited under the influence of the advancing and retreating Scandinavian ice sheet during the Pleistocene. Pleistocene and Holocene sediments range from clay-rich tills deposited directly by glaciers to well-sorted sands and gravels deposited by meltwater streams and rivers.

The distribution of rare earth elements (REEs) in sediments generally depends on their content in the parent rocks and their distribution in the mineral phases. Sources of variation in REEs and major and minor elements could be various: suspended river runoff, aeolian dust, glacier runoff, etc. We used geochemical data to reconstruct sedimentation, weathering, etc. Major, minor, and REE data can also be used to compare sediments and past environmental conditions. Previous studies have shown that the geochemistry of Quaternary sediments indicates a mixture of sediment sources and shifts in the depositional environment, ranging from carbonate-dominated to siliciclastic conditions, most likely in response to glacial-interglacial dynamics. Some calculated average proxies of major and minor elements suggest low to moderate chemical weathering intensity from the Holocene to the Pleistocene. However, although major and minor element geochemistry is widely used, REE data is scarce for Pleistocene and Holocene sediments in Lithuania.

As a result, the variation in the geochemistry of the studied sediments, especially the REE, was used to compare the sediments and to study the sedimentation peculiarities of the transition from the Pleistocene to the Holocene.

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Modelling of the Quaternary Subsurface: Workflow and Initial Results for a Pilot Area in Northern Germany

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Detailed knowledge of the Quaternary subsurface and its visualisation in three-dimensional models constitute a fundamental basis for hydrogeological and geothermal applications. For a pilot area in northern Schleswig-Holstein (N-Germany), all relevant datasets—including boreholes, geological cross-sections, and geophysical surveys – were compiled and systematically evaluated. The primary data foundation comprises more than 5,000 boreholes; missing stratigraphic information was supplemented wherever possible. Marker horizons from the Eemian and Holsteinian interglacials, as well as from the Saalian complex and their documented depth levels, serve as key reference points. In addition, the spatial distribution of near-surface Weichselian and Saalian deposits provides an important framework for stratigraphic interpretation. Supplementary data were derived from the Geological Map of Schleswig-Holstein at a scale of 1:50,000, as well as from selected palaeontological, clast-provenance, and geochronological studies.

The compiled data form the basis for modelling the base of the Quaternary and selected Pleistocene horizons. These horizons can be correlated with the hydrogeological stratification scheme of Schleswig-Holstein. Delineation of the Quaternary base is locally particularly challenging due to gradational lithological transitions to Pliocene and Miocene sands. Furthermore, the heterogeneous spatial distribution of boreholes in under-explored areas results in increased uncertainties. Modelling was conducted using the software Aspen SKUA V15. Existing hydrogeological models and previously developed three-dimensional models of the Quaternary base were used to validate the new modelling results and to ensure a consistent representation.

The systematic compilation, evaluation, and quality assessment of the data enable a robust three-dimensional model of the Quaternary subsurface in the pilot area of northern Schleswig-Holstein and provide a reliable foundation for applied geological investigations.

Cladocera-based reconstruction of Late-Glacial and Early Holocene environmental changes at Lake Velykoye (Belarus)

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Subfossil Cladocera assemblages from Lake Velykoye (54.160330 N; 28.148995 E), a shallow dystrophic lake in central Belarus, were analysed to reconstruct environmental changes during the Late-Glacial and Early Holocene (ca. 13,200–8,100 cal yr BP). The sediment core analysed in this study was collected in 2013 and has previously been investigated using multi-proxy analyses, including pollen and plant macrofossils (Stančikaitė et al., 2022). The present study provides new information on the ecological development of a shallow postglacial lake in eastern Europe and the response of freshwater ecosystems to rapid climatic transitions.

The earliest phase of lake development (before ca. 13,000 cal yr BP) is characterised by very low cladoceran abundance and species richness. Assemblages were dominated by the tolerant littoral taxon *Chydorus sphaericus*, indicating low productivity and unstable environmental conditions under a cold Late-Glacial climate. The rare occurrence of planktonic taxa suggests the absence of a persistent pelagic habitat, whereas sporadic occurrences of thermophilous taxa may indicate short-lived warming episodes. During the Late-Glacial transition (ca. 13,000–11,700 cal yr BP), cladoceran assemblages remained species-poor and unstable. Fluctuations in the abundance of littoral and macrophyte-associated taxa indicate repeated changes in lake level and habitat availability. The dominance of ecologically tolerant taxa reflects environmentally stressful conditions and reduced habitat stability, particularly during the Younger Dryas. A major ecological change occurred at the onset of the Holocene (after ca. 11,700 cal yr BP), when cladoceran abundance and species richness increased markedly. The expansion of macrophyte-associated taxa (*Alona affinis*, *Acroperus harpae*, *Alonella nana*, *Eurycercus lamellatus*) indicates the development of well-structured littoral habitats and increasing primary productivity. The appearance of thermophilous taxa (*Camptocercus rectirostris*, *Pleuroxus trigonellus*, *Pleuroxus uncinatus*) around 10,200–10,000 cal yr BP reflects progressive Early Holocene warming and increasing nutrient availability.

The cladoceran record from Lake Velykoye demonstrates that postglacial ecosystem development was controlled by the combined influence of regional climate change and local environmental processes, particularly hydrological fluctuations and the expansion of littoral habitats. The Lake Velykoye record provides new cladoceran-based data for the reconstruction of Late-Glacial and Early Holocene environmental changes in eastern Europe.

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Groß Buchholz (Perleberg, Prignitz) — a remarkable series of Eemian to Early Weichselian sediments — first results

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Since spring 2025, a sequence of Eemian (MIS 5e) and early Weichselian glacial-lake sediments has been exposed in the gravel pit Groß Buchholz-2 (near Perleberg, Prignitz district, location: see Fig. 1), which is being continuously documented in the course of the extraction process. The gravel pit is located in the north of a ridge structure that has now been largely mined and had been interpreted as esker by Sonntag (2008). This genetic interpretation is also supported by our geomorphological investigations.

In western Prignitz area, sediments of the younger Saale advance (Warthe s. str., MIS-6) predominate at the surface and show strong periglacial overprinting. Also, a possible Weichselian ice cover (MIS 2?) of the area is being discussed, as the regional extent of last glacial maximum (LGM) remains uncertain (Sonntag, 2008; Lippstreu et al., 2015).

The limnic Eemian sequence is located in the northeastern part of the gravel pit and is relatively small, extending approximately 250 m. The limnic basin fill is underlain and overlain by carbonate-free fine sands. According to the current state of pollen analysis, the limnic sedimentation began during the Eemian pollen zone (PZ) 2 sensu Erd (1973; 'pine period') and continued into the Early Weichselian. Most thickness of the Eemian limnic sequence were deposited during the PZ 9 ('pine-birch period').

The Eemian sequence starts locally with a thin layer of calcareous mud (PZ 2-3), with some isolated Characeae oogonia. However, its main part consists of olive-black, carbonate-free organic-rich mud (PZ 5-9). It is highly compacted, tough in dry conditions (becoming elastic when wet), and broken into coarse clasts several centimeters thick. Its basal part (PZ 5) is characterized by an abundance of diaspores of the thermophilic *Najas marina*. This indicates shallow, standing or slowly flowing water under meso- to eutrophic conditions (Jäger and Werner, eds. 2002). Xylotomical studies show a dominance of pine trees (*Pinus*) in the lake's environment.

The Eemian limnic sequence, up to 2.3 m thick, is overlain by an alternating humic, silty fine sands and humus-free fine sands attributed to the Early Weichselian cooling phase. The profile is overlain by several meters of periglacially redeposited fine sands, locally with some gravels (coarse vertifacts), beneath a periglacial cover layer ('Geschiebedecksand') up to 1 m thick.

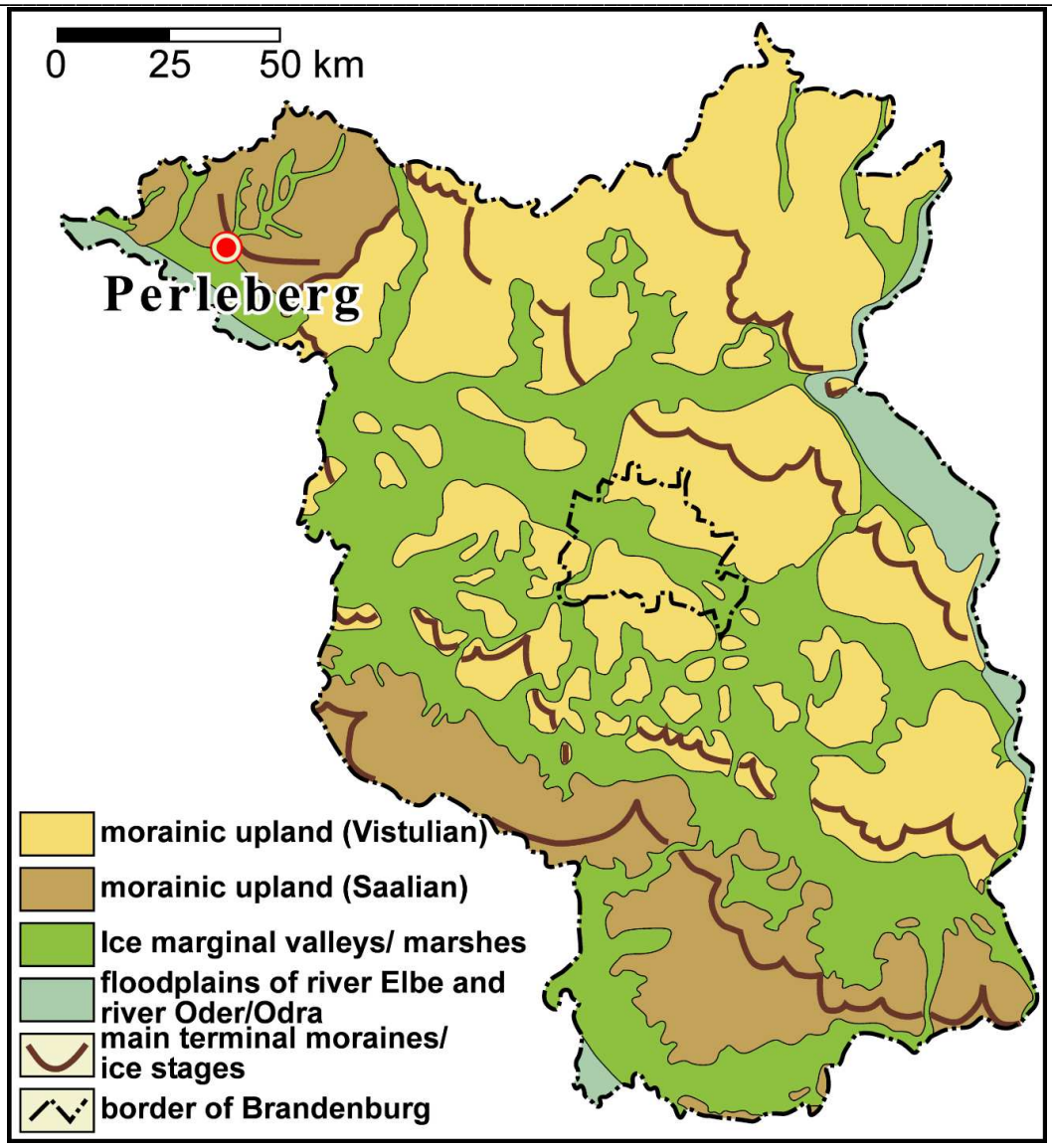

Fig. 1: General geologial map location of NW Brandenburg showing the location of the Groß Buchholz-2 gravel pit.

The Eemian muds show intense deformation in sections within both, into the underlying and overlying strata, and are interlocked with the adjacent fine sands. We observed differences in structural deformation styles. In the lower part of the central basin, meso- to macroscale subsidence structures are dominated by downwarping and injection of Eemian mud into the underlying sand unit. In the shallow lake zone and in the upper part of the Eemian unit, we observed scour structures, recumbent folds progressing to overturned folds, locally developed thrust structures, and intraformational breccia. We interpret these structures as most likely generated by mass-flow movement (slides) of the upper Eemian mud into the overlying Early Weichselian unit, associated with active-layer processes under periglacial conditions.

According to our research, there is indeed no evidence of Weichselian ice cover in this part of Prignitz. Due to this, the regional LGM limit is likely to lie further North and East. Next investigation steps are: absolute dating of whole sequence by OSL (quartz and feldspar), detailed palaeoecological (e.g. cladoceran) and geochemical studies.

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Quaternary calcareous sandstone from the Izbica profile (Central Poland) as a product of carbonate cementation in shallow groundwater under interglacial conditions

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Quaternary calcareous sandstones are unusual rocks found in glacial sediments of Polish Lowlands. Their origin has been attributed primarily to the leaching of calcium carbonate from tills by meteoric waters (interglacial and Holocene conditions) or to cementation in the subglacial zone (during glaciations; for an overview, see Kulus, 2025). This study focuses on a sandstone layer from Izbica in Central Poland. The examined site lies within the extent of the Saalian glaciation (MIS 6) on the border of the morainic plateau and the regional depression (Warsaw Basin). The occurrence of sandstone layers in this region was previously described by Skompski and Nowak (1965).

The aim of the study was to describe the sandstone's microstructure, mineral and isotopic composition, and determine its origin. Grain-size analysis, calcium carbonate content analysis, X-ray diffraction (XRD), microscopic analysis of thin sections (optical microscopy with cathodoluminescence, scanning electron microscopy) and fresh fractures, and carbon and oxygen isotope analysis were used.

The sandstone occurs at the top of the sandy-gravel fluvioglacial series, under the limnoglacial series of varved clays. It forms a cemented layer 2-5 cm thick with ripplemarks. On its top surface, a discontinuous micritic cover, a few mm thick, occurs in places. The sandstone layer shows the strongest cementation in the upper part and the weakest in the bottom. The cements are calcite. In the thin sections, primary sediment layering is visible. Sparry isopachous rims ranging in thickness from 10 to approximately 20 µm occur around the grains. These isopachous rims are interconnected by microsparry meniscus cements. The remaining intergranular space is in places completely filled with massive micrite or equant microsparite and sparite. The cements are non-luminescent. Older detrital carbonate grains, however, are distinguished by their orange color in the cathodoluminescence image. Sometimes, they form fine detritus dispersed in the form of a matrix. Needle-fiber calcite, approximately 10-40 µm long, occurs in the pore spaces. The limestone erratics (dropstones in varved clays, grains from fluvioglacial series and from sandstone) show $\delta^{13}C$ and $\delta^{18}O$ values (respectively) −1.09‰ to 1.21‰ and −6.88‰ to −1.85‰. The varved clays above the sandstone fall within a similar range for carbon (−1.4‰ to 0.34‰), but form a more compact group of oxygen results (−5.55‰ to −4.09‰) than the limestones. The sandstone samples form a distinct group with ranges of −10.07‰ to −7.65‰ for carbon and −7.19‰ to −6.57‰ for oxygen.

The first stage of cementation was the formation of isopachous rims around grains in the phreatic zone. The non-luminescent nature of the cements indicates that they formed under oxidative conditions, i.e., in shallow groundwater (Barnaby and Rimstidt, 1989). The development of the first generation of cements was probably related to the mechanism of the common ion effect (Wright and Tucker, 1991). Groundwater saturated with bicarbonate ions from acidic soil waters rose until it encountered the clays, which served as a source of Ca^{2+} ions and, at the same time, a condensation surface. The second stage of cementation (meniscus cements) occurred under vadose conditions. Then, the groundwater level rose again and massive micrite and equant cement filling the intergranular

space (or part of it) precipitated. After this process, on the sandstone surface, micritic cover (discontinuous lamina) was secondarily formed. This is displacive calcite, forming alpha-fabric calcrete (Alonso-Zarza and Wright, 2010). It was formed with small amounts of meteoric water infiltrating the clays. Due to the poorly permeable nature of the clays, small amounts of meteoric water reached the bottom of the series, where, upon contact with calcareous sandstone, precipitation occurred. In this way, calcite displaced the overlying sediment, creating a micritic cover on the top of the sandstone. After the formation of solid rock, needle-fiber calcite precipitated in the vadose pore zones due to the activity of microorganisms (Cailleau et al., 2009).

Cements in the sandstone retain the influence of the carbon signal from erratic carbonates, but their values are shifted due to the influence of biogenic carbon (Tolliver, 1992). Such isotopic composition is characteristic of interglacial environments (Tolliver, 1992; Letsch, 2014), as it indicates the presence of vegetation (Gradziński et al., 2014). Moreover, the oxygen isotope record does not show a shift towards very negative values around -20‰, typical for glacial waters (Letsch, 2014). Therefore, the precipitation from high-level groundwater should be associated with the Eemian interglacial (MIS 5e) or Holocene.

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Reconstructing palaeo-ice lobe dynamics in Latvia from the glacial landform record

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We continue to map and investigate glacial landforms in Latvia with an aim to infer and revise ice lobe dynamics, ice flow pattern and deglaciation of the southeastern sector of the last Scandinavian Ice Sheet (SIS). A 1-m-resolution LiDAR-derived digital terrain model (DTM) serves as basis for the nationwide geomorphological mapping. Several tens of thousands of streamlined bedforms such as drumlins, megaflutes and mega-scale glacial lineations, eskers, tunnel valleys and meltwater channels, crevasse-squeeze ridges, plateau-like glaciolacustrine hills, cupola hills, hummocky moraines and ice marginal landforms comprising composite glaciotectonic ridges and massifs and push moraines are mapped as a first step.

Ice flow directions and deglaciation of Latvia has been investigated mainly using topographic maps (e.g. Zelčs, Markots, 2004; Zelčs et al., 2011; Lamsters, Zelčs, 2015), however LiDAR DTMs have already demonstrated unprecedented detail in the identification of the even slightest glacial landforms as crevasse-squeeze ridges (Lamsters et al., 2021), which allow inferring surging or very fast ice streaming behaviour followed by widespread ice stream stagnation in several lowlands in Latvia. A large number of glaciofluvial features comprising thousands of eskers, tunnel valleys and proglacial meltwater valleys and channels, which are largely not included in the regional reconstructions of the deglaciation of the SIS, clearly reveals abundant glacial meltwater and wet bed deglaciation. Abundant marginal landforms including recessional end moraines, composite ridges, thrust masses attest highly dynamic and oscillatory deglaciation. Potential ice lobe subglacial and submarginal freeze-on is also revealed in places from the detached and displaced substrate blocks along shallow décollement zones represented in topography as streamlined or almost intact megarafts and related depression with sometimes steep and pronounced back and side walls.

Overall, the palaeo-ice lobe dynamics in Latvia demonstrate the impact of bedrock topography on the regional and local scale ice flow pattern and highly dynamic nature of ice lobes during the deglaciation of the Late Weichselian ice sheet margin during the Oldest Dryas. The database of OSL, 14C, and beryllium-10 ages is being compiled to serve as a base for the reconstruction of deglaciation chronology and possible correlation of ice margin positions.

We use the glacial landform database to establish an automated workflow for mapping glacial features. This includes testing various approaches based in computer vision, like YOLO and RetinaNet, and traditional machine learning on the results of unsupervised DEM derivative segmentation with Simple Linear Iterative Clustering. Preliminary results show a high potential for a robust machine learning framework for glacial landform delineation.

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Multiproxy analysis of biogenic cores from kettle holes and lake: case study from the Ostrowite archaeological complex (Northern Krajna Lakeland, N Poland)

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Biogenic sediments of kettle holes are important geoarchives of environmental changes on recently glaciated areas due to the possibility of preserving indicative plant and animal remains. These small depressions are characteristic land relief forms for Pomerania Lakeland (N Poland) covered by last Fennoscandian ice sheet. Numerous palaeoecological studies of the past environment of the Pomerania Lakeland area focused mainly on large lakes, mostly situated on the outwash plains, and not on small kettle holes on moraine plateaus. Large lakes differ significantly in their evolution from small depressions. In the Pomeranian Lakeland, a few kettle holes have been investigated in terms of their Late Weichselian and Holocene evolution (Leszczyk, 2024).

The Ostrowite archaeological complex is an interesting area for palaeoecological studies due to vicinity of numerous kettle holes and Ostrowite Lake. The area is also well documented archaeologically, which makes it possible to assess the impact of past local societies on lakes' and swamps' ecosystems. Our research aims to reconstruct the evolution of three small kettle holes in the Ostrowite area during Late Weichselian and Early and Mid-Holocene based on palaeoecological and geochemical proxies record in biogenic sediments cores. Analysis of the biogenic deposits core from Ostrowite Lake (named "OSI") is focused on the reconstruction of the paleoenvironmental conditions in the Late Holocene, i.e. during the period of intense human occupation on the lake shore.

Biogenic sediment cores named "OST1", "OST2B", and "OST4" were collected from small, closed depressions situated on the moraine plateau. The profiles were examined by palaeozoological analyses (subfossil Chironomidae, Cladocera, and Mollusca), palaeobotanical analyses (pollen, plant macrofossils), diatom analysis, geochemical analyses, and radiocarbon (^{14}C) dating.

"OST1" core consist of 6 meters biogenic sediment, mainly fine detritus gyttja, calcareous fine detritus gyttja, and fine detritus gyttja with silt and clay (Kittel et al. 2025). Small basin was created after melting of dead ice block(s) in Bølling-Allerød interstadial. Postglacial lacustrine ecosystem was favourable for

chironomids development like *Corynocera ambigua*, *Microtendipes pedellus*-type and *Chironomus antracinus*-type and stonewort (*Chara*) meadows. At the onset of the Holocene, in Preboreal, progressive overgrowth of the lake with macrophytes and significant shift in the composition of zoological assemblages occurred. Cold stenothermic chironomids decreased replaced by numerous chironomids typical of meso-eutrophic water and organic deposits, (e.g. *Chironomus plumosus*-type, *Tanytarsus pallidicornis*-type, *Procladius*). All studied proxies indicate that transformation of the lake into a mire occured ca. 7100 cal BP. This was a habitat for tyrphophilous chironomids, such as *Limnophyes*, *Paratendipes nudisquama*-type, and *Pseudorthocladius*. Drying out "OST1" depression occurred after 4700 cal BP.

The evolution of the "OST2B" depression differed slightly from that of "OST1". This situation occurs despite the close proximity of both reservoirs (ca. 200 m between studied cores). The organic deposits layer is 3 meters thick and consists mainly of basal peat, fine detritus gyttja, and clayey-calcareous gyttja. During the Allerød, a peatland developed on melting dead ice, forming a basal peat layer rich in numerous fragments of wood. The wetland was overgrown by *Salix* and covered by Cyperaceae and Poaceae. A Late Glacial lake began functioning at that time and provided favourable conditions for chironomid assemblages due to the presence of a permanent water body. By the end of the Late Glacial, chironomid remains reached 89 individuals/ml, dominated by *Corynocera ambigua* and the *Microtendipes pedellus*-type. At the onset of the Holocene, chironomid abundance decreased significantly; palynological analysis indicates two hiatus—one at the beginning of the Holocene and another at the onset of the Preboreal period. During the Boreal, chironomids associated with meso-eutrophic conditions and macrophytes dominated. Another hiatus occurred at the end of the Atlantic period, when no chironomid remains were identified. In the Subatlantic, the depression functioned as a mire overgrown by *Typha latifolia*, *Sparganium*-type, *Oenanthe aquatica*, and Cyperaceae. The uppermost, Late Holocene core section contains pollen evidence of human activity, reflected in high abundances of ruderal nitrophilous plants such as *Urtica*, Chenopodiaceae, and *Artemisia*.

The 140 cm of organic sediments in the core "OST4" indicate alternating lacustrine and peat bog phases. The core mainly contains coarse-detritus gyttja and peat. Analysis of chironomids shows their high frequency throughout the profile, which may indicate favorable conditions for their development and the absence of periods of drying of the lake.

The "OSI" core from Ostrowite Lake is 11,5-meters long, consist of clayey-fine detritus gyttja and basal peat at the lowermost section of the core. Radiocarbon dating indicates that the lake formed at the beginning of the Younger Dryas (12,715–12,625 cal BP). The 2.5 meters of the uppermost section of core were analysed in detail. Radiocarbon data set and results of ^{210}Pb and ^{137}Cs dating indicate a record of paleoenvironmental conditions from the Middle Ages (651-949 cal AD) to the present times. Analysis of subfossil remains of Chironomidae indicates eutrophic conditions in the lake since the Middle Ages and a well-developed aquatic plant zone in the lake, as evidenced by a large representation of phytophilic chironomid taxa preferring eutrophic conditions (including *Cricotopus intersectus*-type, *Dicrotendipes nervosus*-type and *Glyptotendipes pallens*-type).

Multiproxy research provides insights into the evolution of three small lakes in the Pomeranian Lakeland. The results indicate that kettle-hole lakes undergo different evolutionary pathways depending on their morphometry and depth. The analysis of sediments from Lake Ostrowite allows us to identify medieval human impact on local ecosystems.

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High-resolution grain-size variability within a Late Glacial inland dune foreset at Przyłubie, Toruń Basin, Poland

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The study was carried out at Przyłubie, within the dune field of the Toruń Basin, which forms the eastern part of the Toruń–Eberswalde ice-marginal valley, north-central Poland. The investigated object is the foreset of a Late Glacial inland dune exposed in the wall of an excavation made for the construction of the S10 expressway in the Bydgoszcz Forest. The site preserves a well-developed internal depositional structure of aeolian sediments and provides favourable conditions for analysing small-scale textural variability within a single dune-building element. Material was collected along a 106 m long horizontal transect crossing the dune foreset. Samples were taken at 1 m intervals, and each sampling point was represented by five horizontally adjacent samples. In total, 530 samples were obtained. Owing to the geometry of the exposure, it was not possible to follow the same lamina continuously, and the transect therefore crossed successive foreset laminae visible in the dune face.

Grain-size analyses were carried out using laser measurements. Textural characteristics were assessed on the basis of Folk and Ward grain-size indices, full grain-size distributions, subfraction analyses, end-member modelling analysis (EMMA), and hierarchical similarity analysis of the samples. Both individual samples and mean values calculated for successive metres of the transect were analysed. In addition, the distribution of individual subfractions was visualised using heat maps, which made it possible to capture the spatial organisation of grain-size variability along the sampling line.

The analysed foreset is composed of sandy sediment with a highly uniform textural character. All samples are unimodal and belong to the sand fraction, with fine and medium sands clearly predominating. Sorting is generally good to moderately good, skewness is mostly symmetrical, and kurtosis is most commonly mesokurtic. The metre-averaged results confirm only limited grain-size variability along the transect and the absence of abrupt transitions to distinctly different sediment types. At the same time, subfraction analyses and heat maps reveal subtle but ordered differences in the proportions of particular grain-size classes. The EMMA results and similarity dendrograms indicate that this apparently uniform foreset is not entirely monotonous, but instead comprises recurring textural arrangements with only a low amplitude of variation.

The results indicate that the analysed foreset was formed from highly uniform material typical of aeolian deposition, although its internal structure retains small-scale heterogeneity that becomes visible only under a very dense sampling scheme. This variability reflects minor fluctuations in depositional conditions and sediment sorting within successive elements of the foreset structure, rather than fundamental changes in the depositional mechanism. The study shows that high-resolution

grain-size analysis, supported by end-member modelling, similarity analysis, and cartographic presentation of subfractions, makes it possible to refine substantially the picture of the internal organisation of a single inland dune foreset.

Development and Disappearance of a Palaeolake in the Araxes River Valley: Evidence from the Argishtikhinili (Davti Blur) Archaeological Site, Armenia

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The Argishtikhinili (Davti Blur) archaeological site, located in western Armenia in the Araxes River Valley, provides new insights into the functioning of a dammed palaeolake and enhances our understanding of past tectonic activity in this seismically active region (Karakhanian et al., 2004; Karakhanian and Abgaryan, 2004). Despite high geological hazards, including earthquakes, liquefaction, and volcanic eruptions, the Araxes River Valley has long been a centre of intensive human settlement. Lacustrine deposits outcropping in close vicinity to the Argishtikhinili (Davti Blur) archaeological site indicate the presence of a palaeolake.

The texture and structure of the lake deposits, examined according to Miall's lithofacies code (1977), modified by Zieliński and Pisarska-Jamroży (2012), together with grain-size and geochemical analyses, structural and thin-section studies, and OSL dating, enabled the reconstruction of the lake development.

The lake deposits, comprising laminated clays, sands, and gravels, reach a total thickness of approximately 4 m. These sediments locally exhibit a complex transpressional fault pattern and associated liquefaction features. The lake deposits occur upon Araxes River alluvium and are overlain by coarse-grained, open-work gravels deposited during river activity. The occurrence of such gravels at the top of the sedimentary succession indicates a reduction of the original thickness of the lake sediments during river activity. The OSL dating results indicate the presence of the lake at least between 32 ka and 24 ka. Deposition of the lake sedimentary succession was preceded by the accumulation of deposits related to mass-wasting events on the slopes of the Sardarapat Ridge.

We interpret the development of the lake as resulting from the blockage of the Araxes River outflow at the point where it leaves the wide Ararat Plain and enters the Reshteh-Ye-Dagn Massif. The blockage of the outflow may have resulted from an earthquake or a volcanic eruption of Mount Ararat, which could have dammed the valley through the deposition of volcaniclastic sediments. Another probable cause of the Araxes River outflow blockage may have been the uplift of the Reshteh-Ye-Dagn Massif (Karakhanian et al., 2021).

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A Quaternary sediment budget for the North Sea Basin

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Over the last 20 years, mapping of the entire Quaternary North Sea Basin (350 000 km^2) has established that a total sediment volume of 140 000 km^3 exists between the Netherlands (52°N) and the Norwegian Sea (62°N) (Ottesen et al., 2018). During the Early Pleistocene, large fluvial and glaci-fluvial systems transported and deposited material, gradually filling the southern and central North Sea Basin from the east and southeast. In the northern North Sea, the Scandinavian Ice Sheet reached the palaeo-shelf break beyond western Norway from 2.6 My. The central and eastern side of the basin was filled mainly with glacigenic debris flows sourced from the Norwegian mountains. On the western side of the basin, a large delta along the eastern margin of the East Shetland Platform (100 km long N-S, 20 km wide E-W) was formed during the Early Pleistocene. The Norwegian Channel was carved out during the last ca. three glaciations (last 500 000 years) by the Norwegian Channel Ice Stream (NCIS), depositing more than 40 000 km^3 of sediments on the North Sea Fan.

An upper regional unconformity (URU) separates the underlying Early Pleistocene fluvial/marine sediments of the central/southern areas and the glacigenic debris flow sediments in the northern North Sea, from the more flat-lying sediment packages with a stronger glaciogenic character above. These sediments are thought to represent sediments from the last three glacial cycles.

We have reconstructed the catchment areas for each depositional system and calculated the volume and average erosion rate using a first order source-to-sink sediment budget for the different catchment areas. Our results have important implications for understanding the timescales of development of glacial relief in the hinterlands of the North Sea.

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Reconstructing cold-stage ecosystems in a Warta Valley: multi-proxy insights from Warenka site

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The Warenka site in the middle-reach of the Warta River valley provides an important but rare record of Upper Plenivistulian environmental conditions in an extraglacial zone. Thick fluvial successions, up to 16-20 m, were formed by a low-energy, sand-bed braided river active from about 30 to 24 kBP. Within this aggradational system, intermittent hydrological stillstands produced shallow floodplain ponds that enabled the accumulation of thin organic and mineral-organic layers. These horizons, dated in profile A-1 to 22.54±0.21 and 23.17±0.23 ^{14}C kBP and in profile A-4 to 22.37±0.15 and 19.58 ±0.12 ^{14}C kBP, represent brief intervals during the cold Upper Plenivistulian when aquatic and terrestrial ecosystems could temporarily develop despite climatic severity.

Integrated analyses of pollen, plant macrofossils, Cladocera, and Chironomidae document a dynamic mosaic of tundra-steppe and shallow-water habitats. Profile A-1 reveals particularly rapid vegetation shifts. Its lower levels are dominated by Cyperaceae and Poaceae with sparse arboreal pollen, indicating shrub tundra-steppe with *Betula nana*, *Ephedra*, and *Juniperus*; long-distance *Pinus* influx is also recorded. A transient increase in *Pinus*, accompanied by *Larix* and *Salix*, suggests a short-lived forest-tundra episode. A notable climatic deterioration is marked by the mass occurrence of *Selaginella selaginoides* in both pollen and macrofossils, coinciding with the disappearance of algal taxa and aquatic plants, suggesting both sharpening of climatic conditions and desiccation of the water body. The upper part of A-1 registers a return to shrub tundra-steppe in response to renewed cooling and drying.

Profile A-4 displays three pollen assemblage zones dominated by *Pinus sylvestris* alongside abundant sedges, grasses, and mosses. Persistent low shares of *Picea abies* and the presence of *Pediastrum* indicate that a shallow pond existed within an open landscape. Macrofossils reflect tundra-shrub vegetation with *Betula* sect. *nana*, *Salix* sp., and *Dryas octopetala*, accompanied by aquatic taxa such as *Hippuris vulgaris*, *Batrachium* sp., *Callitriche autumnalis* and *Nymphaea* sp. Presented association is correlated with cool climatic conditions. Cold, weakly eutrophic water conditions are indicated by organisms including *Daphnia pulex* and *Gloeotrichia* sp. Gradual lowering of water levels led to low peat-bog development dominated by *Juncus* sp. as well as sedges of the genus *Carex*, with a progressive decline of aquatic elements.

Palaeozoological proxies emphasize the severity of the climate and the episodic nature of the water body. Cladocera assemblages are sparse and dominated by cold-tolerant taxa, reflecting shallow pond,

periodically affected by floods. Chironomid communities include exceptionally cold-stenothermous taxa such as *Derotanypus sibiricus*, *Orthocladius trigonolabiris*-type, and *Propsilocerus lacustris*-type. Their life-cycle requirements imply that the floodplain ponds persisted through warm seasons, possibly across several years, even under low temperatures.

The records from profiles A-1 and A-4 show that during the coldest part of the Upper Plenivistulian the valley floor hosted a patchwork of tundra-steppe vegetation and ephemeral water bodies embedded within a dominantly mineral fluvial system. Short-term fluctuations in hydrology – rather than long-term climatic trends alone – regulated the establishment of aquatic habitats, the development of peat-bog vegetation, and the brief expansion of forest-tundra elements. The convergence of pollen and macrofossil evidence refines the interpretation of local presence, whereas faunal proxies provide insights into ecological conditions that are not detectable from botanical data alone. The Warenka archive demonstrates that even within highly aggradational braided-river systems, biogenic interbeds can yield high-resolution information on ecosystem functioning during extreme cold phases, thereby substantially improving reconstructions of Plenivistulian environments in central Poland.

Lithodynamics and evolution of the sedimentary environment in the marginal zone of the last Fennoscandian (Valdai) Ice Sheet: The Serteyka River valley case study

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The study area is located in the lower sector of the Serteyka River valley, a tributary of the upper Dvina, in the East European Plain. The aim of the study was identify depositional conditions and reconstruct the dynamics of the sedimentary environment of glaciofluvial deposits formed during the last glaciation. Field investigations included a series of boreholes drilled using a manual geological auger and the excavation of an exposure in the slope of a gully developed on the surface of a sandur plain. Laboratory analyses comprised laser diffraction granulometry and sieve analysis. Basic sedimentological parameters (M_z, σ_I, Sk_I, K_G) were calculated. The depositional environment was interpreted using Passega's C/M diagrams, Visher's cumulative curves and relationships between the values of individual sedimentological parameters.

The results indicate a pronounced lithological variability of the deposits. Within four distinguished stratigraphic units, significant variability in transport and depositional conditions was identified. The lowermost units (C and D unit) consist of sandy silt deposits interpreted as proglacial sediments, most likely representing a marginal or shore zone of an ice-dammed lake. The overlying units (A and B unit) comprise sediments accumulated under higher flow-energy conditions, with intermittent phases of reduced hydrodynamic activity. The analyses suggest that sedimentary processes were strongly controlled by local lithodynamic conditions and fluctuations in the hydrological regime, with a possible contribution of aeolian transport affecting the finest grain-size fractions.

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Intraplate seismicity triggered by ice-sheet loading and unloading: insights from the Peribaltic region

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Although present-day seismicity in the southern Peribaltic region is relatively weak, sedimentary successions preserve compelling evidence of repeated earthquake activity during the Late Pleistocene. This contribution synthesizes more than ten years of interdisciplinary investigations carried out within the GREBAL research framework, focusing on the recognition and interpretation of earthquake-related deformation structures preserved at eleven sites across Germany, Poland, Lithuania, Latvia, and Estonia. The documented deformation phases correspond to Marine Isotope Stages (MIS) 6–2 and are linked to processes associated with the Fennoscandian Ice Sheet.

Sedimentological analyses reveal diverse soft-sediment deformation structures (SSDS), including load casts, pseudonodules, flame structures, ball-and-pillow forms, clastic injections, water-escape features, and synsedimentary brittle fractures. These structures occur within discrete, laterally traceable deformation horizons interlayered with undeformed strata of comparable lithology, indicating episodic seismic shaking rather than continuous glaciotectonic disturbance or gravity-driven redeposition. At several localities, multiple generations of deformation structures and erosional surfaces capping liquefied layers point to recurrent liquefaction affecting the same sediment bodies.

Temporal correlations suggest clustering of seismic activity during phases of ice advance, dynamic oscillation, and retreat. Numerical modelling of Coulomb stress variations indicates that glacial isostatic adjustment promoted reactivation of inherited basement faults within this intraplate setting, while ice-sheet–related seismicity (icequakes) likely contributed to near-margin liquefaction processes.

The study advances criteria for distinguishing seismites in formerly glaciated terrains by integrating sediment susceptibility, stratigraphic architecture, deformation continuity, and the coexistence of ductile and brittle features. Experimental data further indicate that saturated fine-grained sediments may liquefy under lower-magnitude seismic loading than traditionally assumed. Collectively, the Peribaltic sedimentary archive demonstrates that glacially influenced intraplate regions experienced more frequent and complex seismic activity during the Pleistocene than previously recognized, underscoring the importance of revisiting palaeoseismic interpretations and seismic hazard assessments in comparable geological settings.

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Warmth or chill? New insights into Late Weichselian summer conditions in the Polish Lowlands

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During the Late Weichselian, Europe experienced pronounced climatic fluctuations, when overall thermal amelioration was punctuated by several cold events, including GS-1. As central Poland occupies a transitional zone between North Atlantic influences and the Siberian High, its regional climate is expected to closely reflect well-known western European trends. However, there is increasing evidence that summers remained relatively warm and the Younger Dryas cooling was only weakly expressed. Although several Chironomidae-inferred mean July air temperature reconstructions provide a broad overview, they often lack sufficient resolution. Here, we present high-resolution Chironomidae-based summer palaeotemperature reconstructions from the reference sites of the Żabieniec and Węgliny mires. These records indicate consistently warm summer conditions throughout the Lateglacial interstadial, with no significant cooling during the Younger Dryas. Notably, the Żabieniec sequence encompasses the period of Kamion oscillation recently identified in central Poland. Such relatively warm summer conditions in Eastern Europe during the Late Weichselian were likely associated with high seasonal contrast; while winters remained severe and the Polish Lowlands persisted within the periglacial zone. As widespread insects with short life cycles, Chironomidae remain sensitive to rapid thermal shifts and short-lived cold oscillations, whereas plant communities and geomorphological processes often exhibit a lagged response to climate forcing. The Żabieniec mire and Lake Gościąż currently stand as the two representative Chironomidae-based palaeoclimate reference sites for the Eastern Europe.

This research is part of the IDUB project entitled: "Was the Kamion Phase the first warming after the Last glacial maximum? – an attempt to explain the sequence of environmental events using paleoecological methods" IDUB UŁ 15/IgB/2024

Middle Pleistocene climate and lake ecology in Central Poland inferred from palaeobotanical and Chironomidae evidence

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Palaeolake deposits were uncovered in the Kuźnica 2017 and 2019 profiles, collected from the Szczerców Lignite Open-Cast Mine (Bełchatów Lignite Mines). The palaeolake basins, situated within glaciofluvial sands and tills, are filled with silt-gyttja sediments. The Kuźnica 2017 (Ku2017) profile comprises 36 samples, whereas the Kuźnica 2019 (Ku2019) profile includes 13 samples from the gyttja layer. The pollen record in the lower layers of Ku2017 is characterised by the dominance of tundra communities from the Sanian 1 Glaciation (MIS 16). In contrast, the upper part of the profile is dominated by arboreal pollen (>80%), corresponding to the lower optimum of the Ferdynandovian Interglacial (MIS 15). The presence of *Pinus*, *Betula*, *Ulmus*, *Quercus*, *Fraxinus,* and *Corylus* indicates the development of dense deciduous and mixed forests in temperate climate conditions. Palaeobotanical analyses for Ku2019 are underway. The Chironomidae assemblages in Ku2017 are composed mainly of cold-stenothermic taxa, among which *Corynocera ambigua* and *Chironomus anthracinus*-type are the most frequent. The lake was relatively deep, as suggested by the presence of several taxa associated with the profundal zone (e.g., *Monodiamesa*, *Sergentia coracina*-type, and *Heterotrissocladius maeaeri*-type). Only four warm-stenothermic taxa were identified; of these, the *Chironomus plumosus*-type is frequent, although this species also tolerates oxygen depletion in deeper waters. Phytophilous taxa are almost absent in Ku2017, indicating a narrow littoral zone. The Ku2019 chironomid assemblages developed in a warmer climate within a shallower, eutrophic lake. Cold-adapted taxa are rare, while seven warm-stenotherms and two phytophilous taxa are present, with *Ablabesmyia* being quite abundant. The lake was likely fed by a small stream, as evidenced by a few rheophilic morphotypes. *Zalutschia* type B indicates lower pH and dystrophic conditions in certain parts of the water body. The age of Ku2019 remains unknown, though the sediments probably date to MIS 11 or MIS 15. The Kuźnica 2018 profile, which documents a later stage of the Ku2017 palaeolake history, is planned for the next stage of research.

This research is part of the IDUB project entitled: "Eemian palaeolake ecosystems (Szczerców field, Bełchatów Lignite Mine) in the face of rapid climatic and hydrological changes" (No. 12/IGB/2025).

Cladocera communities from the Miocene (Bełchatów, Central Poland)

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Exceptionally preserved cladoceran remains from the Middle–Late Miocene (ca. 12–8 Ma) deposits of the Bełchatów Lignite Mine (51°15'46,4"N 19°18'49,2"E) provide new insights into the evolutionary history and paleoecology of freshwater zooplankton. The fossil-bearing sediments were deposited in a slow-flowing river valley with swamps and oxbow lakes, most likely within an abandoned channel of a meandering or braided river system characterized by stagnant or slowly moving waters. The site represents a rich repository of plant and animal fossils, yielding abundant Cladocera remains accompanied by numerous plant macroremains (mainly leaves), pollen grains and spores, and algal microremains, including Botryococcus, Closterium, and Zygnemataceae.

The cladoceran assemblage includes representatives of the families Chydoridae and Bosminidae, comprising both littoral and pelagic taxa. Identified genera include Alona*, Acroperus, Camptocercus, Chydorus*, and at least two species of Bosmina. These fossils constitute the oldest confirmed pre-Pleistocene record of Bosminidae. Several specimens preserve three-dimensional morphology, including taxonomically informative structures, enabling detailed systematic comparisons. The material reveals combinations of characters not observed in modern species and suggests the presence of extinct ancestral lineages. The findings challenge the hypothesis of pronounced morphological stasis in anomopod cladocerans, previously inferred largely from ephippial remains. Notably, Daphnia is absent from the assemblage; this absence is interpreted as the result of fish predation pressure and local hydrochemical conditions, while Bosmina appears to have occupied the pelagic niche, possibly representing a case of paleo-competitive release.

Integration of cladoceran data with paleobotanical evidence allows detailed paleoenvironmental reconstruction. The presence of leaves and pollen of Potamogeton, as well as pollen of Alisma, Nuphar, and Typha/Sparganium, indicates well-developed aquatic and marsh vegetation. Paleobotanical analyses suggest a warm-temperate and moderately humid climate comparable to the Cfa type of the Köppen–Geiger classification (warm temperate, fully humid with hot summer). Mean annual temperatures were estimated at 13.5–16.5°C based on plant macroremains. The ecological structure of the cladoceran community is consistent with a productive freshwater oxbow-lake ecosystem under warm and humid climatic conditions.

These results significantly expand the fossil record of Cladocera and demonstrate the high potential of Miocene lacustrine deposits for reconstructing freshwater ecosystems and regional paleoclimate in Central Europe.

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Deglaciation of the eastern sector of the Scandinavian Ice as evidenced from ^{10}Be exposure ages

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The Scandinavian Ice Sheet (SIS) was an important component of the global ice sheet system during the Last Glacial Maximum (LGM) and subsequent deglacial times. Constraining the extent, dynamics and timing of former ice sheets contributes to our understanding of their sensitivity to past climate change and their contribution to sea-level variations. From the accuracy of these reconstructions depends our capabilities to simulate future changes. Synoptic studies have summarized the former spatial extent and chronology of the last SIS providing an exceptional state of the art empirical datasets (Hughes et al., 2016; Stroeven et al., 2016). The latter represents the primary source of information for the modelling community to test and develop glaciological models (Patton et al., 2017) which are then further embedded into climatic and general circulation models. These synoptic studies have also highlighted vast geographical regions where chronological data are all but lacking.

Well-identified and dated ice-margin positions are one of the most valuable parameters for empirically-based ice sheet reconstructions. In Western Russia, early geological and geomorphological studies of the ice sheet demise dynamics are numerous but geochronological data are virtually inexistent over large areas. In an attempt to contribute to the reconstruction of the SIS demise chronology, we present 63 new ^{10}Be ages of erratic boulders sampled along a broad southeast-northwest transect from the town of Vologda, southeast of Lake Kubenskoye, to the town of Belomorsk, west of the White Sea. The 19 first exposure ages available so far show a broad distribution between 4.2 to 215.9 ka with a majority of ages (n = 16) grouped around the Last Glacial Maximum (26-20 ka) and Marine Isotope Stage 4 (71-57 ka). The remaining samples are currently analyzed by accelerator mass spectrometry.

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Geological 3D modeling of the Quaternary in eastern central Germany (Saxony-Anhalt) using stacked lithofacies maps and borehole information

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Located to the south of the maximum Weichselian ice limit, the Quaternary geology of central Germany comprises a wide variety of pre-glacial lower Pleistocene and glacial/interglacial middle to upper Pleistocene depositional sequences. Since the seminal work of early Prussian Geologists (e.g. Keilhack, 1910; Siegert & Weißermel 1911), the area to the north and east of the Harz Mountains has traditionally served as the type region for the Elsterian (MIS 12) and Saalian (MIS 6) glaciations (Eissmann et al., 1995). A key feature of the depositional architecture is the stratigraphic interfingering of northern-derived glacial facies with southern-derived fluvial terrace systems. This led to a complex Quaternary stratigraphy with repeated successions of glacigenic, glaciofluvial, glaciolacustrine, and periglacial sediments, interbedded with extensive fluvial deposits and locally preserved organic-rich interglacial sediments. Overall, the sequences represent a highly dynamic depositional environment with frequent lateral facies changes and alternating phases of aggradation and erosion.

Within this framework, the geological 3D modeling of the regional Quaternary is challenging, requiring a balance between the need for an adequately resolved depiction of the lithostratigraphic complexity and finding a technically suitable and still manageable topological modeling approach, respectively. Here we present first results from the modeling of Quaternary strata in central Germany based on the 'Lithofacies Map Quaternary' 1 : 50,000 (*Lithofazieskarte Quartär, LKQ50,* Cepek, 1999). The LKQ represents a specialized geological map series issued between 1968 and 1987 for the territory of the former German Democratic Republic (GDR), using stacked horizon maps to provide geological information on the Quaternary stratigraphy, facies, lithology, petrogenesis, distribution and depositional thickness. In the case of Saxony-Anhalt, 39 x LKQ50 map sheets with a total of 196 horizon maps are available, covering the entire lower Pleistocene to Holocene succession with depth information and additional geological cross-profiles.

Following the georeferencing and digitization of the LKQ50 geological attribute data, further preparatory steps included the modernization of the original stratigraphic concept and lithostratigraphic nomenclature, data quality checks and corrections to eliminate topological inconsistencies in the geometric data. Primary input data from the LKQ for the 3D modeling are vectorized distributions, isobaths, georeferenced geological cross-sections, which were supplemented by additional drill core information and newer geophysical data.

As a first work package the project aims to develop a state-wide 3D model of regionally significant marker horizons, beginning with the base of the Quaternary followed by a further differentiation of the most relevant stratigraphic complexes (i.e. Pre-glacial, Elsterian, Holsteinian, Saalian, Eemian, Weichselian and Holocene). This will be achieved through an iterative modeling approach involving: (I) resolution of map sheet boundary conflicts, (II) combining units representing different lithologies and petrogeneses, but of equal stratigraphic rank, (III) the geometric construction of continuous lower boundary surfaces for major regional marker horizons and (IV) the subsequent selective refinement of the model.

Technical challenges for the 3D modeling are mainly posed by the comparably low thicknesses of most of the Quaternary sequences combined with significant spatial facies complexity, requiring a high vertical and horizontal modeling resolution and associated computational effort. Accordingly, modeling is implemented first for smaller sub-areas, followed by harmonizing the individual model boundaries (geometry, topology, stratigraphy) before generating a combined state-wide Quaternary subsurface model.

Anticipated practical applications of the model aim at providing an easily accessible and improved digital resource for engineering geologists seeking detailed depth-differentiated lithostratigraphic information, including virtual vertical profiles and geological cross-sections along freely definable line traces. Further model development will focus on hydrogeological aspects by parameterizing strata into aquifers or aquitards/aquifuges as well as incorporating the data into ground water flow models.

The presentation will provide a project overview, the current state of play and highlight selected model outcomes.

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Reconstruction of abrupt climate changes at the Late Glacial–Holocene transition based on Cladocera from two peatlands in central Poland

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Biogenic sediments accumulated in lakes and peatlands constitute some of the most valuable geoarchives of environmental change, enabling the reconstruction of ecosystem dynamics under conditions of natural climate fluctuations. Of particular importance is the transition from the Late Pleistocene to the Early Holocene, encompassing a sequence of abrupt cooling and warming episodes that led to rapid reorganizations of aquatic and wetland environments. The analysis of these transformations not only allows for the reconstruction of local ecosystem responses, but also provides a reference framework for interpreting contemporary climate change.

The aim of this study was to reconstruct the impact of abrupt climatic changes at the Pleistocene–Holocene transition on the functioning of aquatic ecosystems in central Poland, based on subfossil remains of Cladocera. Due to their short life cycle, high sensitivity to the physicochemical parameters of water, and rapid response to environmental changes, these organisms serve as precise indicators of habitat conditions such as water temperature, trophic status, pH, water depth, and the development of aquatic vegetation.

The research material was obtained from two sites with different geomorphological and hydrological settings: the Żabieniec peatland, located on an upland within a closed depression, and the Ługi peatland, situated in a river valley. Both profiles include Late Glacial and Early Holocene sediments; however, they differ in origin, sediment thickness, and hydrological regime. To obtain a high-resolution record of environmental changes, a sampling interval of 1 cm was applied. The Cladocera analysis was complemented by radiocarbon dating, palynological studies, lithological analysis, and, for the Żabieniec site, geochemical analyses.

The results indicate clear differences in the response dynamics of the two basins to changing climatic conditions at the Pleistocene–Holocene transition (Rudna et al., 2023; Rudna et al., 2025). During the final phase of the Oldest Dryas, both basins were characterized by shallow-water conditions and limited development of Cladocera fauna, reflecting cold and unstable environmental conditions. The warming associated with the Allerød interstadial promoted an increase in species diversity and the expansion of taxa associated with warmer and more productive waters, including planktonic forms. During the Younger Dryas, a deterioration of habitat conditions occurred again, manifested by a decline in species number and the dominance of taxa tolerant of colder and shallower environments.

The transition to the Holocene was associated with a dynamic increase in community diversity and the stabilization of aquatic conditions.

A comparison of the two sites revealed that the course of environmental changes was strongly controlled by local hydrological and geomorphological conditions. The type of water supply and the location of the basin influenced how it responded to climatic changes. This indicates that the paleoecological record reflects not only the climatic background but also the specificity of local environmental conditions.

The conducted research demonstrates that the analysis of subfossil Cladocera fauna is an effective tool for high-resolution reconstruction of environmental changes during periods of abrupt climatic transitions. The application of high-resolution sampling made it possible to capture short-term fluctuations that remain undetectable in lower-resolution analyses. The results confirm the key role of peatlands as archives of climatic and ecological changes occurring at the Pleistocene–Holocene transition.

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Record of SIS dynamics in the relief of the Polish-Lithuanian border area in the Suwałki region (NE Poland)

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North-eastern Poland (the Suwałki Lake District) is an area that was covered by all the Pleistocene glaciations. The last glaciation left behind a varied landform. This reflects numerous subglacial processes and the final shaping of the morphology during deglaciation. A characteristic feature of this area is a hilly landscape with numerous small depressions, usually filled with organic sediments. The latest research results on paleolakes sediments in the northern part of the Suwałki Lake District document several important stages in this area after the end of the last glaciation, which was largely related to the process of dead ice blocks (DIB) melting (Rychel et al., 2026). This led to an inversion in the topography, mainly final stage of the Late Glacial period.

One example of a combination of sedimentation processes, DIB melting and organic accumulation—and thus a fundamental change in the landscape—is the Budzisko site on the border with Lithuania. At the Budzisko site it was confirmed the functioning of small basins during the Late Glacial. Our studies document the time and rate of melting of DIBs at the end of the Allerød interstadial. Radiocarbon dating of organic sediments indicates that the paleolake was still functioning between 13,909-14,874 calBP. The melting process of the DIBs accelerated significantly at the end of the Allerød interstadial and was associated with the ongoing permafrost degradation and the increased drainage of the substrate. The sediments of some reservoirs were subject to redeposition and runoff into subsequent reservoirs, as was the case at the Budzisko site. This ultimately led to the morphology inversion and formation of hummocky landscape. A similar sequence of events during the retreat of the Scandinavian Ice Sheet has been reconstructed at other research sites in the Suwałki Lake District.

This suggests that deglaciation of this area occurred mainly through the blocky disintegration of ice masses, the formation of various types of basins between DIBs, and subsequently their melting during the final phase of the Late Glacial. This led to an inversion of the landform and the creation of a hilly landscape.

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Portable analysis method for analysing very low concentrations of gold

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The use of portable geochemical analyzers has become more widespread and diversified in ore exploration. The most used analyzer is the portable, hand-held X-ray fluorescence (pXRF) analyzer, which has been found to be effective in the analysis of both geological samples and metals. For example, in till geochemical ore exploration, pXRF is particularly effective in the analysis of base metals and several major elements (e.g., Sarala et al. 2015; Sarala, 2016). Portable analyzers enable the analysis of boulder, rock and soil samples directly in the field, which significantly speeds up the exploration process and improves cost-effectiveness. However, the analyzers have their limitations, as the detection limits can be quite high for several elements and, on the other hand, low concentrations cannot be analysed reliably. Typically, the detection limit is tens to hundreds of ppm depending on the element.

Although pXRF technology has provided an effective way to analyse a wide range of commodities, there are certain elements which analysis is not possible. For example, precious metals such as gold occur in such low concentrations in soil that their analysis cannot be reliably performed with pXRF. Recently, new analytical concept called DetectORE™ was launched and that technology provides fast and practical analysis of low concentrations of Au (even in 5-10 ppb level) directly in the field or field camp. The analytical procedure includes sample preprocessing, 6–24 hours of leaching supported by rotational mixing, leaching solution and collector to adsorb and concentrate Au, and data processing software usable for different portable XRF analyzers (Sarala et al., 2024). More than 30,000 samples and tests have been carried out during the research and development phase using field samples, gold solutions and CRM systems, and the results have proven the method to be effective. This was also supported by the test campaign done in the Oulu Mining School in 2024-2025 for the basal till and weathered bedrock samples from northern Finland. The pXRF and laboratory-based analytical results showed strong correlation in the several Au exploration targets.

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Existence and environmental effect of black shales in glaciated terrain in the Oulu region, northern Finland

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Black shales are widespread in the bedrock of southwestern Lapland, Kainuu and the Oulu region, where they contain high levels of sulphur and heavy metals. The area is also known to have acid sulfate soils covering glacigenic sediments. When exposed through land use activities such as peatland drainage, raw material production and infrastructure construction, these materials oxidize and generate acidic conditions that mobilize harmful metals into soils and waterways. Climate change increases these risks by intensifying precipitation, warming and extreme weather events, thereby accelerating acidification and contaminant transport. These processes affect drained peatland forests in black shale areas and influence restoration planning under the EU Restoration Regulation (EU 2024/1991). Despite their importance, climate-related impacts in black shale regions remain insufficiently studied.

Addressing these challenges requires accurate localization of black shale formations and assessment of their contaminant loads and acid generation potential. However, no unified guidelines exist for site-specific risk assessment, and monitoring data remain limited. Geochemical analyses of soils, surface waters and aquatic sediments provide valuable tools for evaluating both current and historical impacts.

This project integrates geological, geochemical and hydrological methods to fill these knowledge gaps. It will map black shale occurrences using targeted geophysical measurements and characterize their contaminant concentrations and acid production capacity through surface geochemistry and laboratory analyses. The project will also investigate the influence of black shale-derived contaminants on soils, and river and stream sediments, and quantify leaching of suspended solids, nutrients and heavy metals from restored peatland forests. The retention performance of constructed wetlands will be evaluated through field and laboratory experiments.

The project will develop operational models and cost-effective methods to support land use planners and environmental authorities in managing black shale-related risks under changing climatic conditions. Its outputs will inform land use planning, construction, agriculture and national implementation of the EU Soil Health Law and the EU Restoration Regulation. The research is funded by the ERDF Grant A81863.

Environmental changes during the Late Glacial and Early Holocene transition revealed by palaeolimnological record from southern Lithuania

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Current climate change has a significant impact on biodiversity. In order to accurately assess and predict the extent of these changes, the factors that caused them, and future trends, it is necessary to understand how these processes have unfolded over a longer period of time.

Our research present environmental reconstructions based on cladoceran, diatom and plant macrofossil studies of the Čepkeliai Bog (southern Lithuania) sediment section deposited during the Late Glacial–Early Holocene period. The goal of this study was to evaluate the paleoenvironmental changes, with a primary focus on the trophic state, dissolved mineral salts, and water-level fluctuations, as well as to explore how these communities respond to climate change. To the present day, no palaeoecological studies based on Cladocera have been conducted in Lithuania. Diatom assemblages are presented alongside Cladocera remains, providing an additional line of palaeolimnological evidence that enhances the interpretation of environmental dynamics recorded in the Čepkeliai Bog sediments. Supporting multi-proxy datasets—comprising pollen, plant macrofossils, loss-on-ignition, magnetic susceptibility, and geochemical data spanning the Holocene—have been previously reported by Stančikaitė [34] and serve as a contextual framework for interpreting our biological proxy data.

Čepkeliai wetland complex, located in southeastern Lithuania, covering more than 5,858 ha and is one of the largest and best-preserved peatland systems in both Lithuania and Northern Europe. The sampling site lies in the southeastern part of the bog (54°00´N; 24°30´E), at an elevation of ~131 m above sea level, within gently undulating terrain ranging from 128.5 to 134.4 m a.s.l. (Figure 1).

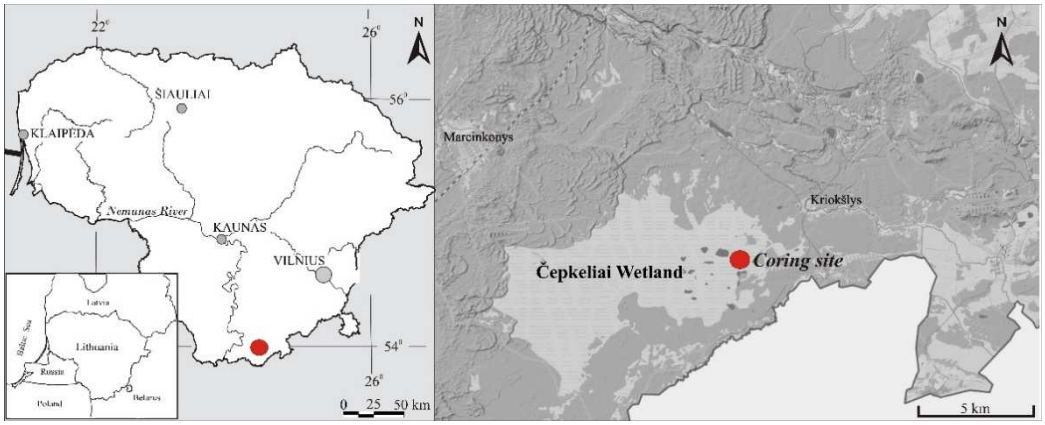

Figure 1. Location of the study site. The coring site is shown by a red circle.

Recent studies at Čepkeliai peatbog provided the opportunity to reconstruct the Lateglacial and Early Holocene environmental history of the site**.** The initial phase of the palaeobasin development

(13,200–13,000 cal yr BP) was marked by a deep, oligotrophic and cold-water conditions and can be correlated with GI-1b event (Gertsenzee oscillation). A significant ecological shift towards a shallower, warmer and more ecologically diverse littoral system was observed at around 13,000 cal yr BP. This transformation was driven by gradual climatic warming and accompanied by increasing aquatic productivity and macrophyte colonization and is consistent with GI-1a (Allerod) warming period. The beginning of the 12,850–11,650 cal yr BP time period (GS-1; Younger Dryas) is characterized by rise in lake level and development of oligo-mesotrophic high water transparency conditions. The existence of thermophilic species alongside cold-adapted taxa indicates that environmental conditions were not stable throughout the entire period. At the end of the Younger Dryas, around 12,000 cal BP, an improvement in climatic conditions and a drop in water levels were recorded in changes in the composition of Cladocera. Meanwhile, significant changes in diatom flora are observed around 11,500 cal BP, at the beginning of Preboreal. This transitional period is characterised by climate warming that foster a shallow environment with low water transparency and a tendency towards eutrophication. Intensive palaeobasin swamping processes began around 9,700 years BP (Boreal), as evidenced by changes in the fauna and flora studied and the increasing amount of organic matter. Changes in the composition of Cladocera and diatom taxa allowed us to record a short-lived "9,2" cooling event at about 9,200-9,000 cal yr BP. The data obtained show that using several biotic methods for paleoenvironmental reconstruction is perfectly compatible and significantly complements the information obtained from each method, providing the most reliable results possible. The results of the environment reconstruction correlate perfectly with previous studies conducted in Lithuania and neighbouring areas, adding to our knowledge of postglacial paleoenvironmental dynamics in the south-eastern Baltic region.

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Coleoptera-based MCR temperature reconstructions of the Last Glacial termination in Lithuania

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The Eastern Baltic region has a complex history of deglaciation during the Late Glacial period, when the ice retreated non-linearly to the north. In the last decades, due to the improvement of statistical techniques and modern training sets, quantitative Late Glacial temperature reconstructions based on pollen, plant macrofossils, and chironomids have been made for Estonia, Latvia, and Lithuania. An underused proxy for paleo-temperature reconstructions are Coleoptera (beetles), which were instrumental to Late Glacial temperature reconstructions in Western Europe (Coope et al., 1999). In Central and Eastern Europe, this proxy remained underexplored. Our study presents the first temperature reconstructions from Coleoptera-based mutual climatic ranges (MCR) for Lithuania and the wider region.

Three Late Glacial sediment outcrops were revisited for this study: Ventė at the Eastern coast of the Curonian Lagoon, and Pamerkiai and Zervynos in Southeastern Lithuania. New radiocarbon dates confirmed and improved the age of the peat and gyttja layers of the outcrops. The Ventė Outcrop contains a thin peat layer between medium-grained sand, which was dated 13,161–12,915 cal BP. Two gyttja layers of the Pamerkiai Outcrop were deposited between ~13,700–12,500 cal BP, and the Zervynos Outcrop was dated between 14,700–11,700 cal BP. Sandy layers deposited between the beds of organic origin discovered in Pamerkiai and Zervynos outcrops were likely caused by redeposition in a dynamic environment. Bulk sediment samples of 5–10 liters were taken from all organic layers and from some of the interlying sand beds from Pamerkiai and Zervynos. Samples were washed over 0.2 mm sieves, after which insect cuticles and Coleoptera exoskeletons were extracted by flotation with paraffin oil. Coleoptera remains were identified by comparing with museum specimens at the Tadas Ivanauskas Museum of Zoology in Kaunas and at the National History Museum in London. The Coleoptera-based Mutual Climatic Range (MCR) method is based on a list of 436 species that were frequently found in Quaternary deposits on the British Isles and North America, that are not limited in their distribution due to host plants or trees, and therefore should mainly be limited in their distribution by temperature tolerances. The species assemblages identified from the Ventė, Pamerkiai, and Zervynos outcrops consist of a typical tundra fauna and have been described from various Late Glacial sites in Western Europe and Poland. MCR results are based on the overlapping climatic ranges based on 3–19 species, depending on the sample. Pollen-based WA-PLS temperature reconstructions were made based on pollen records from Pamerkiai and Zervynos and compared to the MCR reconstructions. The beetle MCR results show slightly cooler temperatures than the WA-PLS reconstructions, but within the standard deviations. MCR winter temperatures show much larger ranges than the WA-PLS, with minimum winter temperatures of -20°C to -30°C on average which correspond to findings from recent chironomid- and plant macrofossil-based reconstructions from Estonia. In paleoclimatic studies, Coleoptera-based reconstructions offer independent, quantitative results to support reconstructions based on regressions. Our results show that the Coleoptera MCR method can be applied and further developed in the Eastern Baltic region.

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Spatial distribution and morphometry of polygonal crop marks in the lowlands of the Pannonian Basin, NW Hungary

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Relict periglacial polygonal networks are widespread across the Peri-Baltic lowlands and adjacent areas of Central Europe, where they serve as indicators of historical permafrost or deep seasonal frost conditions during the Late Pleistocene. Recently, there has been increasing interest in the regional-scale detection and quantitative analysis of these landforms through remote sensing and GIS (Bertran, 2022; Ulrich et al., 2011). However, at the southern margin of the former periglacial zone, systematic spatial datasets remain scarce, and the extent to which polygon morphometry reflects genetic differences or environmental gradients remains debated (Farkas et al., 2023, 2025). This study presents a GIS-based mapping and statistical analysis of relict polygonal networks in lowland Hungary.

The study area is located within the Pannonian Basin, a low-relief intramontane basin situated at the southern edge of the Late Pleistocene periglacial zone. Polygonal networks primarily occur on flat or gently sloping alluvial surfaces, former alluvial fans, and terrace-like geomorphic units at elevations ranging from approximately 110 to 350 meters above sea level.

Mapping was conducted using a non-invasive, multi-source GIS workflow. High-resolution orthophotos, multispectral satellite imagery, and UAV-based datasets were integrated to identify polygonal patterns, primarily expressed as cropmarks on cultivated surfaces. These cropmarks reflect subsurface sedimentary contrasts associated with relict frost-cracking features. Polygon outlines were manually digitised in a GIS environment to ensure consistent interpretation, followed by systematic filtering to exclude false positives related to agricultural parcel boundaries, drainage features, or modern anthropogenic structures.

The resulting geodatabase contains nearly 5,000 individual polygon objects distributed across five geomorphologically distinct subregions. For each polygon, a comprehensive set of morphometric and spatial parameters was extracted, including area, perimeter, number of vertices, circularity, aspect ratio, orientation, elevation, slope, and surface exposure. These parameters were selected to match those commonly used in Peri-Baltic morphometric studies, allowing for direct comparison with published datasets from Poland, Germany, and the Czech Republic.

Descriptive statistical analysis indicates that the mapped polygonal networks are dominated by Y-junctions and near-hexagonal geometries, consistent with contraction-crack-driven polygon formation. The distribution of polygon sizes shows moderate variability both within and between subregions, but no clear latitudinal or elevation-dependent trends are evident. Contrary to expectations based on studies from northern Europe, polygon area and shape parameters do not systematically decrease toward the southern margin of the periglacial zone.

Multivariate statistical analyses explored relationships between morphometric, topographic, and geological variables. Principal component analysis reveals that the first two components explain

slightly more than 50% of the total variance, with relatively low eigenvalues and significant overlap between polygons from different subregions. This suggests that the dataset cannot be easily divided into distinct morphometric clusters corresponding to separate genetic types.

Further spatial analysis shows that polygonal networks are not limited to a single lithological setting. While many polygons occur on fluvial gravel and sandy gravel surfaces, a substantial number are also associated with loess-covered areas. This challenges earlier assumptions, largely derived from northern and western European contexts, that polygonal ground formation is closely tied to glacial till substrates. From a GIS perspective, substrate variability adds complexity to the interpretation of polygon morphometry and emphasises the need to integrate geological layers into spatial analyses.

Several methodological limitations have been identified. The visibility of cropmarks varies significantly with crop type, season, and soil moisture conditions, affecting detection efficiency and introducing spatial bias. Moreover, the scale of digital mapping exceeds that of previously documented field exposures, raising questions about minimum size thresholds and the criteria for defining "true" polygonal networks.

Overall, this study demonstrates that large-scale GIS-based mapping, combined with descriptive and multivariate statistics, is a powerful tool for documenting the spatial distribution and morphometric variability of relict periglacial polygonal networks. However, the results also indicate that polygon geometry alone does not define discrete genetic categories, particularly at the southern margin of the Late Pleistocene periglacial zone. The recent dataset supports a continuum-based interpretation of polygonal ground, shaped by the interacting controls of substrate, moisture availability, and frost regime. The presented geodatabase provides a robust foundation for future integration with sedimentological studies.

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Glacial geomporphological map of Verkhoyansk Mountains, NE Siberia

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The Quaternary glacial history of northeastern Siberia, particularly east of the Lena River, remains poorly constrained compared with the major Northern Hemisphere ice-sheet sectors. This region is commonly regarded as having been unfavourable for the development of large ice masses, partly because the Eurasian Ice Sheet may have limited atmospheric moisture transport into interior and eastern Siberia. However, recent syntheses and geomorphological evidence suggest that older or episodic glaciations may have been more extensive than traditionally assumed, potentially involving local mountain glaciers and ice caps, as well as ice domes or ice sheets in northeastern Siberia–Beringia and on adjacent continental shelves. The glacial footprint in Verkhoyansk Mountains therefore represent a key archive for testing these hypotheses and refining wider palaeogeographical reconstructions of northeastern Siberian glaciation.

The purpose of this study is to constrain glacial reconstructions of the Verkhoyansk Mountains through glacial geomorphological mapping. For this purpose, we performed manual mapping in QGIS using the 2 m resolution ArcticDEM dataset. Our results identify more than 12 500 moraine ridges, 10 700 marginal meltwater channels, 912 glacial lineations and 205 eskers. The east–west extent of the moraine systems is nearly 300 km, with moraine limits generally located approximately 100 km from the inferred ice divide on both the eastern and western sides. These results suggest that, despite presumably limited moisture availability in northeastern Siberia, regional moisture supply was sufficient to sustain the development of an extensive mountain ice cap in the Verkhoyansk Mountains. However, no clear glacial landforms were identified along the Laptev Sea coast or in the lowlands farther east of the Lena River. In addition, the mapped landforms do not indicate geomorphological continuity between the Verkhoyansk and Chersky mountain ranges.

3D microtomography of till from the Baltic Sea floor: record of subglacial and ice-marginal processes?

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The Baltic Sea in northern Europe is a relatively shallow epicontinental sea whose postglacial development was controlled by eustatic sea-level fluctuations and glacio-isostatic adjustments. During the Pleistocene glaciations, the Baltic Basin served as one of the main flow corridors of the Fennoscandian Ice Sheet toward the Central European Plain. Repeated ice advances and retreats profoundly reshaped the basin, leaving a wide range of subglacial and ice-marginal landforms and deposits. Recent geomorphological investigations based on high-resolution bathymetric data from the central and southern Baltic Sea have enabled the mapping of various types of glacial landforms, including subglacial lineations, ribbed bedforms, eskers, grounding-line landforms, meltwater channels, crevasse-squeezed ridges and recessional moraines (Greenwood et al., 2024; Szuman et al., 2024; Tylmann et al., 2025). In many areas, the seafloor is composed of glacial diamicton, providing an opportunity to collect sediment cores containing till layers and to investigate their micromorphological characteristics.

Here, we present the results of 3D imaging of sediment cores recovered from the Swedish sector of the southern Baltic Sea. The aim of this study is to reveal the physical properties and internal structure of the analyzed till using 3D X-ray microtomography. Ultimately, we seek to reconstruct the processes of till formation and to improove our understanding of the dynamics of the ice sheet responsible for their deposition. Two sediment cores (SGU-04-0267 and SGU-07-0288) containing till layers were selected for 3D X-ray microtomographic analysis. Core SGU-04-0267 was retrieved from a water depth of 47 m in an area with mega-scale glacial lineations cross-cut by poughmarks. The core is 2.8 m long and comprises a 1.5 m thick clay layer overlying at least 1.3 m of massive, clasts-rich till. Core SGU-07-0288 was collected from a shallower site (30 m water depth), located within the ice-marginal grounding zone of the retreating ice sheet. This 5 m long core consists of a 27 cm thick layer of coarse sand and fine gravel overlying approximately 4.7 m of massive, matrix-supported diamicton. Till monoliths were extracted from both cores and scanned at voxel resolution of 40 and 50 µm. The resulting 3D datasets were processed using myVGL, Dragon Fly, and Blob3D software. The internal structure of the diamictons was analyzed with particular attention to clasts contacts, grain crushing, and grain lineations. In addition, grain-size distribution, clast orientation, clast shape, and roudness were quantified within the sand and gravel fractions. These parameters provide constrains on depositional processes and on the dynamics of the last Fennoscandian Ice Sheet during its advance into the central and southern Baltic Basin and its retrreat at the end of MIS 2.

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Directions of glacial transgression in the frontal zone of the ice sheet during the Saalian Glaciation (MIS 6) in the north-western foothills of the Holy Cross Mountains – preliminary results

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Research into the maximum extent of the ice sheet during the Warta Stadial of the Saalian glaciation in central Poland remains a subject of debate. In traditional approaches, the limit of the maximum extent of the ice sheet is traced along the Pilica valley (Różycki 1967, Turkowska 1992, Marks et al. 2006, Rdzany 2009). However, an alternative concept was proposed by Turkowska (2006), assuming a further advance of the ice-sheet into the south-eastern part of the Łódź region. In order to verify the directions of ice sheet movement during the Saalian Glaciation and the nature of glacial deformations, an analysis of the glacial landforms was carried out using a DEM. Additionally, measurements of the anisotropy of magnetic susceptibility (AMS) of glacial tills were taken from five sites located within the Opoczno Hills, the Gielniowski Ridge and the western part of the Radom Plain.

The study area contains several terminal moraine sequences with a complex spatial structure (Ziomek 2001). In the northern part, these sequences have an east–west orientation, whereas in the western part, they are oriented along a NE–SW line. This configuration can be interpreted as a system of at least two distinct terminal moraine seqeunces, reflecting successive stages of ice-sheet retreat and variations in glacial accumulation conditions over time. Based on the orientation of the moraine ridges, it can be concluded that the ice sheet generally advanced into the study area from the north or north-west.

The AMS data obtained indicate that, for the most part, the tills studied have not retained the original magnetic fabric typical of lodgement tills, in which the axis of maximum magnetic susceptibility is parallel to the direction of ice-sheet movement. At many sites, features of glacitectonic disturbances were observed, manifested, among other things, by the orientation of the axis of maximum susceptibility perpendicular to the direction of compressive forces and the locally horizontal orientation of the axis of minimum susceptibility. The interpreted deformations are associated with the influence of morphological obstacles related to the elevations of the Jurassic bedrock, which may have caused local disturbances in ice flow and the compression of deposited sediments.

Despite local glacitectonic deformations, consistent AMS results from most sites suggest a general direction of ice-sheet movement close to NW–SE, which is consistent with the regional direction of transgression in this part of Poland. The data obtained support the concept of an active ice sheet in the analysed area and indicate a significant influence of the local topography and bedrock morphology on the course of transgression and the dynamics of the Saalian glaciation.

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^{14}C-OSL chronology of the Warta River oxbow lakes generations in the Śrem Basin – central-western Poland

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A chronological model has been developed for the generations of the Warta River oxbow lakes located in the Śrem Basin in central-western Poland. Geomorphological mapping based on GIS analyses was used, in conjunction with sedimentological studies and the verification of two absolute dating techniques, namely AMS ^{14}C and optically stimulated luminescence (OSL). Based on GIS analysis, five terrace levels were identified, the oldest of which (Terrace V) was formed during the deglaciation of this area as a result of glacial marginal flows. The remaining four terraces represent post-glacial (from approximately 17,000 years ago to the present day) fluvial succession in the Śrem Basin.

New radiocarbon and OSL dating results were synthesised from nine profiles located on terraces IV-I, and ^{14}C dates from earlier studies were calibrated (Pazdur et al., 1982, 1983; Gonera and Kozarski, 1987; Bonhncke et al., 1995). The results show that the radiocarbon age of composite samples from oxbow lake fills are often significantly outdated, sometimes exceeding 30,000 years, which highlights the clear influence of freshwater reservoir effect. On the other hand, OSL results show less inversion, providing reliable constraints on paleochannel activity and mineral material input during floods. Part of the organic succession on terrace IV, previously identified as paleochannels, is, according to our analyses represent a sedimentary succession of depressions after dead ice blocks. The paleochannels on Terrace IV functioned as oxbow lakes from the Allerød interstadial until about 11,000 years ago, when they transformed into peat bogs. The oxbow lakes on terrace III appeared at the end of the formation of the so-called large meanders, approximately 13,000 years ago, and their accumulation lasted from 7,800 to 7,200 years ago. For terrace II, OSL results show that the open oxbow lake phases persisted from at least around 11,100 years ago to around 7,000–8,000 years ago. The youngest fillings (terrace I) reflect a period of isolation in the middle and late Holocene.

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Provenance of MIS 4 Loess Inferred from Microtextural Analysis of Silt Grains: Evidence from Poland and Ukraine

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The global cooling that occurred during MIS 4 (~71–57 ka) resulted in a worldwide increase in ice cover (Doughty et al., 2021), sea-level changes, increased climate aridity, and significant changes in terrestrial ecosystems. This period is still poorly understood and the identification of sediments correlated with this glaciation is difficult. Spatial distribution and degree of preservation of the MIS 4 deposits is limited due to erosion and burial caused by successive glacial advances. Although records of MIS 4 glaciation are found on the Scandinavian Peninsula (Helmes, 2013), no evidence of the presence of this ice sheet has been documented in Poland or Ukraine. Other terrestrial deposits recording climate change in this part of Europe are also extremely rare. The exception are loess deposits. Despite their small thickness (0.5-2 m; up to 4 m in individual profiles), these sediments bear features originating from processes operating in a cold and humid environments, such as gelifluction and cryoturbations.

The lack of evidence of the presence of MIS 4 glaciation in Poland and Ukraine provides a unique opportunity to verify the classical model of loess formation that assumes its glacial origin. To determine the origin of loess accumulated during MIS 4, silt grains from 5 loess profiles located in Poland and Ukraine were analysed using a scanning electron microscope (SEM). At least 100 randomly-selected grains were selected from each of three given grain-size fractions (>30 µm, 10-30 µm, <10 µm). Consequently, a total of 1800 grains were analysed. Grains were classified based on the characteristics of their surface (A – grains with fresh surface, B – etched surface, C – encrusted surface, D – cracked grains) and the degree of grain roundness (angular / rounded grains). Grain classes A–D reflect different environmental conditions that influenced the grain surface, including formative processes and processes that modified the surface of loess-forming silt grains before their final incorporation into aeolian transport. The obtained results clearly show that the studied loess deposits are dominated by grains with various degree of rounding and etched surface. Such grain features indicate their transport in aqueous (fluvial and/or beach) environment. This, in turn, indicates fluvial deposits as the main source of silt grains for MIS 4 loess. The share of angular and fresh grains originating from sediments subject to mechanical weathering is negligible. All this confirms the hypothesis of the alimentation of loess by alluvia accumulated in periglacial conditions; contrary to the paradigm indicating that glacial deposits or sediments resulting from frost weathering are of primary importance for the supply of loess-forming silt grains.

New data on Weichselian ice advances in the Suwałki Lakeland, NE Poland

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The stratigraphy of the Weichselian succession in north-eastern Poland has, until now, been based almost exclusively on litho-petrographic studies of till layers and inter-till series from boreholes (see Lisicki, 1998, 2003; Ber, 2000, 2006). Due to the lack of sufficiently large-scale excavations at the edges of moraine uplands, no detailed, comprehensive studies of Weichselian deposits in outcrop profiles have yet been undertaken here. In relation to the construction of the S61 'Via Baltica' highway from Suwałki to the Lithuanian border, a unique opportunity has recently arisen to study exposures along the road trench that crosses the moraine upland on the sides of the Osinki tunnel valley, north-east of Suwałki. As a result, detailed investigations were undertaken on sections revealing the geological composition of the moraine upland at the Osinki site between 2020 and 2022. The studies mainly focused on the Osinki 2 site in the north-eastern part of the trench, which is approximately 400 m long and 120 m wide.

In the Osinki 2 site, detailed sedimentological investigations were carried out in the seven most accessible profiles (P1-P7). Research in profiles focusing on the identification of sedimentary layers, delineation of lithostratigraphic units, analysis of sediment lithofacies, till fabric characteristics, palaeocurrent flow directions, and the orientation of deformations. Samples from till and inter-till units were analysed for grain size, quartz grain roundness and frosting, surface microtextures of quartz grains, fine-gravel petrography, and the pollen and geochemical composition of individual samples. Additionally, twenty-four sand samples from inter-till units and periglacial wedge structures were dated using the optically stimulated luminescence (OSL) method.

The Osinki 2 site exposes a succession of more than 20 m of gravel, sandy gravel, sand, silty sand, and clay deposits, with intercalated till layers. Seven major lithostratigraphic units (from bottom to top) were distinguished in the sediment sequence: three till units (U2, U4, and U6) and four inter-till units (U1, U3, U5, and U7). In the upper part of the sediment profile (to a depth of 10 m), two continuous till layers (U4 and U6) are separated by unit U5, which comprises fluvial and fluvial-aeolian sand deposits (subunit U5b), clayey lacustrine sediments (U5c), and glaciofluvial sands and gravels (U5a and U5d). Primary sand wedges were identified within the fluvial/fluvial-aeolian subunit U5b and at the top of the uppermost till layer (U6). In places, the till layer U6 is overlain by aeolian sands of unit U7. Below the till layer U4, a thick (up to 9 m) succession of glaciofluvial sands and gravels (unit U3) lies unconformably on the lowermost till layer (unit U2) and the underlying glaciofluvial sands and gravels (unit U1), both of which are partly glaciotectonically disturbed.

OSL ages from the inter-till units and primary sand wedges suggest that the sedimentary succession at the Osinki 2 site is of Weichselian age. Units U1-U4 record sediment deposition in subglacial and ice-

marginal settings during the first Weichselian ice advance, probably before c. 64 ka. It most likely occurred in the early Middle Weichselian (MIS 4), around 64-70 ka, or possibly slightly earlier. Fluvial/fluvial-eolian (U5b) and lacustrine (U5c) subunits overlying till unit U4 indicate subsequent cold, dry periglacial conditions, most likely at the end of MIS 4 and the beginning of MIS 3. The uppermost till layer (U6) is clearly related to the last Scandinavian ice sheet advance during late MIS 2, probably not earlier than around 15 ka. The primary sand wedges in the U6 till and the aeolian sands of the U7 unit point to permafrost aggradation and aeolian activity under cold, dry conditions following the retreat of the last ice sheet.

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Archaeological Layers as Archives of Human–Soil Interactions: A Multiproxy Study from Northern Poland

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Archaeological layers (ALs) represent the long-term interaction between human activity and soil formation within settlement areas. These deposits, typically dark and humic, develop through a combination of natural processes and everyday human practices such as cultivation, livestock keeping, construction, and waste disposal. As a result, they preserve valuable evidence of past economic activities and human–environment relationships.

Although archaeological layers have been widely studied across Europe using sedimentology, geochemistry, radiocarbon dating, and, more recently, micromorphology, such integrated research remains limited in Poland, particularly in rural contexts. In northern Poland, no comprehensive multiproxy studies have yet combined sedimentological, geochemical, palaeobotanical, micromorphological, and biomarker analyses to reconstruct the formation of these deposits and assess the role of livestock farming and agriculture in their development.

This study aims to: (i) establish the chronology of archaeological layers using radiocarbon dating; (ii) reconstruct their formation processes and the intensity of human impact through micromorphology and palaeobotanical analyses; (iii) detect evidence of livestock presence and manuring practices using biomarker indicators; and (iv) characterize their sedimentological and geochemical properties. By applying a multi-scale, multiproxy approach, we seek to better understand how prehistoric rural economies influenced soil formation processes and shaped the archaeological record.

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