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Content

GEOPHYSICS

Structure of the Qaanaaq ice cap's outlet glaciers, NW Greenland

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The measurements of thickness and internal structure of glaciers are important for the understanding of their evolution and dynamics in response to climate change. Nonetheless detailed geophysical or direct drilling data from High Arctic glaciers, are scarce.

In this study, we obtained the first detailed ground-penetrating radar (GPR) measurement's data of two outlet glaciers of the Qaanaaq ice cap in NW Greenland. We used a combination of GPR and uncrewed aerial vehicle (UAV) data for the reconstruction of the glacier geometry and internal structure (Karušs et al., 2022; Lamsters et al., 2022). Zond GPR in a combination with 38 MHz antenna was used. For the determination of electromagnetic wave propagation speed, we applied a common midpoint method (CMP). The coordinates of each GPR profiles were measured using Emlid Reach GNSS receivers.

The obtained data clearly demonstrate that both outlet glaciers occupy rather sharp V-type valleys (Figure 1). The ice thickness of the Qaanaaq outlet glacier reaches 152 m and the mean is 64.3 m. The ice thickness of the adjacent glacier is smaller – 130 m, the mean – 46.9. The largest ice thickness is reached in a narrow zone in the upper reaches of the glaciers related to the topography of glacier's bed. The Qaanaaq outlet glacier bed elevation ranges from 218 to 639 m (above ellipsoid), while the surface elevation ranges from 264 to 652 m (above ellipsoid). The bed elevation of the nearby glacier ranges from 400 to 665 m (above ellipsoid), while the glacier surface elevation ranges from 426 to 668 m (above ellipsoid).

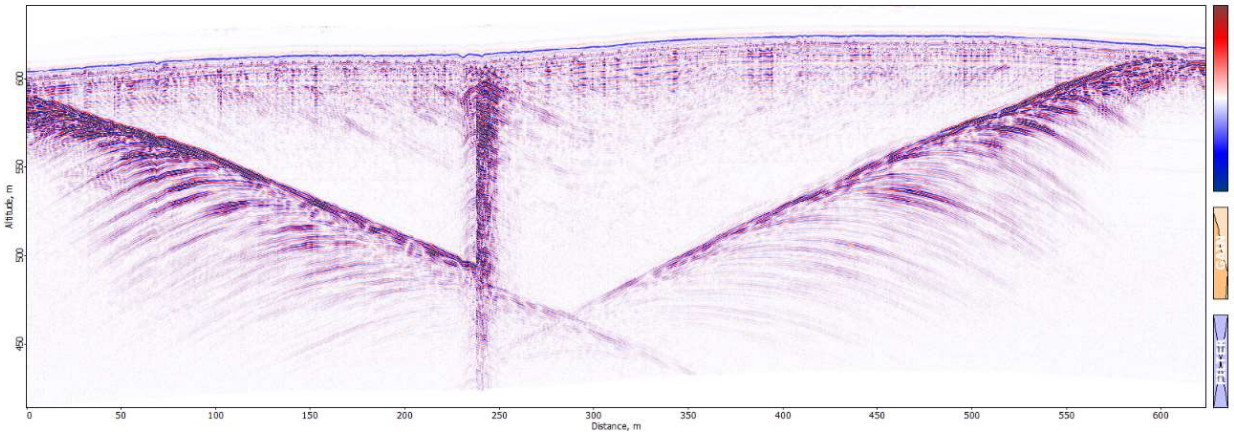

Figure 1. The example of radargram of the Qaanaaq outlet glacier. Not the sharp GPR signal of the glacier bed and deformed ice layers above it. The stacked hyperbolae on the left side are from the supraglacial stream.

We did not observe any zone of temperate ice indicating completely cold glacier. However, beneath the marginal part of the glaciers there are zones with scattered GPR reflections possibly indicating basal debris rich ice. Our study demonstrates that a combination of UAV photogrammetry and GPR can be successfully applied and should be further used for the high-resolution reconstruction of geometry and structure of small glaciers.

Acknowledgments

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Novel land seismic studies for geological storage of CO_2 in Denmark

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Denmark is aiming to reach carbon neutrality by 2050 and is actively working on reducing gas emissions (Chopra et al., 2022). One of the actions in the national strategy is to conduct site investigations for geological carbon storage (GCS) including high-resolution land seismic surveys to delineate favorable subsurface environments suited for this purpose.

In February 2022, a pilot seismic study at one of the potential GCS sites in Stenlille (Denmark) was carried out. The framework and acquisition workflow are described in Gregersen et al. (2022) and Papadopoulou et al. (2022). During the experiment, two separate data recording systems were used simultaneously and comprised wireless recorders with a spacing of 10 m in addition to microelectromechanical systems (MEMs) with 2 m receiver spacing. The wireless data were well suited to image geological structures at depths of > 2 km, while the land streamer with the MEMs provided a detailed image of the near subsurface structures. Merging both data sets leads to considerable improvement in terms of signal-to-noise ratio but also mapping a wide depth range in good resolution.

Based on the results of the pilot study, the same acquisition setup and approach was applied for an upscale project in Denmark in an area adjacent to Stenlille. The survey was conducted from August to October 2022 along eight 2D seismic profiles with a total length of approximately 130 km over the Havnsø domed structures. Data acquisition was carried out by utilizing wireless recorders connected to 10-Hz vertical-component geophones with 10 m spacing, and MEMs mounted on a moving landstreamer with 2 m receiver spacing. Seismic energy was generated using two 12 tons vibroseis trucks with a frequency sweep ranging from 10 to 140 Hz,

operating simultaneously at every receiver position (i.e. 10 m.) The main target was to outline the potential GCS reservoir that is an anticline structure, to map potential faults that may be relevant for the integrity of the structure, and most importantly to characterize the main reservoir consisting of a series of sandstones in the Gassum Formation (Upper Triassic).

Preliminary results of the data processing indicate high-quality reflections that can be connected to the Gassum Formation and other lithological units. Further processing of seismic data will include merging both datasets, analysis and interpretation of reflection horizons and relevant seismic attributes.

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Automatic seismic event detection in low-seismicity areas

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Seismological phase detection is a fundamental part of seismic observation process (Havskov and Ottermoller, 2010). Wave arrival tracking allow us to determine the location of the event epicenters and subsequent calculation of magnitudes and first motion parameters. In most of the seismic observatories the process is half automated – first arrival phases are determined by automatic picking routines which are afterwards confirmed or improved upon by seismologists (Havskov and Ottermoller, 2010). Thus, it is always important to improve the automatic picking routines, as algorithm improvements can significantly remove the workload from involved seismologists. It is even more important in low-seismicity areas where signal-to-noise ratios can be low and classic untuned automatic routines can fail to detect or falsely detect too many of the small-scale seismic events.

We present results of multiple fine-tuned automatic picking algorithms for seismic wave first arrival detection in one such low-seismicity area – the central part of East European craton around Baltic States, centering around Latvia. We have analyzed 11 seismological station data from the region during January 2021. First arrivals have been determined using signal processing based phase picking algorithms - STA/LTA picker, z-detector, recursive STA/LTA picker and Carl STA/LTA filter (Withers et al., 1998). Automatically determined picks have been compared between the observation stations using routines provided in ObsPy (Beyreuther et al., 2010), registering individual seismic events if the multiple arrivals were detected at a similar time. Events have been compared against manually detected events of January 2021, provided by Latvian Environment, Geology and Meteorology Centre.

We demonstrate that the fine-tuning of the classic automatic algorithms can be adjusted for low-seismicity areas. Low signal-to-noise ration can be counteracted with station specific threshold levels and averaging time windows for STA/LTA and z-detector. Automatically determined phases also seem to detect more events than manual observations did, pointing out

potentially missing information from seismic event catalogues. The manually detected phases coincide well with the automatic ones, showing that such methods can be used for routine analysis.

There are also issues that still need to be attended – automatic signal processing algorithms tend to misclassify the first arrival p-waves as s-waves which have higher amplitude values. It is also hard to verify the automatically detected events that were not manually observed before, as there is a chance that some of these cases might be false positives. Thus, seismological observation in low-seismicity areas still needs a significant input from a seismologist. This might change in the near future, however, as machine learning provides us with an opportunity to improve the automatic detection algorithms by a significant margin (Kong et al., 2019).

Acknowledgments

This research was funded by the University of Latvia grant No. AAp2016/B041//Zd2016/AZ03 project 'Climate change and sustainable use of natural resources'.

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A geophysical model of Strenči magnetic anomaly

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In the coming decades the European Union is expecting a great increase in demand of critical raw materials (CRMs) used in renewable energy technologies. To meet this demand, it is predicted that new ore deposits will need to be explored (European Commission 2020). Since these CRMs should preferably come from within EU, this has given an incentive to renew ore deposit exploration also in Latvia. It is known that various metal ore deposits lie in the Proterozoic crystalline basement of Latvia, and one of these deposits generates the Strenči magnetic anomaly, situated in the northern part of Latvia. In the 20th century, a combined geophysical and geochemical exploration was carried out together with borehole drilling (Vetrennikov et al. 1986). A wealth of data was acquired, but it was analysed considering the economic needs and knowledge of that period. Since then, no exploration has taken place in the area. In the present research, a combination of old and new geophysical data, and open-source software was used to develop a geophysical model of Strenči magnetic anomaly.

The input data for the model was Total Magnetic Intensity (TMI) measurements – acquired in the previous research and during 2020 till 2021 in a broader area. Control measurements revealed a variation of ±135 nT between old and new datasets, giving a rather large uncertainty of approximately 6% for the input data. Another complication was caused by the large remanent magnetization of the crystalline basement rocks, as determined in the previous research. The latest case studies around the world prove that remanent magnetization may cause significant changes in the interpretation of ore deposits (Lelievre & Oldenburg 2009). To combat this, alongside the traditional magnetic susceptibility modelling a second method was used - magnetic vector inversion (MVI) modelling. The model was created using *SimPEG* (Simulation and Parameter Estimation in Geophysics) – an open source Python language software (Cockett et al. 2015).

The geophysical model, together with the essential data from previous research, reveal that the magnetic anomaly is indeed caused by metamorphic granulite facies rocks lying in the Proterozoic crystalline basement at a depth of up to five kilometers (figure 1). Interestingly, the angle of magnetization vectors from the MVI model coincides with the rock strata dip indicating a correlation, and although a coincidence is unlikely, more research should be done for any conclusions. Taking into account the limited data of previous geochemical analysis, the model suggests that the Strenči magnetic anomaly ore body might contain a significant amount of CRMs. During the development of the model, notable problems with the previous research were discovered, mainly – large, unexplainable variations and erroneous data. However, it was determined that such data could still be used for preliminary regional exploration, just not for detailed modelling.

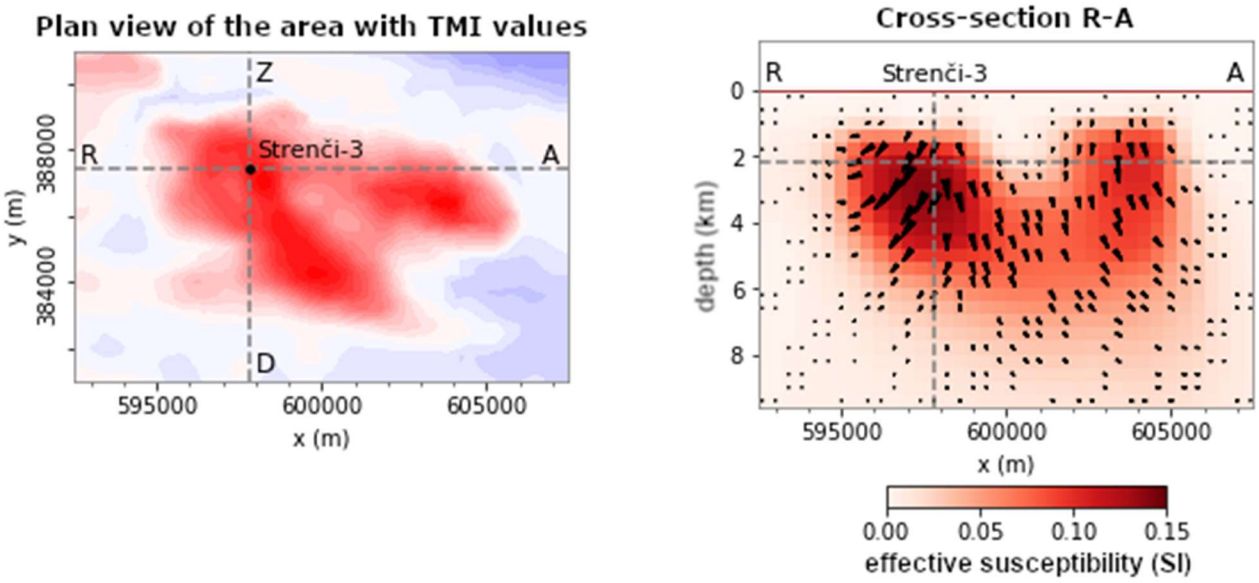

Figure 1. The developed Strenči magnetic anomaly MVI geophysical model with a cross-section through "Strenči-3" borehole.

The use of open-source software has proven to be a cost effective way of developing modern geophysical models, limited mostly due to the quality of the input data. This research was the first step in acknowledging the possibility of future geophysical exploration, and pointed to the need of new, high quality geophysical data, if Latvia is to take part into the EU's search for valuable CRMs.

Acknowledgments

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Application of seismic refraction tomography for karst imaging: a case study of two distinctive sinkholes in Latvia

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In Latvia, karst sinkholes are considered hazardous due to their hazardous and complex nature, which often leads to a negative effect on surroundings and adverse groundwater contamination (Delina et al., 2012). Therefore, apprehension about the time-variable interior structure of an altered surrounding media can be important for risk assessment and mitigation.

This research focuses on applying seismic refraction tomography (SRT) to karst sinkholes, to study their seismic response and evaluate the SRT method's feasibility for reconstructing the image of the altered subsurface related to the sinkholes and their conduits (Kucinskaite, 2022). For this purpose, two recently formed distinct sinkholes with known collapse dimensions were chosen for seismic data acquisition: site "Skaistkalne", where the sinkhole with a depth/diameter ratio of the visible collapse ~ 0.25, is partially filled with water, and site "Salaspils" sinkhole that is filled with air, and depth/diameter ratio is ~ 1.8.

The setup of seismic data acquisition consisted of one seismograph, 24 vertical component geophones with a 14 Hz natural frequency, and one geode. A seismic energy source was generated by a 4.5kg sledgehammer contact with a flat polyethylene plate. For the site "Skaistkalne" 2 profiles placed in the same position with the sinkhole placed in the middle part of the profiles were acquired. Profile 1 with 5 m spacing between geophones and Profile 2 with 2 m spacing. For site "Salaspils" the same spread setup was used, Profile 1 with 1 m receiver spacing and Profile 2 with 0,5 m spacing.

Obtained shot gathers were processed using AGC with a 100 ms time window, Ormsby bandpass filter with frequencies of 5-10-150-250 Hz, and wavelet denoising. After processing, the

first arrival traveltime curves were manually picked and employed in tomographic inversion software “ZondST2D” (Kaminsky, 2013), resulting in P-wave velocity models, related ray path coverage, and vertical velocity gradient. Occam’s inversion algorithm was selected for solving the inverse problem based on prior inversion stability investigations.

The P-wave velocity model for site “Skaistkalne” (Fig. 1) reveals a low-velocity feature that coincides with the visible collapse zone, and the velocity media below suggests a ~7 m prolonged depression with a ~5 m increase in diameter. On the contrary, the P-wave velocity model (Fig.2) for the site “Salaspils” were not able to recognize any confident signatures related to the sinkhole’s internal structure and contrast with the surrounding media.

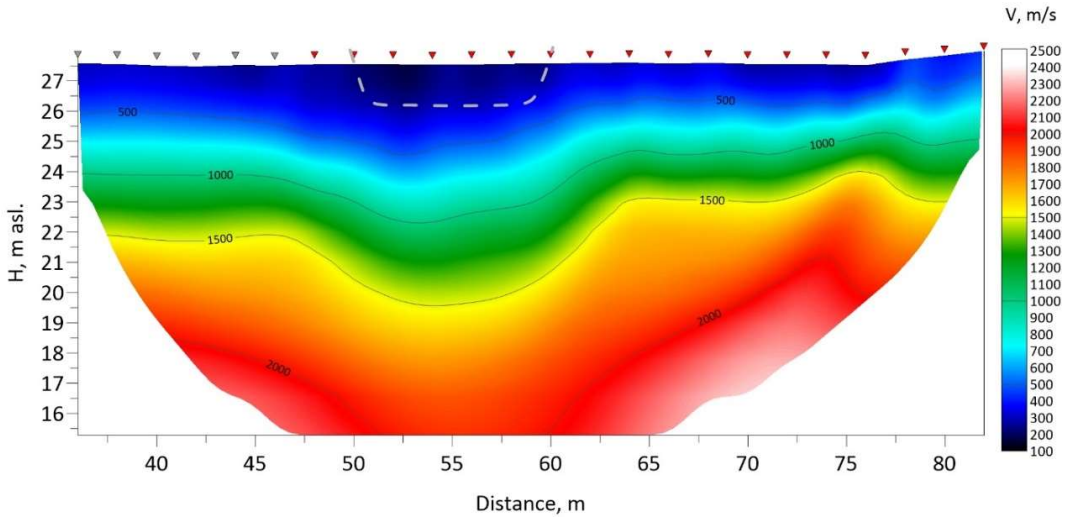

Figure 1. P-wave velocity model for the site “Skaistkalne” 2. RMS error value is 4.1%. Grey line is the boundary of visible collapse. Red triangles are both geophones and shot locations, gray triangles - only geophones.

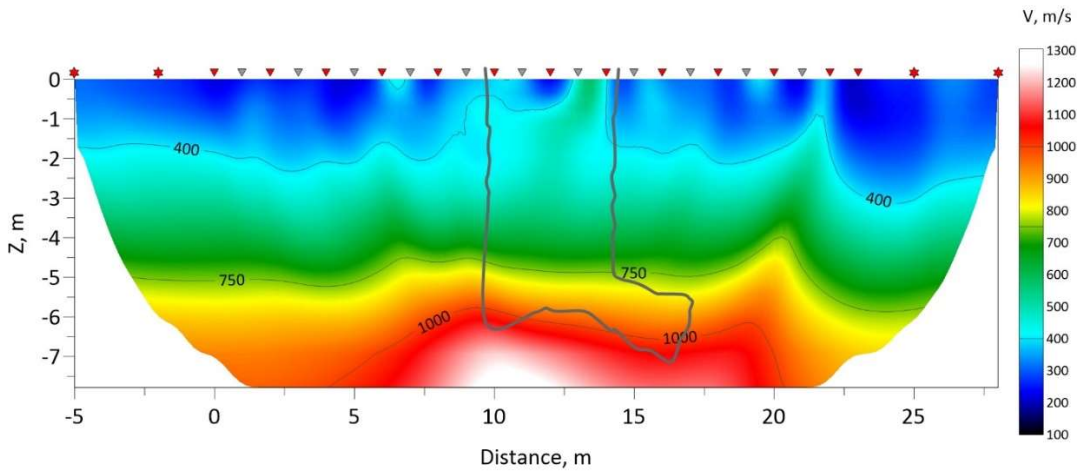

Figure 2. P-wave velocity models for site “Salaspils”, RMS error - 10.4 %. Grey lines are the boundary of the sinkhole. Red triangles are both geophones and shot locations, gray triangles – only geophones, red stars - only shots.

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SEDIMENTOLOGY

Problematic vertical structures in the Šķervelis Formation (Uppermost Famennian to Mississippian)

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The Šķervelis Formation (Fm) has the highest proportion of dolocretes and other features of ancient soil processes in the Devonian to Carboniferous succession of Latvia (Stinkulis, Spruženiece 2011). One of the most peculiar features of this formation are vertical structures, defined by the relationships of carbonate and sandy to clayey material. In 2018-2021 they were studied during fieldwork in the Salnas quarry, Ātrais kalns, Gobdziņas, Lētīža, and Šķervelis outcrops in southern Kurzeme. The structures differ in the lower part (Gobdziņas Mb) and upper part (Nīkrāce Mb) of the Šķervelis Fm.

Vertical dolomite structures, which often become narrower and bifurcate downwards, occur in sandy to clayey deposits of the Gobdziņas Mb. In the Salnas quarry, the vertical structures present in the upper part of the Gobdziņas Mb usually have columnar shape. Their rim with outer diameter up to 30 cm and inner diameter up to 6 cm is formed by sandy dolostone, but core with by loose sandy material with small admixture of dolomite. In places, where the structures are exposed in full thickness, they are up to 0.8 m long.

In the dolocretes of the Nīkrāce Mb the structures are 0.1-1.7 m long and 0.02-0.2 m wide. They are expressed as relationships of sandy to clayey, bluish-coloured material, and sandy to silty, light brown and yellow dolostone. In places the structures are distributed very regularly: 8-20 cm wide vertical dolomite structures laterally alternate with 2-15 cm wide similarly vertical clayey material and honeycomb clay-dolomite veins. Thus the dolocrete has a peculiar vertically columnar-tubular structure. The upper and lower parts of beds with the vertical structures are slightly irregular, with amplitude of approximately 10 cm.

The vertical dolomite structures in the siliciclastics of the Gobdziņas Mb by shape resemble the root structures described in literature (e.g. Algeo et al. 2001). During the Late Devonian

intense evolution of plants took place and archaeopterid forests developed widely. The Frasnian and Famennian archaeopterids had roots reaching depths of more than 1 m (Algeo et al. 2001).

The interpretation of origin of vertical structures abundant in the Nīkrāce Mb is more problematic. They could be plant root structures similar to those of the Gobdziņas Mb. After decay of a root carbonate minerals can precipitate in the root channel, and cement can extend outwards from the channel to the surrounding deposits. The presence of many small rhizoids in the dolocretes of the Nīkrāce Mb suggest the development of vegetation in the studied deposits.

The regular and close distribution of the structures could point to their development in result of shrinkage of clay-rich deposits during their subaerial exposure. Clayey soils influenced of cyclic shrinking and swelling, producing desiccation structures, including vertical open channels, where carbonate veins can form, are named Vertisols (Tabor et al. 2017) and typically develop in seasonally wet climates (Algeo et al. 2001). Prismatic (columnar, tubular) forms are typical for B horizon of palaeosols. They are also noted as typical for calcisols. In this case they can form either in Vertisol along the vertical cracks or as rhizocretions (Tabor et al. 2017).

We suggest that the vertical structures in the Šķervelis Fm are either root structures or a combination of root development and carbonatization in vertical channels of shrinked, deeply desiccated Vertisol or Vertisol-like soils. In any case, they are obviously related to ancient soil development processes during the subaerial exposure times. A seasonally changeable climate is needed for formation of these structures (Algeo et al. 2001; Kraus and Hasiotis 2006).

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The temporal variability of the Holocene calcium carbonate deposition at alkaline fens in the young glacial area of central Europe (NE Poland and Latvia)

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Calcium carbonate precipitating alkaline fens are a specific type of wetland functioning of which depends on the active supply of soligenous waters rich in calcium ions. This alkaline ecosystem hosts many rare and protected calciphilous species with low nutrient demands, particularly sedge-moss communities, accompanied by characteristic mollusc assemblages. Factors controlling $CaCO_3$ precipitation at alkaline fens are complex and include: (i) changes in temperature at the fen surface controlled by climate and changes in tree cover that controls shadowing of the fen surface; (ii) variations of groundwater water supply at the fen driven by shifts in climate humidity and changes in evapotranspiration at the fen and its catchment; (iii) rate of Ca2+ supply controlled by chemical denudation of carbonate deposits in the aquifer and depletion of this Ca2+ source. Whenever $CaCO_3$ precipitation is disturbed, peat is deposited on the fen surface, and specific interbedding peat and tufa sediments form.

Since the 1990s, there has been a conviction that $CaCO_3$ precipitation from freshwaters in Europe was the most intensive during the Holocene thermal maximum (HTM), i.e. ca. 9000-6000 cal yr BP. This was recently challenged by Dabkowski (2020), who compiled data from a range of

$CaCO_3$ depositing sites across Europe and showed much greater complexity than previously thought. The temporal variability in $CaCO_3$ precipitation is also observed at alkaline fens. Tufa deposition continued throughout the Holocene (Dobrowolski et al., 2016), was deposited only during the HTM (Apolinarska et al., 2022) or started in the upper Holocene (Hájková et al., 2020); (Gałka et al., 2021). In central Europe, the distribution of $CaCO_3$ depositing alkaline fens, sediments of which have been studied, is very uneven. In contrast to the Carpathians and Lublin Upland, the young glacial did not receive enough attention.

In the present study, we investigate the time frames of $CaCO_3$ deposition at five sites located in north-eastern Poland and Latvia. Four located in the extent of the Weichselian glaciation: Turtul (Tu; 54°13'22.5" N, 22°48'99.6" E, 197 m a.s.l.), Puszcza Romincka (PR; 54°20'20.5" N, 22°33'55.8" E, 153 m a.s.l.), Maitiku (Mai, 56°50'49.2'' N, 22°38'49.1'' E), and Lustūžkalns (Lus, 56°59'29.724" N, 23°17'1.896", 35 m a.s.l.); and one, Makowlany (Mak; 53°31'56.3" N, 23°26'46.0" E, 155 m a.s.l.) about 50 km south from the Last Glacial Maximum. Time frames and conditions of tufa deposition, and palaeoenvironmental history of the fens, were reconstructed using plant macrofossil, mollusc and geochemical, including loss on ignition and δ13C and δ18O, analyses of two sediment sequences taken from the top and slope of the fen cupola, at each of the sites. The chronology of the sediments is based on radiocarbon dates from plant macrofossils.

The start of $CaCO_3$ (tufa) precipitation differs among sites. The early Holocene onset of tufa deposition was observed in northeastern Poland: PR - ca. 11650 cal yr BP, Mak – ca. 10730 cal yr BP, and Tu – ca. 9250 cal yr BP. In Latvia, deposition started in mid- ca. 6500 cal yr BP - Mai, and late Holocene ca. 3000 cal yr BP - Lus. The early Holocene onset of tufa deposition is associated with the activation of groundwater circulation after the permafrost decline. The exact reasons for the delayed start of $CaCO_3$ precipitation at Latvian sites need to be provided.

The decline in tufa deposition ca. 5400 cal yr BP in Tu and Mak is concurrent with similar observations at numerous European sites where freshwater carbonates were deposited. The ca. 5500 cal yr BP decline in $CaCO_3$ precipitation is usually associated with climate cooling in the mid-Holocene; however, progressive Ca2+ leaching from glacial sediments and groundwater acidification after Picea abies spread are also considered. The Holocene-long tufa deposition at

PR fen, exceptional in NE Poland, likely resulted from site-specific hydrogeological conditions assuring a strong supply of Ca2+-rich artesian waters. The extension to the recent tufa deposition at Mai can indicate the significance of the bedrock of Palaeozoic limestones being an inexhaustible source of Ca2+ ions in the groundwater compared with glacial deposits with scattered $CaCO_3$ detritus.

Acknowledgments

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Downward migrating microplastic in lake sediments is a tricky indicator for the onset of the Anthropocene

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Over the last century, plastic materials have seen substantial increase in their production and usage. Because plastic in general is not decomposed, one might expect to see plastic in different sedimentary environments as a distinct marking horizon characterizing human impact. Microplastics are currently considered among the array of proxies to delimit the Anthropocene Epoch (starting from year 1950 and above). Here we present our findings on microplastics deposition history inferred from sediment profiles of three lakes in Latvia, north-eastern Europe. The sediments were dated with independent proxies which indicates analysed sediment chronology goes back to CE 1730. Regardless of the sediment layer age, we found microplastic particles throughout the cores in all sites. The factor driving microplastic particles to penetrate deeper in sediment layers appears to be particles' dimensional (aspect) ratio: less elongated particles tend to be transported deeper while more elongated particles and fibres have a decreased ability to be mobile. Our findings underline that some microplastic can be mobile in

lacustrine sediments and therefore should not be used as marker indicating the beginning of so-called the Anthropocene Epoch.

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Potential of paludicultures in forming new peat layers and capturing carbon

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Peatlands cover approximately 11% of territory of Latvia and they are both – carbon sinks and carbon sources. Meliorated and degraded peatlands with high variations in water level fluctuations are major source of GHG emissions. Climate change has increased urgency implementing climate change mitigating and GHG reducing activities. Although recent studies prove that stabilizing water level with melioration and afforestation can reduce emissions from degraded peatlands, there are studies proving opposite.

Extracted peatlands are considered as degraded areas with a huge potential in GHG sequestration and long-term accumulation. After peat extraction, it is obligated by the law to recultivate peat mining site. There are different forms for peatland reclamation. Rewetting peatlands including organic soils is one of the major steps which were proposed to tackle climate change. In theory, under water saturated conditions organic matter in peat is decreasing emissions of CO_2, above growing biomass capturing CO_2 and ensuring long-term carbon storage. It is important to underline that implementing paludiculture ensures preservation of existing peat layers and formation of new peat layers and therefore restore peat stock in extracted sites.

To reach the climate neutral goals, rewetting and paludiculture trials have been implemented in Latvia. Due to applied nature, majority of paludiculture projects and pilot studies in Latvia have not been published in scientific literature. Our assessment on paludiculture in Latvia shows that there are private enterprises working on different paludiculture trials with following

steps for large-scale implementation. Assessment also shows there are landowners implementing paludicultures for many years without knowing nothing about paludicultures and benefits they provide for nature and climate.

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PALAEOECOLOGY

Indication of warm summers during Younger Dryas in the Baltic States region

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The Younger Dryas (YD; ca. 12.8–11.7 ka) is the last major abrupt cooling period in which the environment of the Northern Hemisphere returned to a short glacial-like state. The climate shift is typically linked to a slowdown of the Atlantic Meridional Overturning Circulation (McManus et al., 2004). The YD is traditionally interpreted as a generally cold and dry period with distinct cooling patterns in both summer and winter seasons (e.g., Lowe et al., 1994; Heiri et al., 2014). However, multiple YD climate studies have observed a distinct warm summer presence in some localities in Europe (e.g., Birks & Birks, 2014, Schenk et al., 2020). Additionally, a study by Schenk et al. (2018) proposed a new explanation for the YD's impact on Europe's climate in which winters were colder and longer during the YD compared to the previous warm Bølling-Allerød, while the summers were shorter with temperatures remaining relatively constant or even experiencing a slight increase.

Here we focus on the Baltic States region in order to study the local YD summer trends in more detail. The climate change has a direct influence on plant realized niches and thus fossil and subfossil plant assemblages found in the sediments. Therefore, mean July temperature patterns of YD for Baltic State region were reconstructed using local climate proxy, plant macrofossil, data from 13 sites of the Baltic States and surrounding region. Additionally, mean January temperatures have been reconstructed as well for better insight in the seasonal changes during YD.

For this study, climate reconstructions were made using two methods that implement the Probability Density Function approach: CRACLE (Harbert & Nixon, 2015) and CREST (Chevalier, 2022). Our reconstructed summer temperature patterns do not completely confirm a warm-

summer hypothesis with a warming of the Baltics by ~0.5–1.5 °C. Nevertheless, no strong summer cooling can be identified as well. The reconstructed ~0–1 °C decrease in mean July temperatures during YD suggests relatively stable and continuously warm summers. Additionally, reconstructions show up to ~5–7 °C cooling in winter, which leads to a clear indication of higher yearly temperature ranges and rise in the continentality during YD in Baltic States region.

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Reconstruction of the Mid-to Late- Holocene paleoenvironment in the Eastern Baltic region (W Lithuania) based on multiproxy approach

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Multidisciplinary studies illustrating the history of Holocene palaeoenvironmental changes in Eastern Europe are still shortage, especially in Lithuania. In order to understand the basic patterns of palaeoenvironment changes, it is important to have a more detailed overview of the sediments formed during the Holocene. The new data obtained from two parallel sediment cores (A1D and A2D) were taken in the Aukštumala raised bog located at Nemunas River Delta, stretching eastwards from the coast of the Curonian Lagoon. The study based on palaeobotanical (pollen-spores, plant macrofossils), lithological (loss-on-ignition (LOI), measurements of magnetic susceptibility (MS)), chronological (^{14}C), statistical and geochemical results.

Our data suggest the onset of the sediments formation in the investigated part started at about 6000 cal BP. The initial period of sedimentation (before 5900 cal BP) could be characterised by flourishing of alder and poor herbaceous cover. Simultaneously, the highest value of SO_4 with higher admixture of the terrigenous matter was noted. The changes recorded in particular environmental proxies can be caused by an increase of humidity that correlates well with the humid interval noted all along the European territory at that time (Langdon et al., 2003; Edvardsson et al., 2012; Grindean et al., 2015; Stančikaitė et al., 2019).

From about 5900 to 5000/4800 cal BP, a dry period was recorded in the area. The beginning of this period could be characterised by the decreasing representation of wetland plants and the extinction of alder shown by a disappearance of Alnus glutinosa macrofossils. However, the recovery of aquatic plants (i.e. Potamogeton) at about 5400 cal BP indicates the increasing in the water table. This change coincided with the spread of plants tolerant of wet soils,

however surrounding forests still dominated by coniferous, showing dry habitats. No changes were fixed in geochemical record, except insignificant decrease in SO_4 value.

After 5000/4800-4300/4100 cal BP, the sedimentary basin gradually changed to an open wetland. At the beginning of the period, coniferous and Alnus glutinosa decreased and Betula prevailed in the forest structure. A more open landscape was formed. Later, around 4400 cal BP birch trees (Betula sect. Albae and Betula pubescens) significantly decreased and Pinus became more abundant. Simultaneously, first appearance of Picea macrofossils are observed. At that time, the water plants appeared in the plant macrofossils spectra, suggesting the increasing water table. These fluctuations could be caused by an increasing precipitation, synchronous with the cooler climatic regime recorded in the eastern Baltic region at that time (Seppä, Poska, 2004).

At the beginning of the period (4300/4100-3200/3000 cal BP), water plants gradually disappeared and the territory was occupied by wetland plants. During this period (3200/3000 - 2700/2500 cal BP), at the first study site (A1D core), the intermediate type of wetland gradually changes to raised wetland. Meanwhile, the vicinity of the newly formed shallow lakes (A2D core) was occupied by Alnus, Menyanthes trifoliata and also Poaceae, which could be partly composed by Phragmites-type vegetation. Since about 2700/2500 - 2100/2000 cal BP the area (A2D core) was dominated by birch forests, forming a more open landscape. Interval is marked by increased Cl concentrations. Meanwhile, around 2400 cal BP the water level increased as recorded by significant increase in number of wetland plants. After 2100/2000 cal BP, the intermediate wetland type gradually transforms into a raised wetland (A2D core). This is indicated by the appearance of Cyperaceae species and gradual spread of Sphagnum and Ericaceae species in the area. At the latest stage hydrological conditions have changed and raised wetland vegetation degradation started due human interference, including land-use practices, peat exploration and land reclamation.

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First results on a Testate amoebae-based quantitative water reconstruction during the Late Holocene in Ķemeri bog, Latvia

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Testate amoebae are unicellular organisms living in a variety of habitats including lakes and mires (Lamentowicz and Mitchell, 2005). The correlation between testate amoebae communities and moisture conditions is increasingly used to infer palaeohydrological changes in peatlands and, in the case of ombrotrophic peatlands, these data are ultimately used to infer past climate changes. Although palaeoecological and palaeohydrological studies of testate amoebae are widespread throughout the world, only two studies have been carried out in Latvia so far. This means that this topical area of research is in principle underdeveloped in Latvia and that fundamental knowledge on the long-term hydrological regime processes in bogs is lacking (Stivrins et al. 2017). No studies have been carried out on the basis of changes in testate amoebae composition to reconstruct quantitative water levels in the late Holocene for a bog in Latvia. The species composition of the amoebae in Ķemeri bog has not yet been determined, so there are insufficient data on the nature of the palaeohydrological regime not only in Ķemeri bog, but also in raised bogs in this region in general. In our presentation we will present the first results from ongoing study which aim to perform a quantitative reconstruction of the water levels in the Ķemeri bog during the Late Holocene, based on the amoeba diversity and changes in amoeba species composition.

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PALAEONTOLOGY

A Late Devonian sarcopterygian fish assemblage from the Pavāri-2 fossil locality, Latvia

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Late Devonian fish and tetrapod fossil remains from the Famennian Ketleri Formation (Fm) has been studied in detail in two localities: the Pavāri locality at the left bank of the Ciecere River opposite the vanished farmhouse "Pavāri", and the Ketleri locality at the right bank of the Venta River close to the abandoned farmhouse "Ķetleri" (e.g. Lebedev and Lukševičs 2018). Recently, in 2019, a new fossil site named "Pavāri-2" has been discovered at the left bank of the Ciecere River close to the mouth of the Paksīte River, in a distance of about 400 m from the Pavāri-1 site (Lukševičs et al. 2022). Excavations during 2019-2022 field seasons provided a large number of sarcopterygian fish specimens including taxa new for the Ketleri Fm, and some skeletal elements previously not known from this formation.

The sarcopterygian remains can be attributed to various groups of Dipnomorpha (Dipnoi and Porolepiformes) and Tetrapodomorpha (Osteolepiformes and Tetrapoda). The following taxa of dipnomorph sarcopterygians have been found in the Pavāri-2 site: "*Dipterus*" *arcanus* Krupina, "*D.*" *expressus* Krupina, *Orlovichthys limnatis* Krupina, *Dipnoi* gen. et sp. indet., *Holoptychius* ex gr. *nobilissimus* Agassiz, *Glyptolepis*? *dellei* (Gross), *Ventalepis ketleriensis* Schultze. Tetrapodomorphs are represented by *Cryptolepis grossi* Vorobyeva, *Glyptopomus bystrowi* (Gross), Tristichopteridae gen. et sp. indet., and early tetrapod Ventastega curonica Ahlberg et al. The remains of H. ex gr. nobilissimus (most probably a new species) represented mainly by scales and bones of the shoulder girdle or rarely jaw fragments or other bones of the head dominate the sarcopterygian assemblage. Skeletal elements collected during excavations of 2021 and 2022 add significantly to the morphology of this species. The new material demonstrates increased lungfish diversity from the Ketleri Fm. Several new, previously unknown tooth plates and separate bones from the head of dipnoan fishes, e.g. parasphenoid resembling that of Oervigia, B bone from the long-snouted dipnoan, pterygoid and prearticular tooth plates of several species of

"*Dipterus*", have been collected in 2021 and 2022. Relatively large disarticulated bones of the head shield and jaws usually represent tetrapodomorph fishes, but small scales of *Cryptolepis grossi* are also abundant. Newly found lower jaw, gular plate, elements of the shoulder girdle of *C. grossi* add significantly to the morphology of this species. *Scapulocoracoid* mentioned previously (Lukševičs et al. 2022) and newly excavated humerus of *Ventastega curonica* allow deepen the comparison of this tetrapod species with such iconic taxa as *Acanthostega gunnari* and *Ichthyostega stensioi* from Greenland, as well as locomotor capabilities of *Ventastega*. Some sarcopterygian skeletal elements bear pathologies such as traces of possible parasites, diseases or biting marks providing insight into the paleoecological structure of the assemblage.

The sarcopterygian fish and tetrapod assemblage encountered in the new locality Pavāri-2 slightly differs from the assemblage from the Pavāri-1 site by a larger diversity of dipnoans, higher number and variability of the discovered skeletal elements, as well as by relatively larger proportion of the complete parts of skeleton consisting of several elements. Such taxa as "*Dipterus*" *expressus*, cf. *Oervigia* sp. and a large tristichopterid fish have been discovered for the first time in the Ketleri Fm cropping along the Ciecere River. Fossils from the "Pavāri-2" usually are more deformed than these from the "Pavāri-1", sometimes even heavily distorted, making reconstructions difficult. However, these findings indicate the potential of the "Pavāri-2" for the discovery of more partially articulated skeletal elements of sarcopterygians and early tetrapods.

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Pathologies in the fish fossils from the Middle Devonian, Burtnieki Formation deposits of Estonia

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The Burtnieki Stage is spread in southeastern Estonia. The outcrop area forms a 25–50-km-wide belt stretching from Ipiku and Valga in the west to Mehikoorma and Karisilla in the east. The deposits are light fine-grained medium- to weakly-cemented cross-bedded sandstones with interlayers of siltstone and clay (Kleesment & Mark-Kurik 1997). The outcrops of Karksi, Härma, Koorküla and Essi are well known as localities of fossil fishes, vertebrate remains from these localities have been gathered and studied for several decades. Fossils coming from different parts of the Burtnieki Stage belong mainly to arthrodire and antiarch placoderms, psammosteids and sarcopterygians, for full list see Kleesment & Mark-Kurik 1997. Attention to pathologies in these remains has been given only recently (Lebedev et al. 2009; Lukševičs et al. 2009).

Various bite marks and scratches on the fossil material of Devonian psammosteids were first observed by Obruchev and Mark-Kurik (1965) and described more fully in 1966 (Mark-Kurik 1966). Lebedev also described some lifetime damages in Devonian fish fossils, including a predator bite mark with clear signs of bone regeneration on the gular plate of *Gyroptychius* elgae from Burtnieki Formation deposits in Karksi (Lebedev 1993). Previously described specimens together with new material were redescribed and reinterpreted in 2009 by Lebedev, Mark-Kurik, Lukševičs and Ivanov (Lebedev et al. 2009). Pathologies in the material from the Burtnieki Formation include bite marks on placoderms *Actinolepis magna*, *Eastmanosteus* and Microbranchius as well as bite marks, scratches or torn off corners of dorsal and branchial plates of *Psammosteus*, *Ganosteus*, *Tartuosteus* and *Pycnosteus psammosteids*.

The paleontological material in the geological collections of the University of Tartu and Tallinn University of Technology containing fossils from the Middle and Upper Devonian deposits Estonia and Latvia has been thoroughly examined. Pathologies that were found include bite marks

on *Gyroptychius* elgae operculum displaying signs of possible regeneration of the enamel layer in the damaged area. Several bones – gular, infradentary plates as well as fragment of a parietal shield of a porolepiform holoptychiid gen. et sp. indet. display deformations and fractures most likely caused by an attack of another large sarcopterygian or placoderm. Some predator bite marks have also been found on the plates of placoderms *Asterolepis essica*, *Homostius* sp. and *Coccosteus markae*. Two bones of an unknown crossopterygian have small pits on the outer surface of the bones that could have been caused by ectoparasite activity. Pathologies caused by predators can be found on bones from most of the groups of fishes from the Burtnieki time however it is worth noting that the fossil remains from the Burtnieki formation bear almost no traces of possible parasite activity.

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A new antiarch fish (Placodermi) from the Lower Devonian Vitebsk Formation of Belarus

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A new antiarch, *Sherbonaspis* sp.nov., has been found from the Obol and Lepel Beds (Vitebsk Formation), corresponding to the Vitebsk Regional Stage (Emsian, Lower Devonian) of Mogilev and Gomel regions, Belarus. The material comes from three boreholes drilled in the eastern part of Belarus: Osipovichi 6 and Smol'ki 6п in the Mogilev Region, and Korma 1 in the Gomel Region. It has been obtained through detailed studies of the Early-Middle Devonian deposits of Belarus started by D. Plax in 2002 (e.g. Plax 2008). The material is very limited, only one plate from the head shield, several plates forming the ventral wall of the trunk shield, and one partial but articulated fragment of the pectoral fin are represented among skeletal elements. However, the morphology and size of skeletal elements of the new species resembles these in *Sherbonaspis hillsi* Young et Gorter, 1981 from Australia, thus allowing attribution of the new material to the genus *Sherbonaspis*. The new species of *Sherbonaspis* is characterised by a small size, with the length of the ventral wall of the trunk armour of about 75 mm, and relatively high trunk armour. The paranuchal plate, which is yet not known neither in *Sherbonaspis hillsi* nor in *Sh. andreannae* Panteleyev, 1993, is small, asymmetrical, slightly longer than it is wide. The ventral lateral ridge is well developed along the whole length of the trunk armour. The ventral wall of the trunk armour is flat. The contact face for mixilateral plate on the anterior ventral lateral plate is short. The lateral margin of the ventral lamina of posterior ventral lateral plate is almost straight. The length/width index of the lateral lamina of posterior ventral lateral plate is about 2.3. Ornamentation generally consists of small tubercles sometimes fused into tuberculate ridges; tubercles tend to form rows perpendicular or parallel to the margins of the plates. The anterior ventral lateral plates bear a fine-meshed network of the shallow pits in the anterior part of the

ventral lamina, and small tubercles with sharp tips along the margins in the posterior portion of the plate.

In accordance with the current Devonian stratigraphic chart of Belarus (Obukhovskaya et al. 2010) the Vitebsk RS completely corresponds to the Upper Emsian, Lower Devonian. However, earlier the same authors placed the Emsian/Eifelian boundary approximately in the middle of the Lepel Beds, close to the boundary between the lower and upper members of these beds (e.g., Kruchek et al. 2001). Deposits of the Lepel Beds correspond to the upper part of the *Rhabdosporites mirus – Gneudnaspora divellomedium* miospore zone, which is insufficiently correlated with the standard conodont zonation. The age analogue of the deposits of Lepel Beds is approximately the upper part of the Rēzekne Fm of Latvia and Estonia. The upper part of the Rēzekne Fm in the modern stratigraphic chart of Latvia corresponds to the lowermost Eifelian (Lukševičs and Stinkulis 2018), but to the uppermost Emsian in the stratigraphic chart of Estonia (Mark-Kurik and Põldvere 2012). Unfortunately, conodonts have not been found in the deposits of the Vitebsk and Rēzekne formations, therefore the correct correlation with conodont zonation cannot be established. Thus, a broader discussion of the Emsian-Eifelian boundary in the Baltic-Belarusian area is needed.

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GEOMORPHOLOGY

New data on surging phenomena of palaeo-ice lobes in Latvia

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During the deglaciation of the last Scandinavian Ice Sheet (SIS), ice lobes advanced mainly in the Latvian lowlands (Zelčs, Markots, 2004; Zelčs et al., 2011). These advances were often characterized by fast-flowing ice, which created subglacial bedform assemblages including streamlined bedforms ranging from drumlins to mega-scale glacial lineations (MSGLs) (Lamsters, Zelčs, 2015). A possible surging of palaeo-ice streams of the SIS has been known since the end of the 20th century when, for example, Kleman et al. (1997) proposed a term “surge fans” for the ice streams mainly in the southern and eastern sectors of the SIS. As the published information on meltwater features in Latvia was lacking, majority of fans were called synchronous fans, which lack the presence of eskers, and the Zemgale (Central Latvian) Ice Lobe was identified as a surge fan.

Nowadays, the availability of high-resolution digital terrain models (DTM) has promoted the recognition and mapping of even low-amplitude landforms suggesting more widespread activity of surging ice sheet margins, streams and lobes of the SIS (Stroeven, 2016). Several latest studies have compiled data on the landforms characteristic for surging ice lobes in Latvia (Lamsters et al., 2021; Grīnbauma, Lamsters, 2022). Such landforms usually resemble geometric ridge networks and are interpreted as crevasse-squeeze ridges (CSRs), which are widely known from contemporary surging glaciers and surging palaeo-ice stream beds around the globe. However, caution should always be applied in interpreting landform records. As Evans et al. (2016) noted “these landforms individually are not diagnostic of surging or glacier submarginal till extrusion into splaying crevasses”. Patterns of CSR distribution and relationship with other

landforms is essential as narrow concentric arcs and CSR corridors may not be inherited from surging ice streams (Evans et al., 2016).

In the case of Latvia, CSRs have been found at the beds of the Venta ice tongue (Lamsters et al., 2021) and Lubāns ice lobe (Grīnbauma, Lamsters, 2022), which operated accordingly in the Kursa and Eastern Latvian lowlands. The widespread distribution of CSRs along the ice lobe/tongue beds attests to surging behaviour. Occasionally CSRs are superimposed on MSGLs – indicators of fast ice flow. In the lowest areas of the lowlands CSRs may even be missing in nowadays topography due to the accumulation of glaciolacustrine sediments and peat. Generally, good preservation of low-amplitude CSRs including occasional criss-cross patterns suggests rapid ice-lobe shut-down after surging and down-wasting during the deglaciation. It has been suggested that zig-zag eskers are also likely to develop (Evans et a., 2016) together with CSRs, and similar landforms have been identified at the bed of the Lubāns Ice Lobe. However, both morphological analyses and field works have revealed that this zig-zag pattern corresponds to up to 10-km-long continuous CSRs consisting of subglacial till suggesting squeezing of till into complex and connected crevasses systems. The Eastern Latvian Lowland comprises also other landforms that may be related to surging behaviour. For example, abundant meltwater was drained immediately after the surge events creating meltwater channels, tunnel valleys, sandur plains, some eskers and vast proglacial lake plains. The repeated surging activity also led to the development of several end moraine complexes. Further work is needed to establish the chronology of palaeo-ice stream/ lobe surging.

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Oscillations of the ice sheet front along the Gardno moraines in northern Poland: reconstruction inferred from landform analysis and 10Be dating

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A significant warming of climate in the Northern Hemisphere at the Last Glacial Termination triggered the retreat of the Scandinavian Ice Sheet (SIS). After the Last Glacial Maximum (LGM), which occurred between ~24 and ~18 ka in the northern continental Europe, the southern margin of the last SIS receded gradually, leaving glacial landforms clearly visible in the landscape. However, this general ice sheet retreat was often punctuated by the ice margin stillstand or local readvances. Here we present a new results of glacial landform mapping based on the high-resolution LiDAR Digital Elevation Model (DEM) and 10Be surface exposure dating of erratic boulders at the northern fringe of Poland.

The study area covers a part of the Polish middle-coast region with conspicuous ice-marginal moraines. The Gardno moraines are the end moraine ridges recording the ice-margin position after a local ice sheet re-advance, which is recently correlated with the phase of the last deglaciation dated at 16.8–16.6 cal ka BP or 16.5 ± 0.5 ka. However, our new results show that the geomorphological record of palaeo-ice margin positions in this area suggests highly dynamic oscillations of the ice front which may be chronologically constrained with a new 10Be surface exposure dating.

Semi-automatic karst sinkhole detection from digital elevation or surface models

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Karst processes are related to Upper Devonian gypsum layers in North Lithuania. These layers are covered mainly with Quaternary cover (Satkūnas et al. 2007). The dissolution of gypsum causes formation of gaps and cavities the in underground. Development and growth of the cavities causes formation of the subsidences or even sinkholes (Marcinkevičius, Bucevičiūtė, 1997). The spread and intensity of the karst process can be determined by registering the appearance of new karst phenomena, usually sinkholes. New sinkholes can be detected in different ways. Digital elevation models delivered from LiDAR data can be used to detect sinkholes (Wu et al, 2016). Digital surface models delivered from airborne photogrammetry can also be used for this purpose but with some restrictions. Forests and other areas with high vegetation should be excluded during the process of sinkhole detection. The method used for semi-automatic is so-called filled-difference or sink-filled (Rajabi, 2018). Not every of detected subsidence are recognized of karstic origin. Some of them are man-made pits or animal burrows. Because of that, every detected subsidence should be checked and proved by an inspection during field works (Fig. 1)

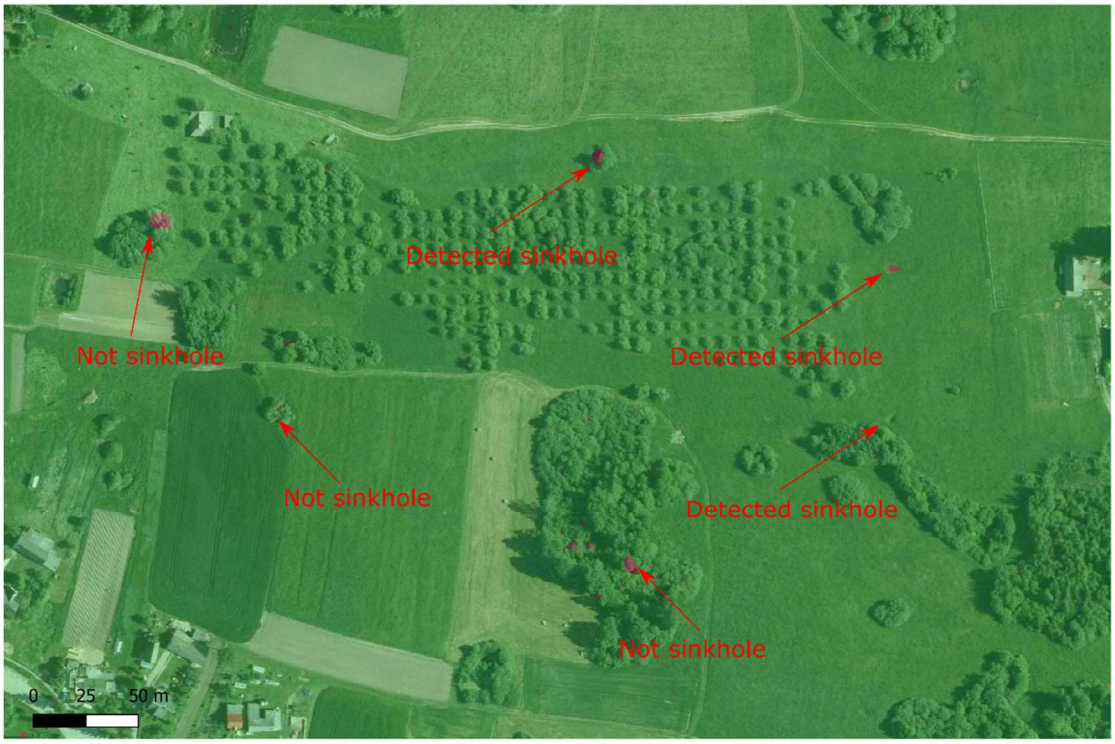

Figure 1. Karst sinkholes in the landscape.

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Morphology and granulometric characteristics of aeolian landforms in the Augšdaugava spillway valley

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The Augšdaugava spillway valley located in the SE Latvia has a system of river terraces formed by both glacio-fluvial and fluvial processes. At the same time, the geomorphic features of aeolian origin and associated sediments that are deposited on the surface of river terraces also are presented in the valley, providing data on the paleogeography and dynamics of wind-driven geological processes during the Holocene. Indications that inland dunes as minor landforms are located in the Augšdaugava spillway valley for the first time was provided by G. Eberhards in 1991 in the functional zoning of Nature Park "Daugavas loki". However, contrary to other inland dune massifs in Latvia, there is a lack of scientific data on aeolian sand granulometry and geomorphological characteristics of these landforms including their geographic distribution, dimensions, planform shape and orientation. Therefore, authors performed studies including (i) identification and GIS analysis of inland dunes using LiDAR-derived DEM with 0.5 x 0.5 m pixel resolution, (ii) field studies and (iii) granulometric analysis of aeolian sand samples.

The geomorphological mapping of aeolian landforms in the valley was performed with the modified methods described in Bernhardson and Alexanderson (2018) and in Holuša et al. (2022). All GIS data processing and analyses were performed using the software package ArcGIS 10.8.1. and ArcGIS PRO (ESRI). DEM derivatives such as hill-shade relief model, slope raster (the steepness of landform slopes in degrees), slope aspect raster (azimuthal direction of the slopes) and slope profile curvature were created. In addition, elevation contour lines of 0.2 m interval were derived from the smoothed DEM. Considering the low relative height of dunes, the vertical scale of hill-shade model was exaggerated five times to enhance the identification of landform features. Dunes were visually interpreted and then manually digitised as vector polygons. Since the visual interpretation of elongate landforms from a single hill-shade model is biased by the azimuth of illumination used (Smith and Clark, 2005), models of four directions (azimuths 315°;

45°; 135° and 225° of sun illumination, respectively) were combined. For identification and digitising of dune foot lines, hill-shade models were overlayed by elevation contour lines of 0.2 m interval, slope gradient and curvature semi-transparent coloured map layers. The polygons obtained in that way illustrate the distribution of dunes within the valley. Furthermore, from polygon shape the dune morphologies were recognised and described according to the terminology of Pye and Tsoar (2009). The morphology of delineated dunes and their crestlines served further as the geomorphic proxies for inferring the paleowind directions under which the aeolian landforms were likely formed.

For grain size analysis of aeolian sediments sand samples were collected from dunes pre-selected during GIS analysis. The samples were taken from the dune crests with a hand auger or from shallow dugs at a depth of 0.8 to 1.2 m directly from the C horizon of soil. In cases where charcoal was identified under the aeolian sand, samples were collected for AMS 14C dating at the Vilnius Laboratory of Mass Spectrometry. The sand samples were processed at the Laboratory of Quaternary Environment (Daugavpils University) using a Malvern Mastersizer 2000 laser grain size analyser with an analytical range of 0.02–2000 μm. Data on the mean grain size and other Folk and Ward indicators, that is sorting, skewness SK and kurtosis KG were extracted from the results of granulometric analysis.

The results of studies indicate that in total 221 dunes have been identified during GIS analysis. These aeolian landforms display a large diversity in terms of their morphology – single parabolic, V-shaped and U-shaped (hairpin) dunes, linear or curvilinear dune ridges, as well as compound hemicyclic and complex superimposed dunes are present, which often form irregular clustered groups. The dunes are located at different hypsometric levels on the surface of river terraces T1 to T8. The inferred paleowind directions demonstrate that the majority of the dunes appear to have been formed by westerly or south-southwesterly winds. The mean grain size of aeolian sand ranges from 190 to 396 μm. Hence aeolian landforms in the spillway valley are composed of rather homogenous, fine or medium sand, which is moderately well or well sorted. AMS 14C dating of charcoal fragments buried under aeolian sediments indicates that at different parts of the valley deposition took place between 1399 and 1450 calAD, and between 1620 and 1675 calAD. Actually, dating reveals that in Medieval Times, i.e. during the Little Ice age (as

indicate the dates), high-magnitude geomorphic processes took place in the Augšdaugava spillway valley, leading to intensive deposition of aeolian sediments and burring of soils and organic material. Hence these dates will stimulate to carry out additional and new studies because geomorphic events of the Little Ice age remain poorly documented in this part of Latvia.

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Morphology of Saalian eskers in Poland

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Eskers are glacial forms which originate in glacial tunnels and channels, as a result of accumulation of meltwater sediments. Analysing their morphological characteristics, spatial distribution and orientation provides invaluable information on the drainage system and allows the conditions and processes occurring in ancient ice sheets to be reconstructed. Esker formation is significantly influenced by the lithology of the substratum over which the ice sheet migrates. It determines the type of tunnels in which eskers are formed. The study presents morphometric analysis of approximately 300 eskers in Poland, to the south of the Last Glacial Maximum. The studied eskers were formed during the Saalian Glaciation. In Poland eskers were formed on soft bed. In this condition the prevailing type of eskers are those formed in N-channels, or combination of N-channels and R-channels.

The dataset of eskers was developed on the base of the Detailed Geological Map of Poland (SMGP) 1:50 000 (573 raster map sheets), 1:10 000 topographic maps and the Digital Elevation Model, GRID 1 m (https://mapy.geoportal.gov.pl/wss/service/PZGIK/NMT/GRID1/WMS/Hypsometry). The measurements included their fragmentation, length, width, elongation, sinuosity, orientation and presence of tributary ridges and their order.

The study revealed that these forms are characterised by predominance of eskers of 1-3 km in length. The maximum length of measured eskers slightly exceeds 10 km and the average is 2.4 km. The slight predominance of forms consisting of a single segment was documented. The average width of eskers is 250 m. The analysed forms are clear elongated and more often straight then sinuous. The average sinuosity is 1.12. The about 64% of eskers do not have tributary ridges. The length of tributary ridges occasionally exceeds 2 km, and they are up to second order. Eskers

in the analysed area are distributed unevenly and their orientation is compliant with the direction of ice sheet motion.

The main elements which influence the morphology of Saalian eskers in Poland are: formation of eskers in N-channels and combination of N-channels and R-channels cut into soft bed, complex genesis of eskers and superimposition of open crevasse sediments over the subglacial facies and subsequent transformations and erosion of eskers in the conditions of periglacial and moderate climate.

Submarine glacial landforms in the southern part of the Baltic Sea basin

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During the last glacial cycle, the Scandinavian Ice Sheet (SIS) was one of the Northern Hemisphere's most extensive ice sheets. The ice flow pattern of the last SIS was characterized by the occurrence of ice streams (corridors of fast-flowing ice). These ice streams were a major factor in controlling ice drainage and glacial debris transport during the ice sheet's advances and retreat. The Baltic Sea basin hosted the Baltic Ice Stream complex, which was one of the main corridors of fast-flowing ice within the SIS. The main goals of the STREAMBAL (Hydroacoustic exploration of submarine subglacial landforms: towards the reconstruction of palaeo-ice streams in the Baltic Sea Basin) project are to: (1) detect and analyze subglacial bed- forms formed by palaeo-ice streams and associated glacial landforms within research polygons of the central and southern Baltic Sea basin (the Baltic Proper), (2) conduct microsedimento- logical analyses of glacial deposits cored from the regions of the seafloor potentially affected by the palaeo-ice streams, and (3) investigate and reconstruct the dynamics of the palaeo-ice streams within selected regions of the Baltic Proper. Here we present the first results of the project related to various types of glacial landforms recognized in the southern Baltic seafloor and indicating diversified ice dynamics during the last deglaciation.

The mapping of submarine landforms is largely dependent on marine geophysical survey methods, such as multibeam bathymetry (Jakobsson et al., 2016). This enables the discovery of previously unknown seafloor landforms produced by past glacial activity and fills the gap in our understanding of the dynamics of the last SIS's southern sector. We mapped glacial landforms in the southern Baltic Sea based on bathymetric models (grids of various resolutions, from 0.5 to 5 m) interpolated from multibeam bathymetric data obtained from the Hydrographic Office of the Polish Navy, RWE company and the Swedish Maritime Administration. In the area of mapping, we identified moraine ridges, potential crevasse squeeze ridges, marginal meltwater channels, potential relict of subglacial channels, and iceberg ploughmarks. All mapped landforms (their

orientation and morphology) can provide important information about the dynamics of the Baltic Ice stream complex during the last deglaciation. They are also helpful in reconstructing the pattern of ice flow and margin positions in the southern Baltic Sea Basin.

During the project, microsedimentological studies will also be conducted. They will be based on sediment cores from the seafloor locations where potential palaeo-ice streams occurred. We selected appropriate cores from the Polish Exclusive Economic Zone (EEZ) which are available in the geological archive. They consist of thick layers of glacial diamicton, which will be investigated with 3D microtomography and thin-section micromorphology.

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Lithosedimentary and pollen-spore record changes through the transition from stadial to interstadial during Late Nemunas glaciation according to the research of Balbieriškis outcrop, south Lithuania

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Research of deposits of the Late Weichselian Glaciation in the Baltic region are of great importance as it can help to assess the transition from stadial to interstadial of glacial. The Late Weichselian Glaciation is referred to as the Late Nemunas Glaciation (Upper Nemunas Formation) in Lithuania. However, despite the rapidly increasing number of new research sites being discovered, investigations of organic deposits, interbedded within cold stages inorganic deposits, is still very scarce. Together with that, the chronostratigraphical position of these deposits is often uncertain, and correlation across NW Europe is often based on biostratigraphical similarities with the implied risk, that they can be aggregated to units of similar fossil content but different ages.

Sedimentary section, recovered from the deposits of the Balbieriškis outcrop located in the Nemunas River midstream (South Lithuania), allows observing multiple changes in sediment lithology and vegetation communities. The assessment of the palaeogeographical conditions of the region was proceeded, the structure of the whole sedimentary section was analyzed, and detailed studies of tills were carried out.

The lower and upper tills differ in their composition and the path of glacier movement. These cold-stage inorganic deposits testify to global climate change in the Late Ice Age and the reorganization of the southeastern part of the Scandinavian Ice Sheet.

Pollen, spore, and other microfauna (microflora) findings also grain size and concentration of organic matter in intertill sediments were analyzed. The results provided the knowledge of

vegetation history and sedimentation conditions. Sedimentation of intertill according to the multi-proxy results could be divided into two sedimentation stages. The first sedimentation interval (Stage I) is the most complex. The water currents brought most old particles here, which provide information about the possible change in the water source or river basin. In the beginning, environmental conditions were very unstable. A lithological sediment composition was influenced by stronger or slower water influxes. These circumstances also did a major impact to pollen and spore influx. Nevertheless, low concentrations of pollen, spore and other microfauna testify that grasses and herbs dominated, but most Pinus pollen probably were brought by wind, as their pollen concentration hardly exceeded more than 50 %.

Sedimentation during the next stage (Stage II) was more stable. At this time in the region, thermophilous vegetation appears, however, the landscape is still open, with scattered wooded parts or distant forests. About increased annual temperature and enriched with nutrients water, which lead to blooming of closed waters or oxbow lakes, states rapidly increased concentration of algae of different species. The high concentration of old pollen, spores and dinoflagellates in the sediments points that water sources still were from a very broad river basin or a distance of the riverhead. Pollen results show that this stage in comparison with the previous one was not only warmer, but also, moister, and in the surroundings of bogy lowlands various moss grew with Picea. Together with that high variability of species of grasses and herbs shows that there was no dominating vegetation.

In summary, the sequence of the Balbieriškis outcrop reflects the presence of nonglacial palaeoenvironment during the deglaciation of Late Weichselian Glaciation. The relatively continuous sedimentation process is indicated by intertill sediments, which separate the last glaciation deposits and testify to global climate changes in the Late Ice Age. This indicates a restructurization of glacial lobes during deglaciation in the southeastern part of the Scandinavian Ice Sheet and can be named as phenomenon of the rank of a significant stage of deglaciation. The available material allows us to legitimize the Balbieriškis interstage period between the Grūda and Baltija Stages (Grūda and Baltija sub-Formations) of the Late Nemunas Glaciation in the regional Quaternary stratigraphic scheme.

Investigation of buried karst sinkholes under bog using GPR and ERT methods

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Active sinkhole formation in Latvia is associated with a few relatively small regions where Salaspils Formation gypsum can be found close to the ground surface. One such area is located near the Pandu bog in Allaži municipality. This study aims to investigate karst sinkhole distribution nearby the Pandu bog using remote sensing methods and to identify peat-covered sinkholes under the bog itself. Mūrnieks et al. (2007) performed a karst study of Allaži municipality and identified the highest sinkhole density to the south of the Pandu bog. However, no information is available on karst activity under the bog itself which could have potential effects on karst processes in the nearby region.

For the mapping of potential karst sinkholes under the Pandu bog, a combination of Ground Penetrating Radar (GPR), Electrical Resistivity Tomography (ERT), and conventional geological drilling methods were used. GPR was used to identify depressions within the bog substratum. In total, 47 profiles and a total length of 14.6 km were recorded. Over 2 of the identified depressions ERT profiles were carried out and in total 10 boreholes were drilled to correlate the geophysical results.

For the mapping of karst sinkholes in the surrounding area, LiDAR-based DEM of 1 m resolution provided by the Latvian Geospatial Information Agency was used. Also, several orthophoto maps of different ages were used to identify the most recent formations. After the remote mapping of the sinkholes, a field visit to confirm the observations was performed.

As a result, a detailed map was produced of the bog substratum topography from geophysical survey data. We identified 15 distinctly expressed sinkholes with diameters of several tens of meters under the bog and 140 potential sinkholes in the near vicinity (Fig. 1). Over the sinkholes formed under the bog, we identified scatter-free zones in the GPR data and higher resistivity anomalies in the ERT measurements, both interpreted as a water layer within the peat.

Borehole data confirmed the presence of these water layers. We suggest that these water layers may have formed due to the subsidence of the peat, therefore representing more recently formed sinkholes. By comparing different orthophotos it was possible to identify that one of the sinkholes in Pandu bog was formed between 1997 and 2003. Since then, the once lake-like feature has been overgrown with vegetation.

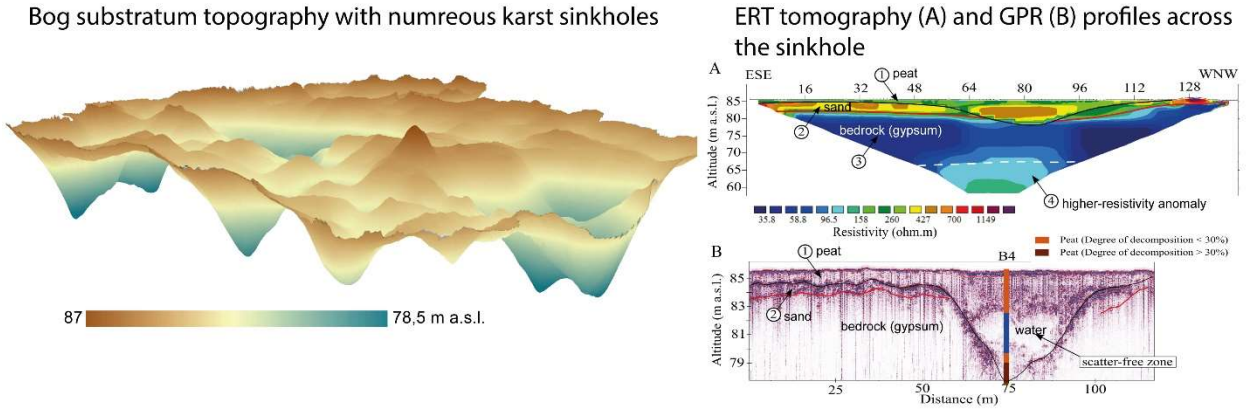

Figure 1. Bog Pandu substratum topography, ERT tomography and GPR profiles.

Our results demonstrate the widespread karst activity within the Pandu bog region and under the bog itself, which has not been previously known. We suggest a potential effect of karst activity under the bog on gypsum dissolution and sinkhole formation in the nearby proximity to the Pandu bog. However, additional hydrogeological investigations in the area would be needed to verify the hydrogeological conditions within the study area.

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Silakalni hilly massif: new data of genesis and geological structure

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Silakalni composite hilly massif is one of the morphologically most expressed landforms on the Eastern Kursa Upland in Western Latvia. Literature sources contain only general information about the genesis and structure of the hilly massif (Meirons, Straume, Juškevičs, 1976). According to the authors, the hilly massif morphogenetically corresponds to the mesoforms formed by the glacier, it is noted that it belongs to the marginal formations and the possible correspondence to the Gulbene deglaciation phase of the Weichselian glaciation. They also emphasize the main importance of intraglacial glacio-aquatic deposits - siltstones, clayey siltstones, sand, gravel and pebble layers in the structure.

In the geological literature, the Silakalni hilly massif is also known as the Zebrus composite hilly massif (Strautnieks, 1998, 1999) in which the morphological and fragmentary description of the geological structure is supplemented by outcrop drawings. The hilly massif has a triangular shape, one corner of which, like a wedge, is directed to the north-northeast (against the regional direction of glacial movement). The morphology of the hilly massif, the articulated relief and its geological structure show that it is morphologically similar to such marginal formations as the Talsi (Aklaisciems) massif in the Ziemeļkursa and the Jurģi hill in the Vidzeme Highland. However, the Silakalni (Zebrus) massif occupies a smaller area and is more compact, so it is very expressive. Its length is about 4 km, and its width reaches 3 km, thus its area is about 10 km^2.

The surface at the top of the hilly massif in its highest part and is generally uneven. It consists of an alternation of small and medium hills and depressions. The hills are mostly elongated, some oriented in the direction of the local ice flows, but there are also transverse and branched grid-like hills. The maximum height in its central part reaches 130-141 m above sea level (asl), while in the southern part, it varies from 110 to 125 m asl. In the west, east and north from the hilly massif are several kilometres long and wide glaciodepressions. The depression at the

west-southwester part includes about 4 km long and 2 km wide Lake Zebrus. The relative elevation of the Silakalni hilly massif varies from 30 to 60 m. In general, the hilly massif has significant surface fragmentation and morphological diversity of landforms. The alternation of narrow (50-150 m) elongated ridges and depressions oriented in the direction of glacial movement (northwest-southeast and north-south) can be observed in the northern and eastern parts of the hilly massif. The length of depressions and ridges is mostly 300-700 m.

In some places, in the depressions near the wall-shaped forms and in some places also on them, are hills that resemble erosional remnants with dome-shaped or conical tops. The amplitude of the heights of peaks and depressions reaches 15-40 m, while the angle of relatively steep slopes is often 20-30^{o}. The linear depressions, which morphologically resemble ancient ravines and walls between them, are not only erosion relief, but probably glaciogenic relief modified accordingly by the action of glacial melt waters. On the slopes of the edge of the massif, the overlying layer is clayey-sand till with pebbles and boulders. In outcrops, on different side slopes of the hill massif, scale-like thrusts of till layers can be observed, which reflect the movements of glacial flows and also the direction of the material moved by them. The slope of the hilly massif facing Lake Zebrus is step-like and is distinctly marked at several levels - 100-102, 107-110, 115-117, 120-123 m asl. level, of which each top-level ladder is older.

All step surfaces can be traced both as narrow (50-80 m) pseudo-terraces and also as 120-300 m wide bands of gently undulating till plains. The slopes between the steps are the slopes of the active ice contact, which were obviously formed during the deglaciation of the Weichselian glaciation, as the thickness of the glacier and its activity decreased, marking the contact of active and passive ice.

However, the main role in the composition of the hilly massif is coarse-grained and multi-grained sand, in some places also silty sand, gravel and pebbles. Boulders 0.5-1.5 m long are often found on the surface together with the dominant sandy material, which indicates the role of glacial melt waters in the transformation of the relief. Sandy and gravely (primarily glaciofluvial and glaciolacustrine) material forms the core of the massif and, in fact, the majority of the sedimentary volume.

The Silakalni hilly massif is important as a deposit of sand and gravel, therefore several sand-gravel quarries have been created in the area. Disjunctive dislocations, which are characteristic of glaciofluvial sediments, can be observed in the walls of gravel quarries, in various outcrop planes, especially in the core of the hilly massif, in its central, highest part, in the stratum of glacio-aquatic sediments, the thickness of which reaches 15-20 m. Observations of such a structure in the Silakalni massif were the basis for why earlier it was mistakenly considered to be a kame massif (Veinbergs, 1968). In the highest part of the Silakalni massif, there is no till at the top, but glaciofluvial sediments are exposed. In the walls of the quarry created there, 10-15 m thick, mainly sand is exposed with a bedding of 18-28^{o} and a dip azimuth to W-NW.

In the SE wall of the outcrop, a filled channel created by glaciofluvial processes is visible, the width of which is about 20 m. The channel was apparently eroded and filled with sand in the final stage of the formation of the hilly massif when the streams of glacial meltwaters eroded the still partially frozen glaciofluvial sediments. Accordingly, if there was a delta and a local melting water basin at that level, it means that the adjacent depressions, including the depression of Lake Zebrus, were filled by blocks of melted ice. The dismemberment of the proximal part of the hilly massif was apparently formed by the leakage of a local basin of glacial melt water.

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