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Quaternary Sediments, Landscapes, and Early Settlement History in Western Estonia

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Contents

Glaciogenic relief features in the Lithuanian offshore, south-eastern Baltic Sea

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The detailed study of genesis and age of the glaciogenic relief features in the Lithuanian coastal waters of south-eastern Baltic Sea was performed in 2010-2012 during the project "Origin, geological evolution and biology of geogenic Baltic reefs funded by Research Council of Lithuania. The project findings have not been published and a number of questions remained open for a decade after the project, but recent geological investigations on the Baltic shores and the seabed enabled a fresh look at results of earlier seabed mapping.

Underwater moraine ridges in the Lithuanian coastal waters of the eastern Baltic Sea have been mapped in the depths of 10-20 m using traditional combination of side scan sonar and multibeam echosounder. Underwater drop video camera and diving surveys were carried out for visual inspection of features and for groundtruthing purposes. Two geomorphologically distinct types of underwater ridges have been recorded: 1) large scale – up to 200 m width, 1.5 km length and approximately 10 m height – elongated ridges distributed parallel to the coastline, with relatively gentle slopes; 2) small-scale elongated ridges with very steep slopes (very often close to 90°), generally distributed perpendicularly to the coastline and typically clustered within distinct groups. The length of small-scale ridges varies from 8-10 to 150-155 meters, width – from 0.5 to 20 meters, height – from 0.5 to 4.5 meters, one reef covers an area approximately from 10 to 100 m^2. Ridges are composed by very compact grey sandy loam (till), their surface is overgrown by bivalve molluscs (*Mytilus edulis trossulus*), therefore seabed structures were entitled as **moraine reefs**. The reefs are known as high biodiversity areas, maintaining unique composition of benthic community and serving important feeding, spawning and nursery sites for marine fishes and diving birds. According to interpretation of habitat types listed under Annex I of the EU Habitat Directive, these moraine reefs fulfil the criteria of geogenic reefs to be considered for establishment of NATURA 2000 network of marine protected sites.

The origin and age of moraine reefs are still an object of discussions. The fabric analysis shows that small-scale reefs-forming till was left by glacier advanced from the West, whereas large-scale ridges-forming till have not well-expressed gravel orientation. According to the results of petrographic analysis of gravel fraction, as well as interpretation of other results of integrated investigations, the reefs-forming moraine (till) and the large-scale moraine ridges were formed during the Middle Weichselian (MIS 4) glacial advance. A few seabed's relief-forming hypotheses were developed and discussed considering both previous and a new geological data: the large-scale moraine ridges could be De Geer moraines, or marginal moraine ridges composed by deformational till. The moraine reefs can be considered as erosional remnants of more compact part of the till. Thus, it possible to presume marine abrasion during the Ancylus Lake and the Litorina Sea transgressions played a significant role in the relief-forming process. The younger and less consolidated deposits, formed by the Late Weichselian glacial advance, was eroded by waves and currents, and more erosion-resistant older morainic deposits have been uncovered and preserved on the surface of the seabed.

Periglacial transformation of young glacial landscapes of the Central European Lowland

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Previous research work carried out within the area of the last glaciation in the Central European Lowland has documented structures and forms related to the occurrence of permafrost (e.g. Van Loon et al. 2012). At the same time, melting of buried blocks of dead ice have played a major role in transforming glacial landscapes, especially with regard to the formation of post-glacial lakes (Błaszkiewicz 2011; Błaszkiewicz et al., 2015). However, the mutual relations between permafrost and buried blocks of dead ice and their role in transforming glacial landscapes have not yet been comprehensively studied.

Our research area is located in the immediate forefield of the Pomeranian phase of the last glaciation, in the Starogard Lake District of Northern Poland. The subjects of research are intriguing networks of thermal contraction polygons occurring on the surface of ice-walled lake plains, as well as aeolian covers at the base of these plains and organic infills in adjacent tunnel valleys.

The analyses conducted (geological mapping, morphometric analyses and lithofacies analyses of glaciolimnic and aeolian sediments, ice-wedge infills and organic lake infills, and, palaeopedological analyses combined with OSL and C-14 dating) revealed that permafrost was encroaching onto the forefield of the Pomeranian ice sheet at the time of recession. The dating results indicate that the periglacial transformation of this area occurred in two main stages. In the first phase, thermal contraction polygon structures and initial aeolian series formed at the beginning of the Late Glacial; during the second phase intensive aeolian processes dominated during the Younger Dryas. The dating of the melting processes of buried blocks of dead ice in the tunnel valleys indicates that degradation of permafrost in the studied area was completed only at the transition of the Preboreal to the Boreal Period. The coexistence of permafrost and a very large amount of buried dead ice – as well as the similarity to modern areas of "ice-rich permafrost" – allows a special type of permafrost to be identified – dead-ice-rich permafrost. This "dead-ice-rich permafrost" dominated during the deglaciation and late-glacial periglacial transformation of young-glacial areas.

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Holocene sea levels of Latvia: terrain analysis for coastal reconstructions

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The coast of mainland Latvia has been relatively stable since the end of the Littorina Sea stage, apart from several storm events. However, this does not mean that the coast has always been this way throughout the Holocene period. Studies from the previous century suggest that remnants of the Yoldia Sea stage near Latvia are now situated below the current sea level. At the same time, the approximate locations of the coasts of Ancylus Lake and Littorina Sea have been drawn along the present-day coast of mainland Latvia (Veinbergs 1979).

Previously developed methodology for detecting ancient shorelines has demonstrated its efficacy in a case study on the evolution of the ancient Ventspils Lagoon (Breijers et al., 2023), significantly enhancing interpretations of recurrent Stone Age habitation patterns (Bērziņš et al., 2022). This workflow relies upon freely available open-source software, which facilitates digital elevation model analysis to identify remnants of ancient shore ridges. The ridges are adjusted according to set relative glacio-isostatic adjustment values from a similar site and clustered to facilitate the grouping of similar remnants, enabling the reconstruction of Holocene sea levels via trend analysis.

By expanding upon the ideas of the initial case study (Breijers et al,. 2023), machine learning methods are utilized to analyze the relationship between a regional glacio-isostatic rebound model (Vestøl et al., 2019) and relative sea level data points (Rosentau et al., 2021). The enhanced workflow produces relative glacio-isostatic adjustment values at different spatiotemporal configurations, thus reducing the requirement for a comparable location with established glacio-isostatic adjustment values. Analysis of the reconstructed terrain data, new dating data and archaeological finds facilitate the advancement of Stone Age settlement pattern analysis and potential research site identification, not just in Latvia's coastal lowland landscapes, but also in inland landscapes impacted by glacio-isostatic adjustment.

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Current state and methods for mapping the Quaternary subsurface in Mecklenburg-Western Pomerania

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The geological survey of the state geological services in the last since the 1960ies has been influenced by changing priorities. Between the late 1960s and 1990, under the direction of A.G. Cepek in Central Geological Institute for eastern Germany, the mapping project of "Lithofacies Map Quaternary 1:50 000" (LMQ 50) has been created to categorise the Quaternary units in the area of former German Democratic Republic. For the LMQ 50, thousands of boreholes were geologically recorded, sampled and investigated in a uniform manner (Cepek, 1968). For the classification of Quaternary till horizons, has been created a uniform instruction TGL 25232 (1971, 1980) for sampling, processing and analysing of till units by till clast counting method 4-10 mm (TCC). This TCC standard is actually used in Mecklenburg-Western Pomerania (MWP) with a modified lithostratigraphical evaluation methodology. Based on the TCC in the LMQ 50 and the updated state drilling data storage of Geological Survey MWP, Schütze and Krienke (2017) prepared a map of Weichselian till deposits in western Mecklenburg, and between 1995 and 2002 a map of the Quaternary formations of the surface in scale 1 : 200 000 (Krienke, 2003). The Geological Survey MWP actually plan the sampling of new borehole profiles to gain the general knowledge of the Quaternary and the underlying subquaternary according to the following criteria:
- distance to previously investigated drilling profiles > 1,000 m (perimeter buffer),
- deeper boreholes than previously achieved in an area and
- drillings with better quality than previously known (e.g. liner drillings).

Since 2005 drillings for near-surface geothermal energy extraction has been intensified due to the greater borehole depths up to 200 metres (Fig. 1). During 2005 and 2023 the model of Quaternary formations was expanded and refined by the lithostratigraphical classification of 1006 drilling profiles, among them 522 geothermal drillings, and 3141 till clast count samples 4-10mm (TCC, cf. Tab. 1). Several new interglacial features (IG), e.g. 8x Eemian-IG (MIS-5e) and 4x Holsteinian-IG (MIS-11) have been identified biostratigraphically since 2005 by extensive borehole logging and sampling.

Table 1: Statistics on investigated boreholes with till clast counts 4-10mm (TCC acc. TGL 25232, 1971, 1980) in Mecklenburg-Vorpommern

Period	Number of investigated drillings	Number of TCC samples
<1990	3053	11843
1990-2005	293	959
>2005	1006	3141
sum	4353	15943

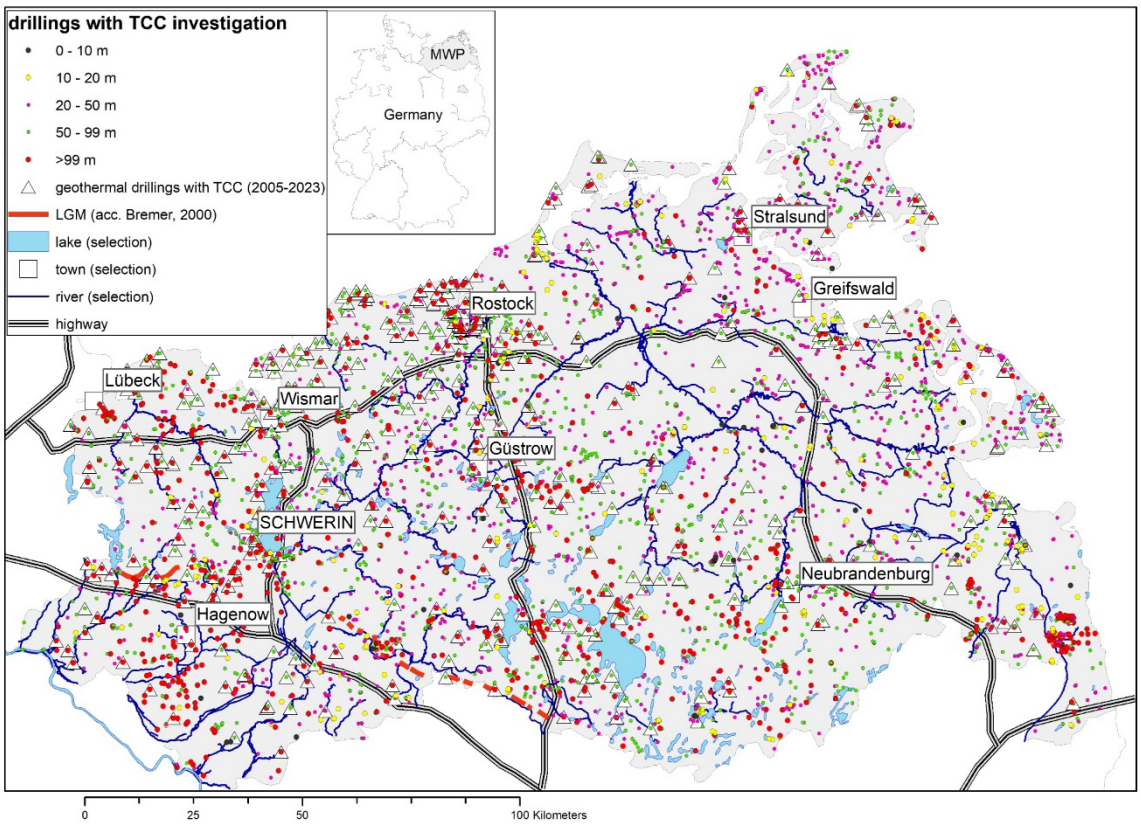

Fig. 1: Regional distribution and depth of investigated drillings with till clast counts 4-10 mm (TCC) in Mecklenburg-Western Pomerania (state 12/2023), LGM = Last Glacial Maximum acc. Bremer (2000).

Summary

- By means of State Geological Survey sampling, profiles from flushing boreholes with lower sample quality are also valuable for mapping the Quaternary subsurface, if their lithostratigraphical classification is confirmed by subsequent analytical results.
- Profiles qualified by the stratigraphic classification of till horizons by TCC, and interglacial periods, horizons qualified by pollen analyses or palaeontological investigations help to classify the Quaternary in regional and local dimensions.
- The regionally improved data basis can be used in hydrogeological modelling to improve the allocation of aquifers or the quantification of groundwater catchment areas, and for high-quality 3D modelling of the Quaternary.

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Geological framework of coastal-nearshore deposits as a contributing factor to the stability of non-tidal barriers

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Introduction. Due to global climate change, there is an increase in hydrodynamic processes that affect the development of coastal zones. In this context, it is important to consider the resilience of coastal barriers in non-tidal seas to changing conditions. The aim of this work is to determine the role of coastal-marine sediment composition in the stability of coastal barriers of non-tidal seas, particularly during extreme storms.
Study area. The objects of the study are coastal barriers (Curonian Spit, Kinburnska Spit, and Arabatska Strilka) located in the coastal zone of non-tidal seas (Baltic, Black, and Azov).
Research Methods. Coastal marine sediment samples were collected from the coastal zone of the studied barriers. The sediments were mechanically sieved. The results of the analyses were evaluated for spatial distribution and were consistent with dynamic shoreline trends.
Results. An analysis of the specific characteristics of wave erosion along the barriers studied has shown that, under the same hydrometeorological conditions, the quantitative parameters of erosion differ from site to site. One of the reasons for this situation is the difference in the fractional composition of the sediment. Within the Lithuanian part of the Curonian Spit, medium-grained sands (0.20-0.32 mm) dominate, with concentrations varying from 35 to 60 percent. Certain areas of the spit show local lithologic anomalies because of the dominance or higher concentration of coarse-grained (0.40-0.63 mm) sands or gravel-pebble material. Such lithologic anomaly is present in the coastal zone of Juodkrantė, characterized by coarse sands. The stability of neighboring areas was analyzed by comparing dynamic situations following extreme storm events.
Between 2002 and 2023, the Curonian Spit experienced four extreme storms. During these storms, the sea level rose by over 100 cm and wind speeds exceeded 30 m/s. The storms occurred on January 9, 2005, January 11, 2015, March 12, 2020, and January 30, 2022. These were the most powerful storms of the 21st century, which caused significant coastal erosion.
The Juodkrantė lithologic anomaly experienced the least coastal erosion during these storms, while significant coastal retreat was observed to the north and south of this area. The most significant erosion occurred in the northern section of the Curonian Spit, where there are large volume of fine-grained sands (up to 0.2 mm).
It was discovered that after the storm, the different coastal stretches recover in different ways depending on the sediment composition. The Juodkrantė area experiences the slowest shoreline recovery, while intense accretion occurs to the north and south.

Studies conducted along the coastal barriers of the Black and Azov Seas indicate a similarity between coastal dynamics and granulometric composition.
Conclusion. Shore areas composed of sediments of different sizes exhibit varying dynamic trends during and after the storms.

Gravel-pebble paradox of the Curonian Spit: genetic, lithodynamic and evolutionary contexts

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Introduction: the coastal zone of the Curonian Spit (at Pervalka, Juodkrantė, etc.) contains lithological anomalies with an increased concentration of gravel and pebbles. The origin of this fraction is unclear, and its dynamics and impact on beach stability within the Curonian Spit are also poorly understood.
Study area: the study area is the coastal barrier (Curonian Spit) and the adjacent waters of the Baltic Sea and the Curonian Lagoon.
Research methods: coastal marine sediment samples were collected from the surface of the Curonian Spit using manually excavated pits (up to 1 m depth). The field analysis included determination of the total fraction ratio of the sediments, morphological parameters, and petrographic composition of the coarse fractions. The spatial distribution of the coarse fraction of coastal marine sediments within the study area was analyzed using satellite imagery. The laboratory study was carried out using specialized equipment (Fritsch Analysette 22 MicroTec plus) to determine the fractional composition of the medium and fine fractions. The results of integrated investigations of boreholes drilled in the Curonian Spit and neighboring waters during previous geological mapping projects were used for the final data interpretation.
Results and conclusions: the petrographic analysis of the coarse fraction sampled from the beach and submarine slope sediments revealed that over 95% of the samples consist of crystalline rocks, and this percentage is significantly lower compared to this parameter in the continental coast. The total content of gravel and pebbles in the lithological anomalies of the Curonian Spit can reach up to 20% (with a maximum of 43%). The size, degree of pollination and flattened shape of gravel and pebbles indicate their movement within the hydrodynamic conditions of the coastal zone over a multi-year period. The movement of gravel and pebbles along the coast takes the form of a wave made up of coastal-marine sediment. This movement is mainly observed during catastrophic storms and is influenced by the wave climate and the nature of the coastal currents that are formed during such events.
For a long time, it was assumed that the coarse fraction was derived from the erosion of moraine sediments on the Baltic seabed. However, coring data in coastal areas and on the Baltic Sea floor show that the uppermost part of the sediment thickness is composed by sand. It can therefore be concluded that the gravel and pebbles are not the result of moraine erosion of the present seabed. The moraine deposits closest to the surface are present in the Lesnoye area and adjacent seabed areas. Thus, it can be assumed that the erosion of these areas occurred at lower sea levels, during the Ancylus Lake or at the beginning of the Littorina Sea. The new hypothesis of the origin of

the gravel-pebble anomaly in the Curonian Spit has been developed as a result of the investigations carried out.

Preliminary lithostratigraphical and pollen results of a long sediment sequence from Southern Ostrobothnia, Finland

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During the last decade, extensive investigations and a drilling campaign have been carried out in the Kurikka area, Southern Pohjanmaa, Finland, by the Geological Survey of Finland to investigate a large and complex aquifer system. Recent drillings have unveiled over 10 meters thick and extensive organic-rich sediments beneath the Holocene sand and fine-grained sediments and a till complex including several till beds. In 2022, continuous sediment sampling yielded a core recovery rate of 70%. For the first time, a record-thick organic deposit in Southern Pohjanmaa has been found and can provide an opportunity to investigate the paleoenvironmental history of interglacial and/or interstadial in detail and complement the previous knowledge of the pre-Late Weichselian ice-free phases and their vegetational and basin evolution.
Two samples were subjected to 14C (AMS) dating at the Poznan C-14 laboratory in Poland, while three OSL samples obtained from above, below and in the middle of the organic-bearing sediments, are yet to be dated at Lund University's OSL dating laboratory. Pollen samples were processed using the LST Fastfloat heavy liquid method (Eskola et al., 2021). Here we present the preliminary, coarse-resolution pollen and litostratigraphic results and discuss the correlation possibilities. The organic-rich sediments and associated sands and silts, sandwiched between two till beds, indicate large (fresh) water basin.

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Highly unstable climate of the last interglacial in the southern Levant

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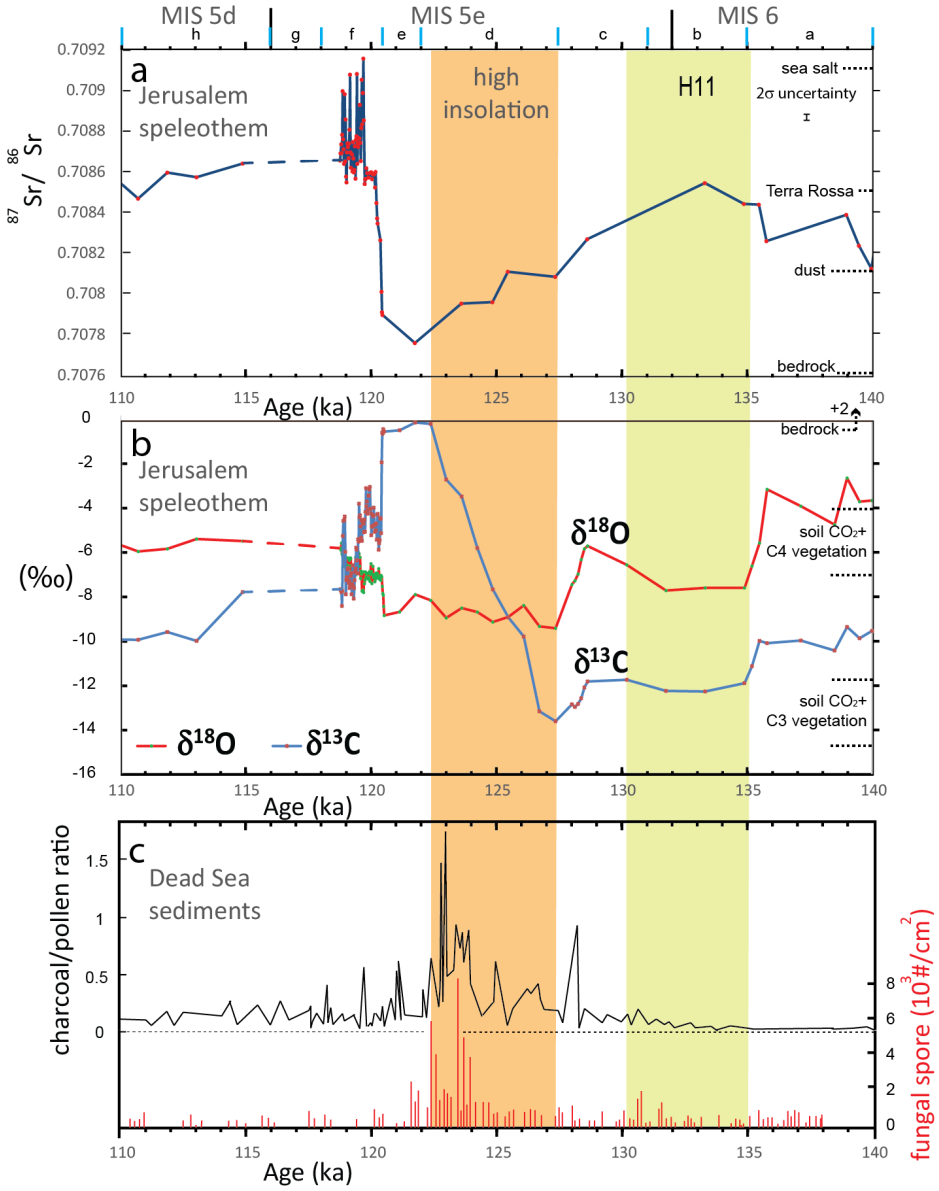
We present a high–resolution record of hydro-climate conditions in the last interglacial MIS5e (~131-116 ka) in the southern Levant by analyzing the simultaneous behavior of Sr, C, and O isotopes in the AF12 stalagmite from the Har Nof cave in Jerusalem. These data are compared and integrated with data from other surrounding speleothems and the contemporaneous charcoal, fungal spores, and pollen data retrieved from the ICDP Dead Sea deep drill core.
The following environmental patterns are observed during MIS5e:

During early MIS5e (~131-127.5 ka) on the rising flank of the northern hemisphere (33 N and 65 N) insolation curves, Jerusalem and the Judea Hills were experiencing a moderate Mediterranean-like climate. Desert dust accumulated in the vicinity of the cave. Salt deposition was occurring in the Dead Sea basin.
Approaching the peak northern hemisphere insolation, and during the interval of peak insolation and Sapropel event S5 (127.5-122 ka), temperature rose and rains arrived to the region from both Mediterranean and tropical sources. The end of this period was characterized by widespread fires, loss of C_3 vegetation, fungal proliferation, and complete soil removal from hill-slopes. Savannah-like C_4 grasses penetrated to soil-accumulation sites in the valleys. The main rainfall season appears to have shifted from winter to summer.
At 122-120.5 ka, high $^{87}Sr/^{86}Sr$ ratios indicate contributions of sea salts. Extremely high $\delta^{13}C$ values indicate no vegetation above the cave, suggesting am arid environment.
At 120.5-118 ka, on the declining flank of the insolation curve, the area was under unstable conditions with occasional storms, and high-intensity rainfall accompanied by sea salt. Soil was formed and savannah-like C_4 vegetation developed.
At ~118-116 ka, the sedimentation rate of Har Nof AF12 stalagmite is extremely low. The region was characterized by arid conditions and major salt deposition was occurring in the Dead Sea. Still, occasional floods reached the Dead Sea with some moisture coming mainly from southern sources.

This detailed record of environmental changes shows that the northward expansion of climatic belts over the southern Levant during MIS5e caused dramatic environmental changes, crossing a tipping point threshold, and was associated with a major ecologic disruption. Such abrupt changes are characterized by nonlinear, threshold-type responses at rates that are large relative to background variability and forcing.



The evidence from the caves and Dead Sea sediments presented here for the MIS5e period suggests that global warming can be associated with periods of increased instability in the south Levant, an area lying at the desert fringe. The tipping point threshold manifested in MIS 5e of the Levant include complete loss of vegetation and soil, devastating fires and a shift of precipitation from winter to summer. These extreme events send a warning message that elevated greenhouse gases may increase desertification and instability of Levant climate.

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Morphometric characteristics of parallel tunnel channels in Poland

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Parallel tunnel channels (PTCs) have been identified and described within the area of the United States covered by the Laurentide Ice Sheet (Sodeman et al. 2021). They have been characterized as quasi-parallel pairs of depressions stretching along a central ridge which separates them. Similar forms also occur in Poland within the range of the Weichselian Glaciation. The aim of the research was to determine the morphological and morphometric features of PTCs documented in the area of Poland.

The research was conducted in the northwestern Poland. Based on Digital Elevation Models (DEMs) and hillshade models, approximately 80 depressions forming PTCs were vectorized. The Morphometry Assessment Tools (MAT) toolbox in ArcGIS software (Gudowicz, Paluszkiewicz 2021) was utilized for morphological analysis. Using this toolbox, morphometric parameters such as area, length, width, orientation, elongation ratio, circularity, compactness coefficient, form factor, and shape factor were determined. Additionally, hypsometric parameters like elevation range, slope, aspects, and terrain ruggedness were analysed. In the study area PTCs vary in length from a few to over 20 km. The length of the depressions forming them ranges from 0.1 to 7 km. Their width does not exceed 500 m, averaging 170 m. Their depth ranges from approximately 5 to 30 m. The depressions exhibit varied shapes, with some forms being considerably elongated while others have a high circularity. PTCs are often filled by lakes or peat bogs.

In the previous research PCTs were interpreted as the result of specific subglacial erosion, representing a drainage system for subglacial waters from the interior of the ice sheet to the ice margin (Sodeman et al. 2021). Additionally, in the Polish region, the formation of PCTs was significantly influenced by the melting of ice blocks after the retreat of the ice sheet.

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Quantitative pollen-based climate reconstructions for Lateglacial and Holocene periods deduced from Dukstelis Palaeolake data

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This research delves into vegetation patterns and offers quantitative pollen-based climate reconstruction patterns spanning the Lateglacial and Holocene periods based on Lithuanian proxy records (Gedminienė et al., in prep.). Utilizing consistent methods and modern pollen calibration datasets, new Dūkštelis palaeolake pollen data were supplemented by the vegetation data from three previously published sites (Lieporiai palaeolake, Čepkeliai peat bog, Kamyshovoye Lake (Druzhinina et al., 2020; Gedminienė et al., 2019; Šeirienė et al., 2021; Stančikaitė et al., 2019), covering a wide geographical and temporal spectrum within Lithuania. The study reveals trends in mean winter and summer temperatures (MWT and MST), showcasing deviations from modern levels across different seasons and locations across various time points.

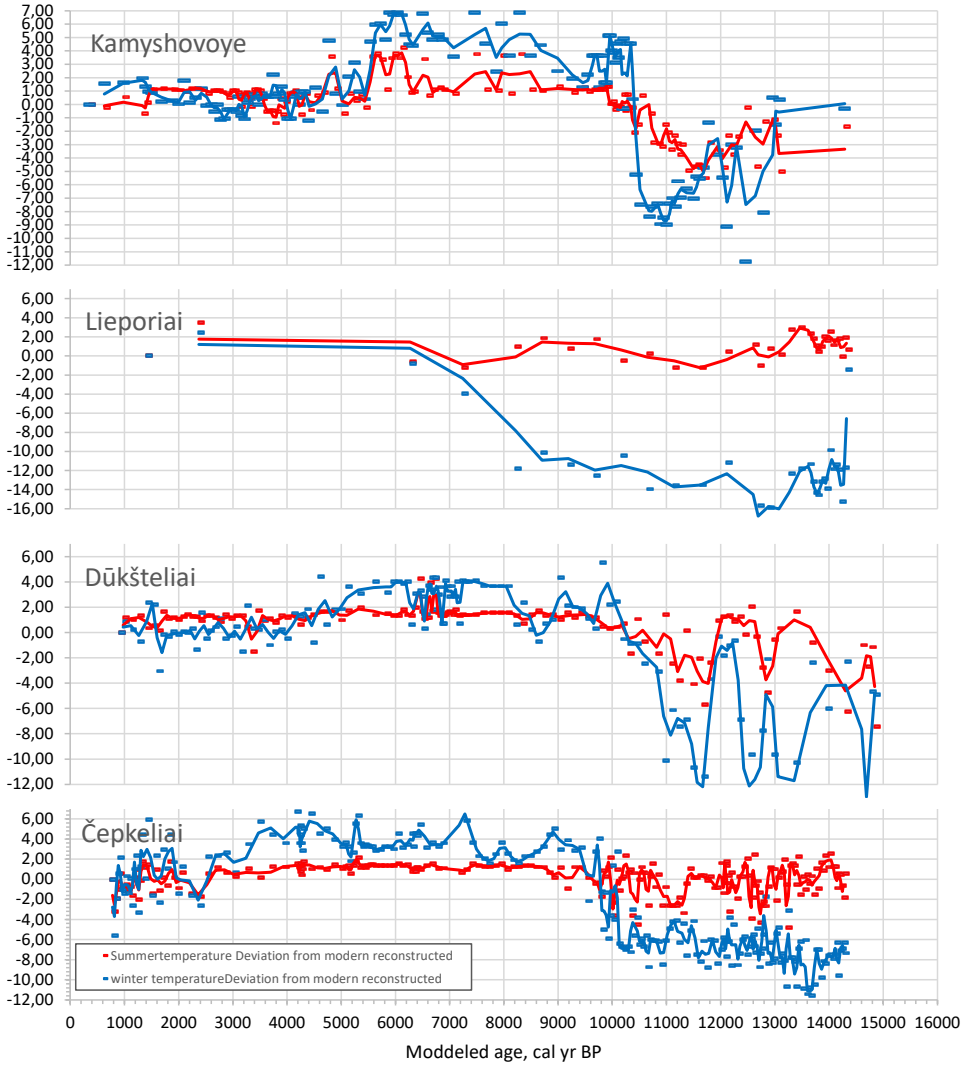
Preceding the Greenland Stadial 1 (GS-1) event, two abrupt warmings occurred. The Lieporiai palaeolake located in northern Lithuania exhibited the lowest reconstructed MWT during the Lateglacial period, plummeting to -14°C below modern level, with modest increases observed throughout the Early and Middle Holocene. Conversely, the Čepkeliai peat bog in the southernmost region recorded the second coldest MWT during the Lateglacial period. Kamyshovoye Lake in the Kaliningrad region and Dūkštelis palaeolake in the southeast exhibited milder MWT during the Lateglacial period. Reconstructed MST during the Lateglacial also revealed disparities among sites, with higher summer temperatures observed farther inland increasing ~2°C above modern levels. Lieporiai and Čepkeliai sites exhibited similar MST values, while the Kamyshovoye Lake portrayed lower temperatures, comparable to the Dūkštelis site.

During the GS-1 event, both Dūkštelis palaeolake and Kamyshovoe Lake experienced a tripartite reversal characterized by a notable temperature increase in the second part of the stadial, particularly pronounced during winter seasons. However, the sites exhibited rapid cooling during the latest part of the GS-1 event.

Divergent trends observed between mean winter and summer temperatures for Dūkštelis palaeolake, occurring at various intervals, were prominently associated with increases in precipitation during warmer winters.

Findings suggest a delayed Early Holocene period and a more gradual response to solar irradiance compared to standardized global mean surface temperature records (Marcott et al., 2013). During the Holocene Thermal Maximum, mean winter temperatures were approximately 3–5°C higher than present levels.

The Late Holocene witnessed a cooling trend interspersed with rapid warming and cooling episodes. Around 3,300 cal yr BP, uncertainties arise in temperature reconstructions due to visible evidence of anthropogenic influences, such as land-use changes and agricultural activities at Dūkštelis palaeolake, casting doubt on the accuracy of reconstructions during this period.



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Sampling erratic boulders for in-situ cosmogenic ^{26}Al and ^{10}Be dating at the southern periphery of the Fennoscandian Ice Sheet

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Poster presents the first sampling campaign of the "DatErr 2.0" project, which aims to reconstruct the exposure history of erratic boulders resting on Saalian glacial landforms in Poland and Germany. Erratic boulders were sampled for quartz, from which paired in-situ cosmogenic nuclides 26Al/10Be will be employed to determine exposure history and surface exposure ages of boulders. Fieldwork campaigns were conducted in June/July in Brandenburg (Germany) and at the end of July in eastern Poland. We collected around 60 samples from the upper surface of large and intact boulders, protruding significantly above the ground surface. Paired in-situ cosmogenic nuclides 26Al/10Be results, which we will obtain in the future, will contribute to a deeper understanding of the Late Saalian ice sheet dynamics and chronology in Europe.

The research is part of the project "DatErr 2.0" funded by the National Science Centre in Poland (grant no 2022/46/E/ST10/00074).

Kolga strandplain, northern Estonia, as an archive of Holocene relative sealevel and storminess.

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The Kolga strandplain of coastal ridge-swale system in the uplifting southern Gulf of Finland, the ridgeplain is spanning 5x3 km and stretches on the altitudes between 0 and 28 m, with younger ridges situated at gradually lower altitudes. Airborne LiDAR-based relief analysis, ground-penetrating radar surveys, sedimentological and magnetic susceptibility analyses, and luminescence and AMS radiocarbon dating were used to reconstruct Holocene shoreline displacement and architecture of the ridge swale system. Analysis reveals over 120 low-relief ridges with relative heights of 0.2–0.4 m, some of which are fully or partially buried under peat. Among these 11 higher ridges (0.5–4 m) with occasionally thicker aeolian covers were identified. Luminescence dating of beach sediments indicates that the older, higher part of the strandplain, situated at 20–28 m above sea level, was formed during the Ancylus Lake and early Littorina Sea stages, approximately 11.1–9.6 thousand years ago. The younger, seaward part of the strandplain developed during the Littorina Sea regression over the past 7,000 years. The dating of ridges and their absolute elevations suggest a nearly linear sea-level decline at an average rate of 2.7

mm/year during this period, consistent with the rate of land uplift relative to the geoid in the Kolga region. The inner structure of these swash-aligned ridges displays seaward-dipping (off-lapping) of sandy-gravelly coastal deposits and are interpreted to reveal the intervals of enhanced storminess. The youngest zone, dated 540 years ago, corresponds to the Little Ice Age, known for its cold and stormy climate (Bond et al., 2001). Similar higher ridges, often partially reworked by aeolian processes, are known from other parts of Estonia, including Saaremaa and Hiiumaa (Tõnisson & Suursaar, 2020). The Kolga area also contains higher ridges formed around 5,400 years ago, with analogous features found in the Narva-Jõesuu region (Rosentau et al., 2013) and Hiiumaa (Suursaar et al., 2022).

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Exploring the Late Glacial Environment of Northern Lithuania: Insights from palaeolake sediments

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The multiproxy data (pollen, plant macrofossils, diatoms, stable $\delta^{18}O$ and $\delta^{13}C$ isotope, magnetic susceptibility, loss-on-ignition measurements (LOI) and AMS 14C dating) obtained from the sediment core (Lieporiai) representing N Lithuania has permitted the reconstruction of the Lateglacial and early Holocene environmental changes. A chronology of the sediment core was determined through the use of AMS 14C dates, which were cross-verified by means of biostratigraphic zonation and the correlation of the core's $\delta^{18}O$ isotope records with the NGRIP $\delta^{18}O$ curve. The results obtained indicate that lacustrine sedimentation began around 14,000 cal yr BP. During the initial phase of sedimentation, the region was characterised by a treeless herbaceous tundra dominated by dwarf shrubs such as *Betula* and *Salix*. The occurrence of cold-tolerant diatoms and macrophytes including *Selaginella selaginoides* (L.) Link and *Potamogeton vaginatus* Turcz., suggests the existence of harsh climatic conditions reminiscent of the Older Dryas (or GI-1d event). The high concentration of minerogenic material within the sediments indicates a period of intense erosion and the influx of terrigenous material into the catchment during that time.

The Allerød is characterised by notable changes in the composition of vegetation. A warmer and more humid climate led to the spread of pine-dominating forests and the degradation of herbaceous cover. The dwarf birch (*Betula nana*) was replaced by the tree birch (*Betula* sect. *Albae*). The gradual rise of organic constituents in the sediments indicates that the vegetation cover was stabilising. The diatom data sugests a rise in water temperature and a decline in water levels within the basin, which may be indicative of the early stages of eutrophication. This warming trend, which occured around 13900-13400 cal yr BP, may be correlated with the GI-1c

event (van Raden et al. 2012, Lowe et al. 2008). However, the brief period of cooling known as the Gerzensee Oscillation, documented in the northern hemisphere during the Allerød period, is not evident in the palaeobotanical data of this sediment section. Nevertheless, a decline in values in the O^{18} curve at a depth of 150 cm is observed, which may be associated with the GI-1b event. Significant changes in sediment structure (including changes in $CaCO_3$, organic, and minerogenic matter values) began at a depth of 140 cm, coinciding with a climatic shift evident in vegetation composition. Pollen records indicate a transition from a pine forest to forest tundra vegetation dominated by *Pinus* and *Betula*. The plant macrofossil diagram shows a significant decrease in the total concentration of plant macroremains but an increase in the number of cold-tolerant species. A notable reduction in diatom species diversity and the prevalence of benthic species suggest the onset of dystrophication processes in the palaeobasin. These findings indicate a transition to the colder conditions of the Younger Dryas.
Data collected from the Lieporiai sequence indicate instability in vegetation composition and sedimentation regime, suggesting cooler and warmer intervals as well as changes in humidity during the Lateglacial period in the area. Some of these variations could be correlated with climatic events documented in Greenland ice cores, European lacustrine and Atlantic Ocean sediments during the Lateglacial period (Yu and Eicher, 2001).

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Record of palaeoecological changes in the sediments of the Čepkeliai bog based on Cladocera analysis (SE Lithuania)

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Cladocerans are small freshwater crustaceans whose remains are well preserved in sedimentary deposits. Remains of subfossil cladocerans allow reconstruction of past lake evolution. They provide valuable information about the lake environment, such as climate changes, trophic levels, pH, and water-level changes. This study presents the first Cladocera research performed on the Čepkeliai profile, in souther Lithuania. The aim of this study was to reconstruct the ecological conditions that existed in the reservoir during the Early Holocene. The survey provided information on the composition of Cladocera species and the ecological conditions in the region. Other studies, including lithological, palaeobotanical, isotopic, and geochemical analyses, have also been conducted in the area (Stančikaitė et al., 2019), which show a good correlation with the Cladocera data.
The study material was collected from the south-eastern part of the Čepkeliai peat bog (54°00´48.54´´N; 24°37´01.02´´E). Cladocera analysis was conducted on 75 samples from the

depth interval 707-1200 cm. The sediments were processed according to the standard method (Frey, 1986). The sequence covers the period from 12000 to 7650 cal yr BP.

A total of 27 Cladocera species belonging to three families, Chydoridae, Sididae, Bosminidae, were identified in the Čepkeliai profile. Cladocera were represented by the remains of planktonic (Bosminidae) and littoral (Chydoridae, Sididae) forms. Chydoridae was the most diverse family (23 species), whereas the other families were represented by few species (Bosminidae-3, Sididae-1). Six local cladocera assemblages zones (LCAZ) were distinguished based of composition of Cladocera and changes in relative species abundance.

During the early Holocene, sediments formed in a warm and wet climate, as indicated by the abundance and diversity of Cladocera species. During this phase, species with different temperature preferences coexisted, indicating moderate thermal conditions. At that time the basin was shallow and the cladoceran assemblage was dominated by littoral species. The presence of species typical of oligo-mesotrophic and eutrophic waters suggests that the water body was relatively mesotrophic at the time. The basin was characterized by low pH. During the second phase of basin development, approximately 11100 cal yr BP, pH levels increased. At 10645 cal yr BP, the trophic level of the basin increased, as indicated by the increased abundance of species that prefer higher trophic levels. Between 9200-9000 cal yr BP, there was a decrease in the number of species that thrive in warmer waters, which may be linked to a brief cooling of the climate. This cooling may be related to rapid climate change events which occurred in Europe around the time of the 9.3 ka BP cold event (Rasmussen et al., 2007). Subsequently, the emergence of *Graptoleberis testudinaria* and an increase in the abundance of *Camptocercus rectirostris* may have resulted from the rise in temperature after 8900-8800 cal yr BP. At that time, the presence of *Alonella excisa* and *Alonella exigua* may have been related to the intensive overgrowth of the basin, low productivity and low pH. Furthermore, the reduction in the number of planktonic species was a reaction to the lowering of the water level. The trophy and productivity of the basin began to increase around 8100 cal yr BP.

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Ring forms near Wejherowo (northern Poland) - analysis of biogenic sediment

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Ramparted depressions are a characteristic feature of the glacial landscape of the Żarnowiec Upland (Northern Poland) consisting of a series of central depression surrounded by a ridge. The filling of the depressions consists of lacustrine and peat deposits of varying thickness.
For the purpose of determining the genesis and evolution of the examined forms from the central part of thirteen of them, undisturbed sediment profiles were sampled using a piston corer. All profiles have a similar sequence of sediments. At the bottom, there is sandy clay, followed by non-carbonate mineral gyttja with layers of peat (the stage of melting dead ice blocks), further mineral-detrital gyttja (non-carbonate). In the middle of the profile, lacustrine sediments transition into peatlands, continuing to the top of the profile. Calcium carbonate appears in the profile at the transition from lacustrine to peatland sedimentation.
Preliminary chronological assessment based on AMS 14C dating of plant remains and palynological analyses determines the beginning of lacustrine sedimentation at the end of the Late Glacial period (13500-13800 cal BP).
A detailed recognition of the examined ring-shaped forms, particularly from the perspective of local hydrogeological conditions, as well as the reconstruction of geomorphological processes and their temporal sequences, will allow the authors to contribute a range of new insights to the discussion on the evolution of permafrost during the last glaciation.
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Small size forms and microstructure of carbonate cementation products in Quaternary sediments in the middle-western Poland

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Carbonate cementation products occur in Quaternary sediments in Poland, especially in Pleistocene glacial and glaciofluvial deposits in the Polish Lowlands (e.g. Biernacka, 1993; Ciborowski & Jankowski, 2007). However large cementation forms such as blocks or layers of calcareous conglomerates and sandstones are rare (Kłysz, 1999; Urban, 1999). This study documents the occurrence and microstructure of small size forms in the region of the LGM zone in the middle-western Poland. Sediments and cemented formations were researched with the use of granulometric analysis, petrographic analysis, calcium carbonate content analysis, analysis of thin sections in a petrographic microscope and SEM.

In the study area 4 types of cementation products were observed: conglomerate lumps, sub-pebble cementation forms, concretions, and rhizolithes.
As a main example, conglomerates will be discussed. Conglomerates form small lumps (from a few to about 30 cm in diameter) scattered mostly irregularly in glaciofluvial and glacial gravels, commonly under glacial tills. They were observed only in 3 sites from 25 sites where cementation products were sought.
The characteristics of the microstructure are presented on an example from a selected site, where detrital grains were connected by meniscus bridges (cementation in the vadose zone). However, the genetic interpretation turns out to be complex when field data are taken into account – there are a few conceptions of the conditions of forming lumps. They could be formed by leaching calcium carbonate down the profile by meteoric water (Sanders et al., 2010), by evaporation of groundwater (see: Chen, 2002) or by precipitation of calcium carbonate on the roof of permafrost (Swett, 1974).
Main conclusions of this study are the following:
In the study area there were observed different small size carbonate cementation products with different origin: rhisolithes – biogenesis (Klappa, 1980); sub-pebble cementation forms – infiltrative and pedogenic origin (Letsch, 2014); concretions – some have infiltrative and some have pedogenic origin; conglomerate lumps – complex and unsure origin.
Sub-pebble cementation forms are the most commonly occurring forms.
Analysis of the microstructure of cementation products is necessary to identify the origin of these forms but it should be considered in the local geological context.

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Quo vadis, geological mapping of Estonia?

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Geological mapping is important for many fields both in geology and outside of geology as well, providing information about geological history of the area, potential mineral resources, status of groundwater *etc*. So far mapping in Estonia has been done mainly in 2D, producing either paper or digital maps. By august 2024, roughly 60% of land area is covered with either digital or a hand-drawn map (Geological Survey of Estonia, 2023). However, the development of modelling softwares, and more specifically geological modelling softwares, has been rapid recently. Therefore, the workflow of geological mapping must be re-thought because 3D models allow us to provide necessary data for a lot more people than 2D maps ever could.

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Subglacial valleys of cold versus temperate glaciers: examples from Greenland and Austria.

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We present a compilation of results from glaciological studies in NW Greenland and Ötztal Alps, Austria related to the thermal structure and subglacial topography of outlet and valley glaciers. We used ground-penetrating radar (GPR) Zond-12e surveys following the methodology described in Karušs et al. (2022a, b) and Lamsters et al. (2022a, b) for the measurements of ice thickness and internal structure. The studied glaciers, although being similar in size, greatly differ in regard to their location, climate and thermal structure. The Qaanaaq glacier (QG) (Fig. 1A) is located in NW Greenland, the Piulip Nunaa peninsula, where it drains the Qaanaaq Ice Cap. The Qaanaaq Airport had the mean annual air temperature of -8.5°C from 2005 to 2015 (Tsutaki et al., 2017), while the annual mean air temperature at Rofenache catchment that includes the Hintereisferner glacier (HG) (Fig. 1B) was 2.5°C at 1,900 m a.s.l. (Strasser et al., 2018). The tongue of the QG is located at elevations at ~200 m a.s.l., while the ice front of the HG is at ~2.5 km a.s.l.

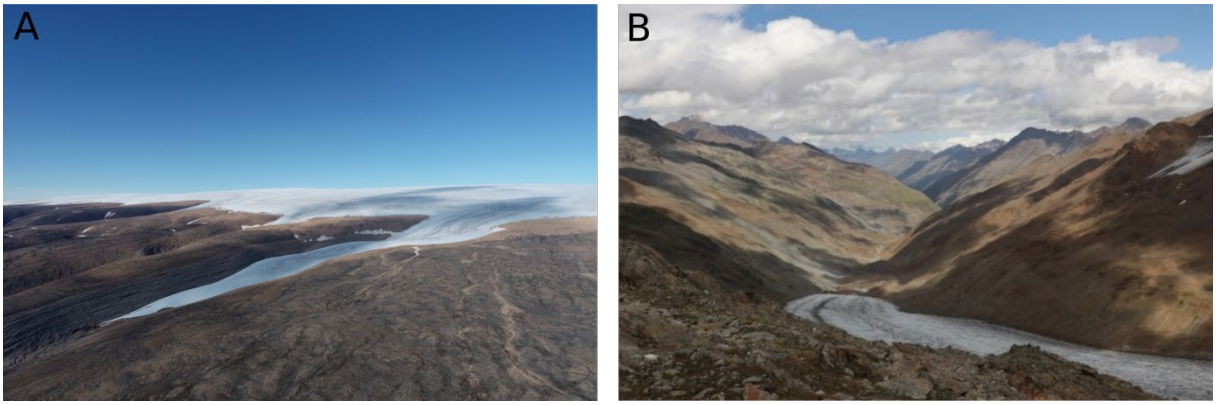

Figure 1. Drone photographs of (A) Qaanaaq glacier in western Greenland and (B) Hintereisferner glacier in Ötztal Alps, Austria revealing narrow V-type valley versus broader U-type valley, accordingly.

Our study results reveal that the studied part of the QG is completely cold, while the HQ is completely temperate. These variations result mainly from the different climatic conditions nowadays and in the past. GPR profiles recorded on the QG show mainly radar transparent ice layers attributed to cold ice. Occasional GPR signal scattering is attributed mainly to the debris concentrations inside the ice. GPR profiles from the HG show mainly intense scattering facies, which are interpreted as temperate ice with a relatively high water content, which limits the signal penetration depth. Thus, there is a lack of GPR reflections from the ice-bed interface in places. The reconstructed ice thickness and subglacial topography models reveal two types of subglacial valleys. Such valleys have been traditionally attributed as fluvial (V-shaped) and glacial valleys (U-shaped). However, in the case of the QG, V-shaped valley is still preserved under the outlet glacier providing indications on the glacier thermal structure and glaciation history. We assume that for the preservation of this V-shaped valley, glacial erosion should have been limited in the past including the Little Ice Age. The main limiting factor for the widespread subglacial erosion could have been glacier thermal regime. Thus, we speculate that the QG is cold not only today but has been mainly cold also in the past. The subglacial valley of the HG coincides with classical U-shaped valleys in Alps suggesting pronounced subglacial erosion.

In conclusion, our studies reveal that shape and type of subglacial valleys are greatly influenced by glacier thermal regime, especially thermal conditions at the ice bed interface among other factors. Under cold polar conditions, the classical transformation of fluvial (V-shaped) to glacial (U-shaped) valleys may be restricted due to the lack of temperate ice and subglacial meltwater.

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Sedimentary archives of coastal flooding and storminess. A regional comparison.

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The past storminess and past storm-induced coastal flooding, in the timeframe of several thousands of years up to a few hundred years, is only deciphered from the geomorphological and sedimentary archives. For the last few hundred years, we also possess contextual historical sources that give an anthropogenic context to extreme events.

Considering storm-induced coastal flooding over a few thousand years, sedimentary archives are scarce. Evidence of coastal marine inundations is usually limited in geographical range and continuity. However, they are a significant source of information on the environmental influence of extreme events.

On the contrary, sedimentary archives of storminess, preserved mostly within inland peatlands and peat bogs, comprise the quasi-continuous record of changes in wind climate, including the intensity and seasonality of wind climate (Björk and Clemmensen, 2004; Goslin et al., 2018). Granulometric and geochemical analyses of mineral matter deposited within mostly organic successions or sedimentary and geochronological analyses (Kylander et al., 2023) of dune activity allows to indicate periods of increased storminess within the history of a few thousand years (Bernhardsson et al., 2019).

In the current review study, we compare the sedimentary record of storminess and storm-induced coastal flooding. We target questions on the complementarity of both archives. Do they tell different parts of the same story? Do the flooding episodes correlate with periods of increased storminess? What if the evidence comes from distant geographical areas?

The review is based on the most recent investigation of the evidence for storm-induced coastal flooding on the southern Baltic Sea coast (Leszczyńska et al., 2022, Moskalewicz et al., 2020) and a review of published research on evidence for past storminess along the eastern, southern and southwestern coast of the Baltic Sea (Björk and Clemmensen, 2004, Goslin et al., 2018, Kylander et al., 2023 and other publications).

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Weathering degree of Late Weichselian till derived from the heavy mineral assemblage and micromorphology of hornblende (N Poland)

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The petrographic and mineral assemblages of tills are valuable sources of information regarding the alimentation area and palaeotransport routes of glacial sediments (Woźniak, Czubla, 2015). However, post-depositional weathering processes can lead to significant alternations. The record of these processes may have an ambiguous character and may not be macroscopically detectable. The aim of the current research is to determine if such alternations may develop in various geological settings. For example, whether an overlay of clay may influence higher resistance and preservation of primary mineral components of tills. The research is conducted in two study sites located in northern Poland: Dmuchowo and Gronowo Polskie. Both contain Late Weichselian till. However, they differ in their thickness and exposition to surface processes. In the Dmuchowo site, the till is 3 m thick. It is partially eroded, and a soil profile developed in its upper part. In the Gronowo Polskie site, the thickness of the till reaches over 5 m, but it is covered by a 2 m thick layer of clay with a developed soil profile.

Research methods aiming to determine the advancement of the weathering processes of tills comprise the following analyses: carbonate content, petrographic fraction of 5-10 mm, heavy minerals assemblage, hornblende micromorphology using SEM (Woronko et al., 2022), and supporting EDS and mXRF measurements. To obtain heavy mineral assemblage, samples from each profile taken in 10 cm intervals were dried, sieved, and then, a 0.125-0.250 mm fraction was separated using sodium polytungstate ($3Na_2WO_4 \cdot 9WO_3 \cdot H_2O$) with a specific density of 2.85 g/cm^3. The heavy minerals were analysed with a Zeiss petrographic microscope (model Axio Imager A2). At least 300 individual translucent grains were counted, and then selected mineral groups were used to calculate the weathering degree of tills. For micromorphological analysis, 50 hornblende grains were randomly selected from each sample and examined in two stages. The first one consisted of an examination of the degree of grain rounding, while the second one focused on assessing the degree of weathering of the youngest grain surfaces. Any effects of chemical and mechanical weathering were recorded. Measurements of linear lengths and widths of microstructures resulting from dissolution, the so-called lenticular etch pits, and the degree of grain coating were performed.

The heavy mineral assemblage in both profiles is dominated by amphiboles, epidotes, and garnets. In the upper part of the Dmuchowo profile, a higher content of more resistant grains was spotted. For example, the relative concentration of zircons gradually decreases downward until around one meter deep. In contrast, the assemblage of heavy minerals in Gronowo Polskie does not change significantly throughout the profile, pointing to the possible role of clay overlay in

partially securing the till profile from weathering. The obtained research results allow us to conclude that a low degree of weathering of the hornblende grain surfaces predominates throughout the profile. Most advanced weathering effects are inherited from previous (pre-Weichselian) geological processes. In Dmuchowo site, hornblende grain coating does not occur in the upper part of the profile but appears in its basal part. This result corresponds to the decalcification zone, which should be associated with the process of carbonate and clay mineral leaching. Rounded grains dominate the profile, indicating that their microrelief is a result of transport in an aquatic environment.

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Littorina transgression-related environmental changes in the area of the Szczecin Lagoon (NW Poland) based on Cladocera and geochemical record from Lake Nowowarpieńskie sediment cores

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The Baltic Sea is one of the youngest seas of the Atlantic Ocean. Four different stages of postglacial development of the Baltic Sea were associated with significant changes in its spatial extent and transformations of hydrographic, hydrochemical and biological conditions. These alterations took place over just a few thousand years and were determined by both climatic and tectonic factors. The key paleohydrological event that played a decisive role on the formation of the modern Baltic Sea was the Littorina transgression (m.in. Röβler *et al.,* 2011). The consequences of this event include the inundation of a vast area of the Odra River floodplain, that today constitute the Pomeranian Bay and the Szczecin Lagoon (NW Poland) (Borówka *et al*., 2017). Conducted study, whose aim was to identify the origins of Lake Nowowarpieńskie (peripheral part of the Szczecin Lagoon) reconstruct its development against the background of environmental changes, show that Holocene environmental changes, especially the drastic ones related to the Littorina transgression, were recorded in the sediments in Lake Nowowarpieńskie. It is a transition zone between river and maritime environments. Geochemical analyzes of sediments (Strzelecka, Wróbel, 2021), Cladocera analysis and radiocarbon dating enabled to distinguish individual stages of its development: stage of lacustrine sedimentation, stage of initial marine-lagoon sedimentation, stage of marine-lagoonal to lagoonal sedimentation, lagoonal sedimentation, lagoonal sedimentation under increasing human impact. Geochemical data allowed for the reconstruction of changes in the water body supply and the determination of a clear transition zone between sedimentation in terrestrial and marine-lagoon conditions. Cladocera, on the other hand, has proven to be a very effective indicator of changes in salinity, trophic conditions and changes in water levels. The results of the CCA analysis indicate that the examined geochemical variables explain 54.9% of the species variability of Cladocera in the JNW1 profile. Among them, the most important role is played by the concentration of nutrients, especially phosphorus, and the content of organic matter in the sediment. The research indicate that the evolution of Lake Nowowarpieńskie reflecting the most significant environmental

changes taking place during the Holocene on the southern Baltic Sea coast conditioned by the pattern of climate changes occurring over the last 12,000 years and varied hydrological changes with changes in water chemistry. In the youngest stage of development of the analyzed reservoir, the factor modifying the natural transformations of the environment is the deepening human pressure.

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Micro-morphology of silt-size quartz grains as a tool for reconstructing environmental, climate conditions and provenance of deposits

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The subject of the presentation is the silt fraction quartz grains obtained from shallow ice cores (<1m) located on five selected glaciers in southern Spitsbergen, Svalbard, Norway (Hansbreen, Storbreen, Flatbreen, Recherchebreen, Werenskioldbreen). Research questions were asked: what was the source of the sediments, what type of weathering (physical or chemical) dominates in the source areas and what was the air circulation responsible for the transport and deposition of the studied grains? To answer the questions, microtextures of silt-size grains were analysed in a scanning electron microscope (SEM). Each time, 25 randomly selected grains were analysed.

Silt-size particles transported by aeolian processes and accumulated on the glacier surfaces, and then incorporated into their mass, are referred to as "cryo-dust." It can be an excellent source of information on local atmospheric circulation, as well as material for identifying source areas from which it was blown. The results indicate that the silt-size grains recorded in the examined glaciers originate from local sources. The sources of sediments accumulated on the surface of glaciers were: (1) exposed soils
(2) sediments exposed on sea beaches and (3) the effects of weathering in cold climate conditions.

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Insights into the genesis and geological significance of iron-manganese precipitates in the Baltic Sea, Gulf of Finland seafloor

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This study investigates the distribution and geological significance of iron-manganese oxyhydroxide precipitates (Fe-Mn concretions) in the Gulf of Finland, focusing on associations between seafloor pockmarks and Fe-Mn concretions. The concretions occur in the areas where modern sediment deposition is absent, and late glacial glaciolacustrine varved clays, glacial tills, or bedrock are exposed at the seafloor. Pockmarks, reaching depths of 3 meters and widths of 30-60 meters, often accompany Fe-Mn concretions, indicating ongoing seepage of chemically reduced fluids. Ubiquitously occurring Fe-Mn concretions are predominantly composed of iron and manganese oxyhydroxides and take spherical, disc or crust-like shapes due to redox-driven precipitation processes mediated by microbial activity. The study examines the morphological, chemical, and mineralogical characteristics of concretions and compares the difference between concentric spheres/discs and crust-like varieties. Elevated concentrations of economically important metals, including the rare earth metals in these concretions, highlight potential industrial applications. Despite numerous studies over the past decades, the genesis of Fe-Mn concretions in Estonian sea areas remains elusive, necessitating further investigation. Integrating data from recent international expeditions, this study aims to provide insights into the interplay between fluid seepage and seafloor processes with an overarching aim to assess the complex geological processes controlling the formation of Fe-Mn concretions. The ongoing collaborative effort enhances our understanding of Fe-Mn precipitates and associated features in the Gulf of Finland but also emphasises the need for further research to fill the knowledge gaps in our understanding of dynamic interactions between fluid seepage, mineral precipitation, and microbial processes on the seafloor.

Sedimentological and geomorphological analysis of glaciofluvial deposits in Eastern Lithuania

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This study analyzes the sedimentological and geomorphological characteristics of glaciofluvial deposits from the last glaciation in the Molėtai region of eastern Lithuania. The main goal is understanding sedimentation processes and factors related to ice melting at the glacier margin. This study employed sedimentological and geomorphological analyses, including cross-bedding inclination measurements, to determine the paleocurrent direction and sediment transport dynamics. Additionally, LiDAR data were used to evaluate the surface characteristics of the deposits, providing additional information for understanding their formation. Preliminary results indicate significant activity of processes within the heterogeneous hydrodynamic environment dominated by glaciofluvial transportation and deposition of sand, gravel, and even boulders.

Vertical sections show decreasing deposit grain size with depth, with coarse material predominantly present towards the surface. The sediment layering patterns indicate sedimentation under the influence of northeastern, eastern, and southeastern glacial meltwater flows. Based on the preliminary results, it can be inferred that the glaciofluvial sediments in sequences studied form a coherent complex deposited by the flow of subeastern direction in a subaqueous environment between the glacier margin and proglacial zones.

Deformation patterns in glacigenic sediments as hints for interpretation of ice sheet dynamics – A case study from northeastern Estonia

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Study ridge in Pikametsa (NE Estonia) represents a glacial complex which belongs to the Pandivere-Neva phase of the Late Weichselian glaciation between ca. 14.3 and 13.8 ka ago (Kalm et al., 2011; Saarse et al., 2012). Late Pleistocene glaciolacustrine sediments in the Pikametsa site show a wide spectrum of soft-sediment deformation structures (SSDS) like: (1) injection structures, dish structures, load casts, pseudonodules, ball-and-pillow structures, flame structures and fragments of broken-up sandy laminae that all occurred in three internally-deformed layers separated by undeformed layers, (2) large-scale upright gentle folds of outcrop size, (3) faults and fractures, and (4) water-escape structures (hydrofractures). We can link the origin of these SSDS to two processes: glacial rebound of the Earth's crust and proglacial glaciotectonic / submarginal processes.

In our presentation we investigate the trigger mechanisms for the development of different SSDS and the space-time relationship in the development of SSDS. Many researchers use water-escape structures (e.g., Menzies, 2000; Denis et al., 2010; Ravier et al., 2015) as a tool for reconstructing glacial palaeoenvironments and pore water saturation of sediments. We recognized two new types of water escaping deformation structures typical for proglacial marginal and submarginal zones. We also show that permafrost can prevent or restrict water escaping (cf. Boulton and Caban, 1995; Piotrowski, 1997). Furthermore, the spatial occurrence of SSDS in relation to the ice-sheet margin can have a fundamental impact on the SSDS development. Finally, we point at the space-time evolution of SSDS in glaciolacustrine sediments related to the dynamics of the ice-sheet front and to the level of sediment water saturation.

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Geological mapping of Quaternary sediments in Estonia – a state of the Art

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The presentation outlines the current status of Quaternary geological mapping in Estonia, along with a short historical background. It describes the tools, methods, and practices used throughout the mapping workflow before, during, and after fieldwork. Audience feedback and advice are appreciated.

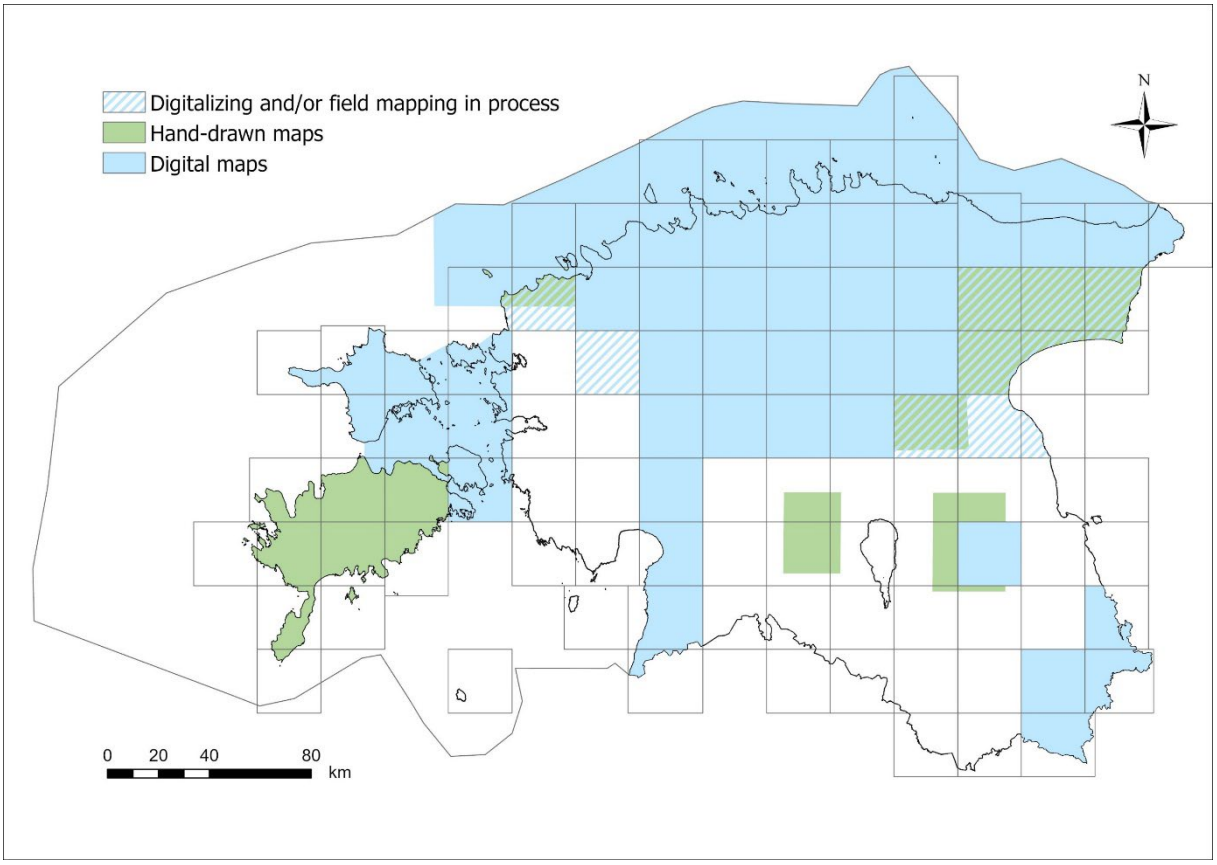

Figure 1. The present state of geological mapping of Estonia in scale 1:50 000

EGT-TWINN Enhancing Research Capacity at the Geological Survey of Estonia to Accelerate the Country's Transition to Green Energy

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The successful completion of the first half of the EGT-TWINN project signifies a significant milestone for the Geological Survey of Estonia (EGT) on its journey towards green energy. This Horizon-funded initiative spans three years and aims to elevate geological research capabilities at EGT while fostering international collaborations.

During the project's initial phase (January 1, 2023, to December 31, 2023), all activities progressed according to schedule, showcasing efficient resource utilization and excellent collaboration among partners committed to achieving project objectives. The project's management strategy, characterized by clearly defined responsibilities and open communication, facilitated overall project smoothness.

The Finnish Geological Survey (GTK), British Geological Survey (UKRI/BGS), Geological Survey of Denmark and Greenland (GEUS), and the University of Oulu (UOULU) collaborated closely with EGT, providing high-level specialized training to EGT staff and facilitating knowledge exchange.

The training covered diverse areas such as geological mapping, database development, 3D modelling practices, specialized geological methodologies, and exploration in geothermal studies. These courses involved site visits, hands-on activities, and theoretical learning, significantly enhancing the existing expertise of EGT geologists.

The project's first half resulted in five mandatory reports, including a project management handbook, a comprehensive overview of EGT's digital infrastructure and data repositories, training guides, a communication plan, and a data management plan, some of which are publicly available on the project's website.

The project's online presence, comprising a website and social media channels, continues to serve as an engaging information hub for thousands of visitors.

Looking ahead, the EGT-TWINN project anticipates another dynamic year filled with numerous training sessions, seminars, lectures, and international conferences as it progresses towards its three-year completion. Noteworthy upcoming conferences include the Conference on Exploration and Exploitation of Critical Raw Materials (October 7-8, 2024, in Tallinn) and the Conference on Urban Geochemical Baseline Survey in Estonia (September 10-11, 2024). For more information about the project and related events, visit the official project website: https://egt-twinn.voog.com/.

Preliminary data on geochemical and geophysical record of weathering of Late Weichselian tills in the Eastern Pomerania, Poland

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Glacial deposits, such as tills, serve as repositories of paleoenvironmental information, reflecting past climatic conditions and glacial dynamics. However, post-depositional processes, particularly weathering, inevitably lead to the loss of critical data initially preserved in original composition of these deposits. Variations in the vertical profile include a reduction in carbonate content, migration of different elements within the profile, changes in clay mineral content, and depletion of minerals less resistant to chemical weathering. Diverse geochemical and, in recent years, geophysical methods support the detailed analysis of these alterations, but studies dealing specifically with glacial deposits are still sparse.
Here, we present data from two study sites located within the ice-sheet extent during the Last Glacial Maximum (LGM) in Eastern Pomerania, Poland. These sites exhibit at least one Late Weichselian (MIS 2) till with varying degrees of weathering and morphological characteristics. The site at Dmuchowo features a profile consisting of massive till with sandy interbedding in the lower part and signs of weathering evident in the upper part. In contrast, the Polskie Gronowo site displays a till profile with no apparent signs of erosion or weathering, protected in the upper part by glaciolacustrine silty-clayey deposits. In this study, we applied a combination of *in situ* geophysical analysis (such as handheld gamma-ray spectrometry and magnetic susceptibility) together with geochemical proxies obtained from elemental analysis (ICP-OES, TIC, TC, TN, TS). Our preliminary findings focus on identifying effective elemental proxies for detecting weathering signatures. Unlike conventional approaches that predominantly examine soil profiles, we explore deeper parts of the profile, which are shielded from surface erosion. There, we observe a continuous record of post-depositional changes, offering insights into the sequence and intensity of weathering processes.

The last deglaciation of the Scandinavian Ice Sheet from the Valday Heights to the eastern Gulf of Finland 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. Recent 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 parameter 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 29 new ^{10}Be ages of erratic boulders sampled along a broad transect from the Valday Heights to the eastern Gulf of Finland. The full data set range between 62.4 and 3.5 ka. When excluding obvious outliers (n = 3) the 26 remaining exposure ages range between 26.5 and 10.6 ka. We first analyse these exposure ages in relation to pro-glacial lake positions during the last deglaciation (Gorlach et al., 2017). We then attempt to correlate the ages with the existing consensus on the geomorphological positions of the ice sheet margins between the LGM position in the Valday Heights (Rinterknecht et al., 2018), and the Younger Dryas position further northwest in Finland. These positions correspond to the Vepsa, Krestetsk, Luga, Neva ice sheet margins. Finally, we discuss the new chronology in the context of already published chronologies of the retreat of the SIS margins further west and north.

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Late-glacial to Holocene relative shore-level data from the Baltic Sea Basin

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The glacial history of the Baltic region is of interest for paleo-climate reconstructions and the sea-level change of this region and its surrounding. One major aspect is the repeated opening and closing of the Baltic Sea since the last glacial maximum. During the different lake stages (Baltic Ice Lake and Ancylus Lake) following the last glacial maximum, the Baltic basin filled up with meltwater of the retreating Fennoscandian ice sheet and so deviated significantly from the global ocean's sea level. Furthermore, variations in relative shore-level height around the respective lake's stage were controlled by the glacial isostatic adjustment of Fennoscandia. The water itself has been transported away continuously through channels or was rapidly drained during

catastrophic events, releasing large amounts of freshwater into the oceans. Baltic Ice Lake drained a large amount of fresh water at least twice, lowering the water levels in the Baltic Sea Basin by up to 20 m and 25 m, around 12.9 cal ka BP and 11.7 cal ka BP, respectively. The magnitude of Ancylus Lake up-damming around 10.8-10.0 cal ka BP varies from 20 to 10 m depending on the intensity of the uplift. Submerged rooted pine stumps from Hanö Bay in the southern Baltic at different elevations suggest a rapid lake level rise of ~40 mm/year of the Ancylus Lake. The reconstruction of the lake levels and their dynamics have to be based on RSL indicators for which a respective database has to be built up. Accordingly, we will extend our recently published database of Holocene data covering the Baltic Sea, which already contains a larger amount of shore-level data covering the Ancylus Lake phase. Also, for this compilation, we follow our preferred strategy and store the already published data in an SQL database system in the format given in the original publication. Homogenization, formatting, and additional information will be given by specific rules and will end up in a HOLSEA-consistent format.

Millennial-scale ^{10}Be erosion rates for the Harz Mountains (Germany): In-sights into the landscape evolution of basement highs in Central Europe

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Understanding how landscapes evolve under changing tectonic and climatic boundary conditions requires the quantification of erosion rates on different temporal and spatial scales. Here we present results of both local and catchment-wide erosion rates derived from in situ-produced cosmogenic ^{10}Be for the Harz Mountains – a typical basement high in Central Europe that was uplifted by reverse faulting during the Late Cretaceous inversion of the Central European Basin. The summit region of the Harz (Brocken peak at 1141 m a.s.l.) is formed by Permian granite and surrounded by an Oligocene low-relief surface that was carved into Palaeozoic metasediments. This planation surface lies at an elevation of 500 - 700 m a.s.l. and stands ~300 m above the lowlands surrounding the Harz Mountains. Our ^{10}Be erosion rates, derived for granitic catchments with a size of 0.3–24 km^2, are slope-dependent and range from 24 ± 2 to 54 ± 3 mm/kyr. We find that catchments situated within the low-relief surface with mean slope angles <10° erode at rates of 24 - 30 mm/kyr, whereas catchments characterized by larger portions with steeper slopes (i.e., 20° to 35°) up- and downstream of the low-relief surface erode at higher rates of 30 - 54 mm/kyr. Local bedrock outcrops on the planation surface erode at lower rates of around ~20 mm/kyr. Taken together, our ^{10}Be data document and quantify the slope-dependent erosion of the Harz topography at a rate of a few tens of metres per million years and the denudation and lowering of the Tertiary Harz planation surface and its progressive incision by rivers. The observed difference between (higher) rates of erosion affecting soil-covered surfaces, compared to the (lower) rates of erosion on exposed bedrock surfaces suggests that the topographic relief within the Harz is still growing at a mean rate of approximately 5-10 mm/kyr. Considering our data in the context of the existing but contradictory conceptual models on the evolution of the Harz topography, we suggest that the post-Oligocene elevation difference of ~300 m between the planation surface and the lowlands around the Harz is the result of three different processes. First, mountain uplift due to a potential reactivation of the range-bounding reverse fault during the Neogene and Quaternary until ~0.5 Ma ago. Second, moderate erosion of weak sedimentary

rocks in the regions surrounding the Harz Mountains. Third, localized lowering of areas in the vicinity of the Harz by dissolution and lateral migration of Permian salt at depth. Finally, we note that active reverse faulting along the northern boundary of the Harz Mountains is not compatible with the available geological, geophysical, and geodetic data.

Sedimentological and luminescence characteristics of beach ridge sediments on the northeastern shore of Lake Schweriner See, Germany

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Lake Schweriner See, located in Mecklenburg-Vorpommern, 20 km south of the Baltic Sea, is the fourth-largest lake in Germany. It consists of two sub-basins, which are separated by an artificial dam: the southern Lake Schweriner Innensee (LSI) and the northern Lake Schweriner Außensee (LSA). Previous onshore studies (Adolph et al., 2022) have addressed two beach ridge structures situated along the northeastern shore of LSA. OSL ages of the youngest beach ridge system located ~200 m from the LSA shore were found to be between 260–340 years, while the second beach ridge located around 500 m from today's shoreline had OSL ages of 3010-3050 years.

This study focuses on the area between LSA and neighboring Lake Döpe, where we extracted a 2.3 m long core from the youngest beach ridge located ~80 m from the shore of LSA (N53°47'09" E11°31'40"). We examined the core within the 0.3–2.3 m depth interval using loss-on-ignition (LOI_{550}) and grain-size distribution analyses in 2 cm resolution, and portable optically stimulated luminescence (pOSL) in 10 cm resolution. Based on the results of the grain-size analysis, the sedimentary sequence is divided into three lithological units. Sediments of Unit I (2.30-1.43 m) represent alternating layers of fine and medium-coarse sand, indicating sub-aquatic conditions with sedimentation in shallow waters influenced by wave action and currents. Unit II (1.43–0.44 m), mainly consists of coarse sand and can be interpreted as beach ridge sediments representing mainly terrestrial conditions. The deposits in Unit III (0.44-0.30 m) still contain up to 60% coarse sand, but they also comprise up to 17% silt and clay particles and are characterized by a higher LOI than the underlying sediments (up to 4.3%). These characteristics suggest the involvement of soil-forming and aeolian processes in sediment accumulation. The pOSL results distinguish two luminescence zones (LZ). LZ1 approximately coincides with combined sediment units I and II and exhibits a gradual decrease in both infrared stimulated luminescence (IRSL) and post-infrared blue-light stimulated luminescence (post-IR BSL) towards the top of the section. LZ2, which roughly corresponds to Unit III, is characterized by 3-4 times lower both IRSL and post-IR BSL, probably indicating a hiatus in the sedimentary sequence. The ages of all three units will be determined using OSL dating.

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Rare Earth Elements composition of Quaternary sediments of Lithuania

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The Quaternary sediments of two outcrops (Krokšlys and Dengtiltis) and one well (Šventoji - 46776) from Lithuania (fig.1) were studied. Major, trace and REE elements data for sediments geochemical peculiarities comparison was used. Major elements like Si, Al, Ca, Mg were mainly used for lithological peculiarities description, i.e. ratio of Si and Al was assumed to reflect the clay content of the sediment. It is known that the clay content directly influences the distribution and quantities of REEs in sediments. High contents of Ca and Mg may indicate increased carbonate content. The latter fact may be related to the periods of warmer climate. Studied sedimentary sequences are lithologically inhomogeneous and are mostly characterized by different distribution of trace elements across the sequences. Rare earth element (REE) distribution in the sediment depends on their contents in the parent rocks and their distribution in the mineral phases. The quantities of REEs may vary depending on transportation and sedimentation. Sources of REEs could be of various origins: suspended river runoff, aeolian dust, glacier runoff, etc. Within the REE suite, Eu and Ce can develop anomalies. Eu anomalies are generally considered to be inherited from source rocks while Ce anomalies are generated post or during a deposition. Heavy REE vs light REE was compared since it could be an indication of aeolian influence etc.

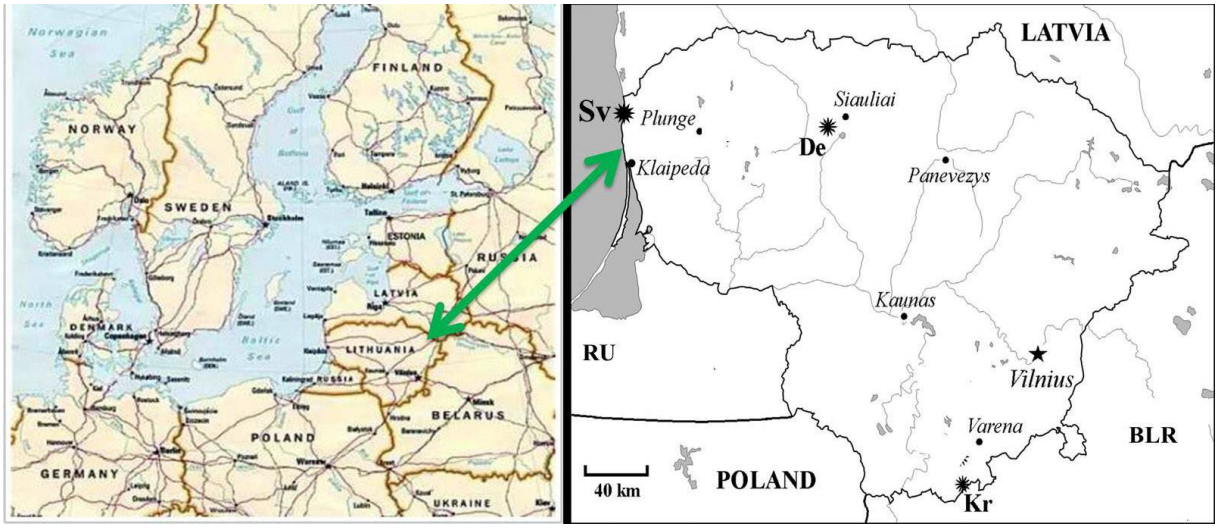

Fig.1. A map showing the location of the studied sedimentary sequences in Lithuania (black asterisks): De - Dengtiltis outcrop; Sv - Šventoji - 46776 drilling site; Kr - Krokšlys outcrop.

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Palaeogeography of the last glacial termination in the Suwałki Lakeland, NE Poland

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Questions concerning the rate and mode of deglaciation of the last glaciation are of interest to many researchers. Ice dynamics in the marginal zone and the uneven timing of deglaciation is a difficult element to determine due to methodological limitations. One indirect way to determine the onset of deglaciation is the onset of organic deposition in the depressions between dead ice blocks. In the aforementioned integration of relief analysis based on a digital terrain model (DEM), this offers the possibility of determining the age and course of deglaciation.
One area with exceptionally vigorous post-glacial relief is the Suwałki Lakeland, NE Poland. This area is a mosaic of subglacial gullies, eskers, glacial curvi-lineations, extensive sand cones and deglacial forms. The complex history of the area can be seen in some of the accumulation forms formed between dead ice blocks, as exemplified by the Lipowo site (Rychel et al., 2023). Results from several more sites support the assumption that the onset of deglaciation of the area occurred around 16-16.5 ka ago. Also, the sedimentological record indicates the high dynamics and role of ice melt in shaping the landscape of NE Poland. Based on multiproxy analysis and geochronological dating, a reconstruction of environmental changes in the lake ecosystem from the stagnation of the Scandinavian Ice Sheet to the melting of the dead ice blocks and the Holocene is presented. Deposition occurred from the stagnation of the ice sheet (c. 16 217 ± 178 cal BP - Oldest Dryas) and continued until the beginning of the Allerød. The disappearance of the reservoirs was caused by an accelerated rate of melting of dead ice blocks and inversion of the morphology (c. 13 431±84 cal BP). Deposition in the reservoirs formed after the melting of the dead ice blocks began in the later Allerød (c. 12 833±95 cal BP) and continues into the Holocene (10 876±96 cal BP). The sediments of some reservoirs were subject to redeposition and runoff into subsequent reservoirs, as was the case at the Budzisko site.
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Surface geochemical methods for the environmentally friendly exploration in the glaciated terrains

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Surface geochemical sampling and analysis techniques are modern ways for the cost-effective and environmentally friendly mineral exploration methods. Traditionally in glaciated terrains, conventional methods based on the secondary transport of the glacier have been used to determine the origin of surface boulders, heavy minerals and till geochemistry. Due to the variable glacial history and landforms, the directions of glaciers' movement, and the complex stratigraphy, tracing the origin can be difficult. Instead, the surface geochemical techniques based on the elements' composition of different sample media provide a direct signal of underlying surface sediment-covered or blind mineralization.

Techniques which are based on the migration of mobile metal ions from mineralization in the bedrock through the top of the bedrock and the sedimentary cover to the upper soil horizons can be use in exploration for all type of elements and their associations. A great benefit is that practically all types of materials, i.e., minerogenic and organic sediments, plants and snow are suitable sample media. Easy sampling and sample processing procedures with relatively low analytical costs make these techniques effective in mineral exploration.

Different sample materials and geochemical analysis methods have been studied recently for mineral exploration in vulnerable northern areas. In several EU-funded projects (e.g., NEXT, SEMACRET, UltraLIM) the methods have been tested in many target areas in the southern and eastern parts of Finnish and in some other European country. The mobile metal ions based geochemical signal is seen in upper soil horizons (mineralized and organic), in different parts of plants, and in snow. Migrated metal ions accumulate first to the upper soil into various trap sites, such as on the surface of mineral grains, porous mineral grains, clay minerals and organic materials forming the exogenic geochemical signal. Weakly bounded ions are possible to dissolute with weak or selective leaches from the soil samples and with stronger acids from organic materials. There are plenty of commercial leaching methods available for extracting metal ions from certain element traps. The benefit is that upper soil is also a main source for nutrients from where the plants collect them with roots to form the basis of biochemistry. In the areas of shallow transported cover roots also can uptake nutrients directly from the bedrock. Plants use major and trace elements as construction materials for trunks, branches, and leaves/needles.

One of the sample media is snow. During wintertime, the mobile ions continue moving upward from the upper soil with water vapour, carbon dioxide and hydrocarbons to accumulate and to be trapped into snow crystals. The bottom part of the snow cover gives the most stable sampling media because of the longest deposition history and the coverage of the upper snow layers which act as a shelter from atmospheric contamination. In addition, the lowest layer is in contact with the ground and is influenced by the gases and heat coming from the underlying soil and bedrock. The snow layer covers the landscape several months each year in large areas in the Northern Hemisphere. Snowing periods and the snow properties are constant in a regional scale, which gives a good foundation for reliable and environmentally-friend geochemical mineral exploration in large areas.

Quaternary conglomerates – their properties and diversity

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Among the Quaternary sediments, locally conglomerates can be found, for example, in northern Poland (Ciborowski, Jankowski, 2007) or in northern Estonia (Rattas et al., 2014). The most common type of cement in the conglomerates is calcium carbonate and/or iron and manganese compounds. The latter are prevalent and form as a result of water circulation and infiltration in the sediments. The matter is more complicated in the case of carbonate cementation; previous studies have shown that the origin of carbonate cements may occur through infiltration (e.g. Ciborowski, Jankowski, 2007) or subglacial processes (e.g. Drozdowski, 1991).
The aim of our research was to investigate conglomerates at three locations in the NW and NE regions of Poland and to explore their differences. The selected test sites were:
(1) an active gravel pit in Koczery, where conglomerates are extensively exposed (Mleczak et al., 2021); we collected 22 samples and cut 75 cubic cube (55x55x55 mm in size) for further tests,
(2) an inactive gravel pit in Rakowo, where conglomerates were found only in one location; we took one sample and cut 4 cubes for testing;
(3) an inactive gravel pit in Nowa Wieś near Grudziądz, from which we obtained five samples and cut eight cubes for testing.
The purpose of the study is to indicate the differences between conglomerates at both in macro and micro scales through: description of the specimens, water absorption tests, compressive strength tests, and microscopic examination of thin sections.
The main conclusions drawn from the studies are as follows:
The collected samples are highly heterogeneous in mechanical characteristics. Compressive strengths vary widely, ranging from 4.3 to 90.4 MPa. High strengths (over 36 MPa) are observed only in conglomerates from the Koczery site; a clear directional change in strength parameters can be traced along with a change in the structure of the sediments, influenced by glacial processes.
Conglomerates from the Koczery site exhibit higher density (ranging from 2.1 to 2.8 kg/dm^3) compared to conglomerates at other sites, where the maximum density does not exceed 2.1 kg/dm^3.
Compressive strength of the samples shows a strong positive correlation with density, R^2=0.81, and a negative correlation with water absorption, R^2=0.79.
Conglomerates are cemented by micritic, isopachous and equant sparitic cements; equant spar predominates, with the growth of its crystals proceeding from the surface of grains toward the center of pores.
The site in Koczery was crucial for the final conclusions, where the large differences in the properties of the conglomerate was found. The diverse characteristics of conglomerate from a one site, with its own origin, make it challenging to interpret the origin of other conglomerates based solely on the description of samples taken pointwise. Further research is planned, however, at this stage, it can be concluded, that to correctly interpret the origin of the Quaternary conglomerates, the regional context and analysis of the cemented sediments on the scale of the entire profile – including the examination of top and bottom deposits – are necessary.

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Evidence of wildfire intensification during the Late Glacial in the central part of the European Sand Belt - an effect of global climate change or local environmental conditions?

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Late-glacial climate change has caused far-reaching changes in terrestrial environments. The aeolian environment, due to its sensitivity to changes in conditions, was characterised by a high degree of susceptibility to change, and the record of these changes can be seen in the emerging overlying sandy sediments and fossil soils and organic layers. The latter are generally considered to be the effect of warmer climatic fluctuations. However, the number of palaeosols in some aeolian sediment exposures (mainly inland dunes) is sometimes greater than the potential warm climatic oscillations. Moreover, a comparison of radiocarbon dating results from earlier studies and recent results shows a concentration of dates mainly in the Allerød and Younger Dryas (Sokołowski et al., 2022; Moska et al. 2023a, 2023b). Of particular interest are the overlying charcoals. These are dominated by fragments of *Pinus sylvestris*. Sometimes palaeosols are developed on their base (Moska et al., 2023a). Analysis of the radiocarbon dates distribution obtained from charcoal overburden indicates a concentration in the Allerød interstadial. In contrast, few dates come from the Bølling interstadial. The frequency of pine charcoal mostly shows a clear correlation with the frequency of pine pollen in aquatic reservoir sediment profiles. Due to the progressive precision and number of radiocarbon dating, it can be assumed that there is some correlation between wildfire frequency and environmental changes during the Late Glacial. However, this issue requires further analysis due to the high potential for reconstructing environmental changes in the central part of the European Sand Belt (ESB). Presumably, in addition to climatic oscillations, local factors played a major role in their occurrence and perhaps contributed to the emergence of human hunter-gatherer groups, as indicated by recent results from the western part of the ESB.

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Conditions of Late Glacial aeolian deposition – case study from Eastern Poland

P. Zieliński, M. Łopuch

Wind is the main medium responsible for aeolian processes. However, in order for these processes to develop/function, there must be (i) favourable thermo-humidity factors that limit the vegetation cover to a great extent, (ii) the presence of loose material in the substrate that allows blowing and (iii) relief that will amplify the wind-bearing force or force deposition. The interactions of these factors influence typological differentiation.
In the Late Vistulian, conditions in Central Europe were favorable for the formation of dunes. The forms formed at that time are located within extensive fields with homogeneous form genesis. In their vicinity there are fields with dispersion, which are characterized by high genetic diversity.
Such observations lead to research questions: (i) does the diversity of dune forms within one field reflect the heterogeneity of shaping factors, (ii) what processes are responsible for the formation of small and dispersed dune fields, with formations that vary in genesis, and (iii) do the reconstructed factors indicate temporal and/or spatial variability?
The conducted research, based on digital elevation model (GIS) analysis and field studies using lithofacial analysis, in eastern Poland, indicates a significant influence of local factors such as relief and orientation of larger formations in relation to wind direction, substrate lithology, including availability of sandy material, and features of the substrate on which dunes form. Regional factors such as the wind regime are no less important.

Relic glacial landforms in the southern Baltic Sea Basin

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The seafloor geomorphology of glaciated continental margins occasionally hosts relic glacial landforms that serve as proxies of the ice sheet dynamics. The Baltic Sea is a relatively shallow, epicontinental, young sea whose formation after the last deglaciation was modulated by global sea-level fluctuations and isostatic adjustments. During the last glaciation, the Baltic Basin (BB) was one of the major advance corridors of the Fennoscandian Ice Sheet (FIS) towards the Central European Plain. It hosted the Baltic Ice Stream Complex – a zone of potentially highly dynamic, warm-based, fast-flowing ice that drained central parts of the ice sheet. Therefore, BB is a key region for reconstructing the dynamics of the last FIS southern sector. However, the availability

of high-resolution bathymetric data which may better constrain BB's geomorphology is still limited. In particular, the southern part of the BB suffers from a lack of high-resolution bathymetry, which leaves glacial landforms, potentially preserved at the seafloor, largely unrecognized here.
Here, we present the results of mapping relic glacial landforms in some areas of the southern BB. The landforms were mapped in ArcGIS based on bathymetric models obtained from the Polish Navy Hydrographic Office and from the Swedish Maritime Administration as 2- to 10-m grids. We identified individual glacial landforms such as: ribbed moraines, ridges of terminal moraines, subglacial meltwater channels, eskers and ploughmarks. Mapping was performed by on-screen digitizing at various scales, depending on landform dimensions. The outcome is a GIS map of glacial geomorphological features preserved at the seafloor. This is a first map displaying the distribution and morphology of relic glacial landforms based on high-resolution bathymetric data in the southern BB.

The record of micro-scale frost weathering in the contemporary active layer of permafrost in the Dry Valleys of McMurdo (Eastern Antarctica).

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Frost weathering occurs in areas where permafrost is present in the ground, as well as anywhere temperatures regularly oscillate around 0°C. A key factor influencing the intensity of this process is the number of freeze-thaw cycles (Matsuoka, 2001; French, 2007). One example of such an area is Antarctica. The subject of the discussed research is micro-scale frost weathering on the surface of quartz sand grain fractions, originating from the active layer of contemporary permafrost developed in the McMurdo Dry Valleys deposits. This area is located in the southern part of the Scott Coast on Victoria Land (East Antarctica). It is the largest oasis in Antarctica in terms of total area, encompassing numerous landforms, including mountain ranges, nunataks, glaciers, ice-free valleys (Dry Valleys), and coastline.
The active layer in this area varies spatially but does not exceed 0.40 meters. The studied samples represent some of the most extreme soil environments on Earth. In the WRB system, these soils are classified as cryosols, while in the USDA Soil Taxonomy system, they are categorized as Anhyorthels, Haploturbels, or Haplorthels (Balks and O'Neill, 2016).
The analysis included 4 profiles: Wright Valley - alluvial fan deposits, Bull Pass East, Bull Pass, Mt Acheron - lateral moraine deposits. Surface microrelief of quartz sand grain fractions was analyzed using a scanning electron microscope (SEM). Additionally, to determine the factors influencing the intensity of micro-frost weathering, sediment grain size distribution, sediment geochemistry, pH, and CaCO3 content were analyzed.
The results indicate variable intensity of frost weathering at the micro-scale in the examined profiles, as well as susceptibility of individual grains in the sample to this type of weathering. The examined sediments represent early stages of frost weathering, characterized by a low number of microstructures resulting from frost weathering. Additionally, among them, small conchoidal fractures (<10 µm) clearly dominate, indicating an initial stage of weathering

progression (Górska et al., 2022). Only sporadically recorded are microforms indicating a more advanced stage of weathering, such as large and small breakage blocks (>10 µm and <10 µm, respectively). This is due to limited water access and temperature below 0°C persisting for most of the year, resulting in a low number of temperature cycles crossing 0°C.

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Response of diatoms to the Early Holocene climate changes, SW Lithuania

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The sediment core from the Lake Amalvas in the south-western Lithuania has been analysed. Radiocarbon dating has revealed the age of the Early and Middle Holocene. A detailed diatom analysis was performed. A total of 103 diatom species were identified in 76 samples taken at a depth of 302-453 cm. Bottom samples taken at a depth of 451-453 cm consist of clay and were devoid of diatoms. Gyttja makes up the rest of the core and it was rich in diatoms.

Lacustrine sedimentation began before 10300 cal yr BP. The lake was alkaline, oligotrophic-mesotrophic, very shallow according to the diatoms (prevail benthic *Cavinula scutelloides*). Such conditions lasted until 9800 cal yr BP.

During the period 9800-9000 cal yr BP, the lake slightly increased in depth (planktonic *Lindavia radiosa*, *Pantocsekiella ocellata*) and became mesotrophic-eutrophic. The lake remained alkaline, but an increase in the number of circumneutral diatoms indicates a negligible increase in the acidity of the lake.

The next stage of the lake development took place during 9000-8400 cal yr BP. The depth of the lake decreased (prevail benthic *Amphora ovalis*, *Cymbellafalsa diluviana*, *Cymbopleura inaequalis*). The alkalinity of the lake was slightly increased at that time, the trophic state was mesotrophic-eutrophic.

Noticeable environmental changes occurred at the beginning of the Middle Holocene. Initially, during 8400-7500 cal yr BP, the depth of the lake increased (planktonic *Aulacoseira ambigua*, *Aulacoseira granulata*). The environmental conditions of the lake remained similar to before. The lake was alkaline and mesotrophic-eutrophic.

The uppermost sediments were deposited between 7500-7200 cal BP. The depth of the lake remained stable, but increased content of small epiphytic diatoms (*Staurosira construens*, *Staurosira construens* var. *triundulata*) indicate abundant growth of vegetation in the shallow areas of the lake. The lake remained mesotrophic-eutrophic and alkaline, but became increasingly eutrophic.

Two short-term climate events can be distinguished on the basis of changes in diatom assemblages. The so-called '8.2 ka event' is characterised by a decrease in the abundance of large benthic species (*Navicula oblonga*, *Navisula radiosa*, *Cymbopleura inaequalis*, *Gyrosigma attenuatum*) and an increase in the abundance of small epiphytic diatoms (*Staurosira construens*, *Staurosira construens* var. *triundulata*). Reduced eutrophication and increased numbers of alkaliphilous and mesotrophic-eutrophic diatoms were also found. However, these changes occur somewhat earlier, at 8250-8400 cal BP in the study area.
The next climate event, known as the '9.3 ka event" is characterised by small changes in diatom assemblages. At the time interval 9200-9300 ka BP the total number of species as well as benthic (*Navicula oblonga*, *Navicula radiosa*) and planktonic (*Lindavia radiosa*, *Pantocsekiella ocellata*) diatoms decreases, indicating a negligible decrease in eutrophication of the lake.

The imprint of a dead ice environment at the margin of the last Scandinavian ice sheet (N Poland) captured in LiDAR data images

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A unique glacial landscape revealing numerous ramparted depressions (a special type of hummocky topography) can be observed in the southern part of the Żarnowiec Moraine Plateau (N Poland). The depressions are surrounded by rim ridges of diverse dimensions that separate one depression from another. The differential morphology of these formations was inferred based on the analysis of high-resolution LiDAR images covering an area of 25 km^2. Fourteen test fields (0.5 km × 0.5 km) reflecting the morphological diversity of the ring forms were selected within the moraine plateau for detailed studies. The ring forms observed within individual test fields are relatively uniform. The designated fields cover various parts of the moraine plateau, e.g. north-facing slope, south-facing slope and the top of the highlands.
The obtained results show that the ramparted depressions of the the Żarnowiec Moraine Plateau (N Poland) form an unusual network of closely spaced, approximately circular, diverse orientated forms of various sizes. Most of them are arranged in cascades. The orientation of the rim ridges was found to reflect the spatial arrangement of the ice crevasses that were formed when the ice sheet passed through the glacial bedrock (pre-Vistulian moraine plateau), while the moraine plateau was a counterslope for the advancing ice sheet. The development of a dense system of perpendicular, parallel, and diagonal crevasses was related to the ice sheet transgression from the NNW direction. Ice masses transgressing at different speeds flowed around the obstacles. The shape of the studied landforms and landscape resulted from the breakdown of dead ice into blocks of various sizes. Here, we introduce the term "pitted moraine" to describe this type of glacial landscape.
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Evidences of late Mesolithic and Neolithic stone-tool manufacturing at the Puck Lagoon, southern Baltic Sea coast

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The area of the Puck Lagoon (N Poland) is the result of a multi-stage development: processes occurring during the last ice-sheet decay, transformation of glacial relief in the terrestrial environment, and then the sea ingression and the creation of the lagoon-marine environment. The multicultural archaeological site in Rzucewo, located at the lagoon coast, is a testimony to the use of environmental resources and adaptation to its changes. At least four stages of late Mesolithic and Neolithic settlement between ~6.5 and ~3.5 ka ago were recognized there: Ertebølle Culture / early Funnel Beaker Culture (6.5 ka), middle Funnel Beaker Culture (5.5 ka), Globular Amphorae Culture (4.8 ka), and Rzucewo Culture (4.5 ka).

During archaeological surveys a significant number of stone objects made of Fennoscandian rocks and those from the bottom of the Baltic Sea were obtained there. In the analysed set (334 items), the most common are sandstone, followed by diabases, amphibolites and granitoids. Sorting of a raw material and use its specific types preferred for the production of a given type of tool is recognized. The places of its acquisition shifted with the changes in the configuration of the coast caused by the sea level rise. In the closest vicinity of the settlement, a bluff and a beach below it, allowing for easy collection of raw material, developed only during the functioning of the Rzucewo Culture. Earlier, it was necessary to travel several kilometers or to obtain raw materials inland.

The most numerous in the analysed set are axes and adzes (91 specimens). Very common are artifacts that are evidence of the production of stone tools, especially polishing slabs (66 specimens, usually only as their fragments), accompanied by 7 polishing boulders. High intensity of tool use was identified, including reuse of worn and damaged tools, simultaneously with the fairly common presence of semi-finished tools and tools without signs of use. This is confirmed by earlier reports that in Rzucewo there is not only a record of the production of stone tools, but also regular processing of other material, such as wood, in order to make dugouts canoes. The complex of intentionally prepared places for the Neolithic production of stone tools is a very rare archaeological find in the northern Poland, and unique in the area of the Baltic countries.