Palaeolandscapes from Saalian to Weichselian

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South Eastern Lithuania

ABSTRACTS

International Field Symposium

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June 25–30, 2013,
VILNIUS–TRAKAI, LITHUANIA

Palaeolandscapes from Saalian to Weichselian, South Eastern Lithuania. **Abstracts** of International Field Symposium. June 25 – 30, 2013, Vilnius-Trakai, Lithuania

SYMPOSIUM PROGRAMME

June 25th	Introduction lecture. Jonas Satkūnas
June 26th	Paper and poster sessions
June 27th	Stops 1-8. Vilnius environs. Medininkai Heights, Eišiškės Plateau
June 28th	Stops 9-14. Environs of Aukštadvaris, Birštonas, Alytus
June 29th	Stops 15-18. South Lithuania: Merkinė, Zervynos
June 30th	Stop 19. The Neris Regional Park

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Layout and cover design: Ieva Serafinaitė

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THE DEAD-ICE LANDSCAPE OF THE VEIKI MORAINE PLATEAUX IN N SWEDEN

Helena Alexanderson[1], Þorbjörg Sigfusdottir[1], Martina Hättestrand[2], Clas Hättestrand[2], Leif V. Jakobsen[3]

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The early stages of the last ice age in Fennoscandia, the Weichselian, are not as well known as the later part. This concerns both timing and extent of glaciations, and climatic and environmental conditions during ice-free phases. Recent investigations of sites in central and northern Sweden and Finland suggest a very dynamic Fennoscandian ice sheet and at least partly warmer interstadials than previously believed, and they have also pointed to the relatively poor absolute chronology of events (e.g. Hättestrand 2008; Alexanderson et al. 2010; Helmens et al. 2012).

The Veiki moraines, which form a lobate belt in northern Sweden (Fig. 1B), are distinct geomorphological features that have been proposed to represent an ice-marginal zone from the Early or the Middle Weichselian (Lagerbäck 1988; Hättestrand 2008). The Veiki moraine plateaux themselves are currently believed to be ice-walled lake plains that formed in a dead-ice landscape and were overridden by later glaciations (Lagerbäck 1988). This suggests that they contain information on the extent and dynamics of at least two ice sheets – the one in which they formed, and the one(s) that later covered them. Some of the Veiki moraine plateaux also contain organic sediments, which can provide unique environmental information from interstadial periods. In an ongoing project we explore the potential of the Veiki moraines as ice-dynamic and environmental archives by looking in detail on their distribution, geomorphology, internal architecture, sediment composition and age. Our aim is to provide better spatial and temporal control on early-middle Weichselian glaciations in northern Fennoscandia and to improve our knowledge of interstadial environments.

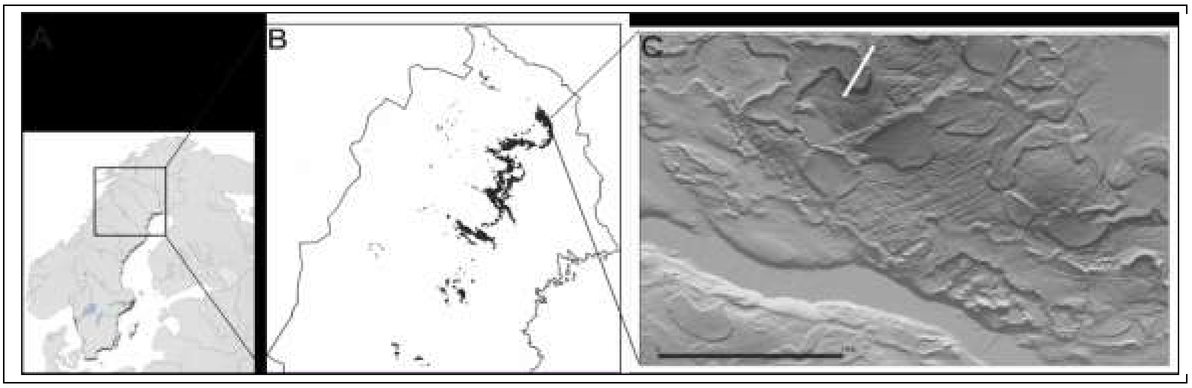

Fig. 1. The Veiki moraines in northern Sweden. The lobate distribution of Veiki moraines in northern Sweden is shown in B (from Hättestrand 1998). In C is a hillshaded view of the Veiki moraine plateaux in our study area at Rauvospakka. The white line represents the location of the GPR-profile shown in Fig. 2; the black scale bar is 1 km.

Mapping based on LiDAR data, recently made available as the New Swedish Elevation Model (GSD-Höjddata grid2+, Lantmäteriet), confirms the general shape and appearance of the Veiki moraine belt as previously determined (Hättestrand 1998; Fig. 1B), but reveals more details for individual landforms (Fig. 1C). For example, most plateaux have double rim-ridges, and some appear to drape moraine ridges at the eastern margin of the Veiki moraine belt.

We have also made ground-penetrating radar (GPR) investigations of selected plateaux to determine their internal structure, and their relation to underlying surfaces or landforms (Fig. 2), while trenches across the rims of two plateaux gave us further details of the sediments. In GPR profiles, the rim-ridges predominantly appear stratified (Fig. 2), and in the two excavated moraine plateaux we find that the rim-ridge sediments are thin beds of massive diamictons, with a few interbedded sorted beds. The central parts of the plateaux appear more massive or contain reflectors suggestive of basin infill. In one trench two organic-rich beds were found. They contained pieces of wood, preliminarily identified as *Betula* and *Alnus*, which have an infinite ^{14}C age. OSL ages are still pending. The lowermost beds in the outer trenches overlay weathered bedrock.

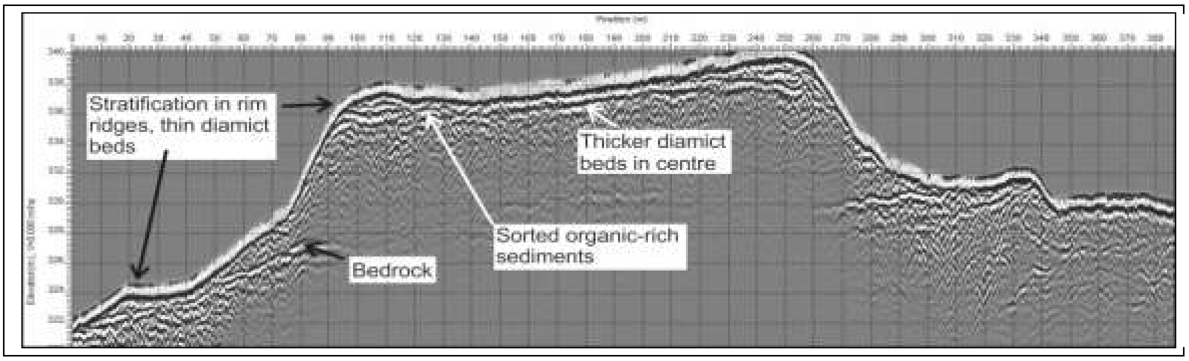

Fig. 2. GPR-profile across one Veiki moraine plateau at Rauvospakka, N Sweden; for location see Fig. 1C. Four trenches were excavated to support the GPR data with direct sediment observations.

In this presentation we will give our interpretation of the data, compare it to previous models of Veiki moraine formation and put our results into the context of the glacial history of northern Fennoscandia.

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UPPER NEOPLEISTOCENE LAKE SEDIMENTS IN THE NORTHEAST EUROPEAN RUSSIAN

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The Upper Neopleystotsene lacustrine sediments in the European northeast of Russia (Timan-Pechora-Vychegda region) are characterized by various granulometric composition. They are represented by silt, clay, loam, and small-and medium-grainesize sands, mainly dark-gray in color, with the vegetable remains, sometimes peaty. The thin horizontal bedding is typical for lacustrine formations.

The Sula (Mikulino) lacustrine sediments in the north of region (the Hongurey River) are of the finest grain size, with the average diameter (d_{av}) equal to 0.023 mm, and the degree of the material sorting S_c = 0.33. The Byzovaya (Leningrad) deposits in the northern part (outcrops of the Chyornaya River) have thin structure (d_{av} = 0.035 mm), S_c = 0.34, too. The Sula lacustrine sediments in the basin of the Shapkina River are composed of slightly coarser particles size (d_{av} = 0.027 mm), and they are better sorted: S_c = 0.47. The lake formation in the southern part of the Bolshezemelskaya tundra (the valleys of the Laya River and Bolschaya Rogovaya River) are presented predominantly by sands, where the average grain diameter is, respectively, equal to 0.147 and 0.107 mm and the sorting coefficient of 0.51 and 0.40. There is an inverse relation between the size of the material of lake sediments and their degree of sorting: sands and larger silts are sorted much better than clay, loam and fine silts in most of the coastal outcrops.

There are mineralogical data for the Byzovaya sediments (in the Chyornaya River) and the Sula lacustrine sediments (in the basins of the Shapkina, Laya and Bolschaya Rogovaya Rivers). The average content of heavy minerals range from 0.31% (in the basin of Chyornaya River) to 0.93% (in the valley of Bolschaya Rogovaya River). Epidote is the main mineral of the heavy fraction, it makes up from a quarter to half of the weight of heavy fraction; the contents of garnet and amphibole vary. In the basin of the Chyornaya River Byzovaya sediments contain abnormally high concentrations of siderite (in some samples up to 46.8%, averaging 20.2%). In the easern part of the region (the Bolschaya Rogovaya River) and in coastal outcrops of the Laya River lacustrine sediments enriched with leucoxenom, its average concentration reaches up to 18.4% in some sections.

The sediments of the paleolake basins in the most part of the study area are represented by silts and clays rhythmically interbedded. This may indicate that the lakes had running waters during long periods of time. Sand and gravel sediments are accumulated usually near the coasts because currents and waves in the lake waters are relatively weak. In the deep and distant areas of the lakes a course material is carried out only by turbidity currents, associated with underwater sediment slumping off the coasts and from the slopes of deltas, or floating ice.

In the southern part of the study area lacustrine sediments along with clastogene are presented by organogenic formations: sapropels and diatomites, both modern and buried. The thickness of sapropels in modern lakes is 7-8 m (for example, lake Donty in the upper Vychegda River). On the right coast of Mezen River 1 km downstream the village Melentyevo in the section of 7-8 meter terrace the packet of sapropel up to 1 m (sometimes a little more) lies on the pebble-gravel cross-bedded sediments and covered by two-meter thick layer of dense peat decomposed in various degree.

A regressive sequence of sediments in the section is characteristic for the lake sedimentation: a gradual transition from subaquatic clay and silt, which were deposited in the deepest part of the lake and the underlying lake cycle, to the coastal, more coarse sand and pebble-gravel sediments. The presence of numerous plant detritus in deposits can be the one of the indications for their lake genesis.

Pollen and spores, plant remains, diatoms, spicules of sponge and other organic materials are well preserved in lake sediments that allows to adequately reconstruct the history of vegetation and climate. Sediments from outcrops in the basins of the Chyornaya and Vychegda Rivers, which were described by palynological analysis, were attributed to Byzovaya period. These sections are the most complete among studied outcrops of Byzovaya age. As a result of the spore-pollen analysis the vegetation zones from Bz_I to Bz_{VII} were identified; they characterize warm and cool periods.

In general, the clear climatic optimum is not observed at the spore-pollen diagrams, because along with the presence of elm, linden, hazel and thermophilic spores of *Osmunda cinnamomea* L. role of periglacial floral elements (*Betula* sect. *Nanae*, *Selaginella selaginoides*) is also significant.

In the warm periods the dark coniferous forests were developed. Among the wood forms the pollen of birch *Betula* sect. *Albae* were of most importance, and they prevailed in the north of the region. The part of conifer *Pinus sylvestris* and *Piceae* sp. was great and the proportion of spruce increased in the northeast. Single pollen grains of broadleaf trees: elm, linden, hornbeam, hazel and alder were noticed in the spectra of the southern sections. The pollen grains of the broadleaf trees: elm, linden, hornbeam, hazel and alder are in the pollen spectra from the southern sections. The elements of boreal flora, swamp and grassland vegetation and the elements of xerophytic flora were present. Climatic conditions of warm periods were similar to present.

There were treeless landscapes during periods of cold climate. In the north of the region the part of wood forms reduced greatly: they were naerly absent, or presented in small quantities. Thus, sparse forest communities with birch and pine with little participation of spruce and a variety of shrubs *Betula nana, Salix* were apparently the major component of the vegetation cover; spores of *Selaginella selaginoides* were always present. In the assemblages of this time, the participation of xerophytic pollen (*Artemisia* sp., species of the family Chenopodiaceae) was significant along with the pollen of tundra and forest-tundra species. Climatic conditions were cold and dry in this time.

Modern lacustrine sediments of Donty Lake were characterized by spore-pollen and diatom methods . Based on these results it can be concluded that sediments were formed in a freshwater bogged water reservoir. Diatom assemblages were dated to Middle Holocene (At + Sb). Palynological spectra show that spruce forests with pine, birch and admixed broad-leaved trees: elm, linden, hazel were widespread in this time in the area. In the diatom assemblages the species of class Pennatophyceae: *Navicula, Eunotia, Pinnularia, Fragilaria* and *Gomphonema* are the most diverse. *Fragilaria construens, F. construens* var. *venter, F. construens* var. *binodis, F. brevistriata, F. virescens* and *F. pinnata* and planktonic species *Aulacoseira italica* are the most common. The benthic forms (species of the genera *Fragilaria, Epithemia, Opephora, Gomphonema, Pinnularia* are abundant) are the main share. The dominant part, and a whole assemblage, consists of species that are characteristic for modern freshwater reservoirs.

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IN SEARCH FOR FINGERPRINTS OF A POSSIBLE ET IMPACT: HR-ICP-MS STUDY OF LATE PLEISTOCENE LAKE SEDIMENTS OF LITHUANIA

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Climate oscillation in the Northern Hemisphere (the Younger Dryas; YD) which occurred between ca. 12.9K cal yr BP and ca. 11.7K cal yr BP (Peteet, 1995; Alley, 2000; Björck, 2007; Lowe et al., 2008; Murton et al., 2010) is connected predominantly to a sharp decrease of thermohaline circulation in the Atlantic Ocean triggered by a sudden fresh-water release to the North Atlantic (Murton et al., 2010; Teller et al., 2002; McManus et al., 2004). Recently, a team of scientists proposed a new hypothesis relating the YD cooling to an extraterrestrial (ET) body impact (Firestone et al., 2007). This hypothesis suggested that just before the onset of the YD cooling (ca. 12.9K cal yr BP), a large bolide exploded over the N. American Laurentide Ice Sheet, and the consequences of such a catastrophic event ("meteorite impact winter") led to the abrupt and significant climate alteration.

In Europe, studies of the YD impact hypothesis are limited. However, some findings could be in favor of the ET hypothesis. Those include the presence of an Ir anomaly in the Bodmin Moor sediments from the LYDB in SW England (Marshall et al., 2011), the discovery of non-radiogenic possibly ET-related $^{187}Os/^{188}Os$ ratios in a sedimentary layer dated 12,893±75 cal yr BP in the S. Netherlands (Beets et al., 2008), and the presence of geochemical markers related to the ET impact in the Late-Glacial lake sediments of NW Russia (Andronikov et al., 2012). Nanodiamonds found in the Usselo Horizon of Belgium and the Netherlands (Tian et al., 2010; van Hoesel et al., 2012) are controversial in terms of their ET origin, and the authors of these papers consider them to be of terrestrial origin, but they are still nanodiamonds and are identified along the LYDB.

When a large ET object hits the Earth, small particles resulted from the impact (both from the impactor and from the targeted material) can travel in the atmosphere for thousands of kilometers before they finally get deposited (Bunch et al., 2008; Artemieva and Morgan, 2011). If the impact occurred over N. America, the dominating west winds (Isarin and Renssen, 1999; Brauer et al., 2008) could have delivered the impact-related microparticles as far east as Europe. Lithuania could be an important place in determining the eastern boundary of the Late Pleistocene ET material occurrence. We are applying here geochemical analyses of sediments across four Late-Glacial lake sequences from Lithuania in order to decipher the trace element distribution. This way, the presence of anomalous (in particular, ET-related) components in the sediments can be detected.

Concentrations of trace elements in Late-Glacial lakes sediments from four sites in Lithuania were studied using HR-ICP-MS (Fig. 1). Most studied sequences are lithologically inhomogeneous and are characterized by uneven distribution of trace elements across the sequences. In some cases the changes in geochemical characteristics are due to changes in lithology and conditions of sediment deposition. However, a few features are not consistent with a sheer lithology change and require other explanations. We were able, with a high level of confidence, to reveal in all four studied sedimentary sequences geochemical fingerprints of the ET event, which occurred at ca. 11.7K cal yr BP. Since there are no known meteorite craters of this age in the region, this event was pronounced, most likely, as an aerial explosion (unless the impact occurred to the continental Ice Sheet). Elevated concentrations of Ni, Cr and somewhat PGE in sediments of this age could be used as a geochemical stratigraphic marker. The presence of possible ET material was also detected for the Ula-2 sequence at the stratigraphic level corresponding to the age of ca. 13.0K cal yr BP, on the basis of sharply increasing concentrations of Ni, Cr, and elevated concentrations of the PGE.

Fig. 1. A map showing the location of the studied sedimentary sequences in Lithuania (black asterisks). De, Dengtiltis outcrop; Lop2, Lopaičiai-2 drilling site; Kr, Krokšlys outcrop; Ul2, Ula-2 outcrop.

In addition to the presence of the ET material in the studied sediments, such geochemical features as elevated concentrations of the REE, Zr and Hf (i.e., the elements abundant in products of the volcanic eruptions) of the sediments from the Ula-2 site allowed us to suggest a presence of volcanic material likely related to the eruption of the Laacher See volcano (12,880 cal yr BP; Brauer et al., 1999).

A proposed scheme (Fig.2) of the distribution of the ET-related material over the Northern Hemisphere suggests that the consequences of the Late Pleistocene impact/explosion would strongly affect North America, but the rest of the world would be affected by much smaller extent.

The applied geochemical methodology, if confirmed by further research on additional sequences, could potentially be used as a tool for correlation between different Late-Glacial records in order to obtain better chronologies for a period during which radiocarbon dating still contains uncertainties.

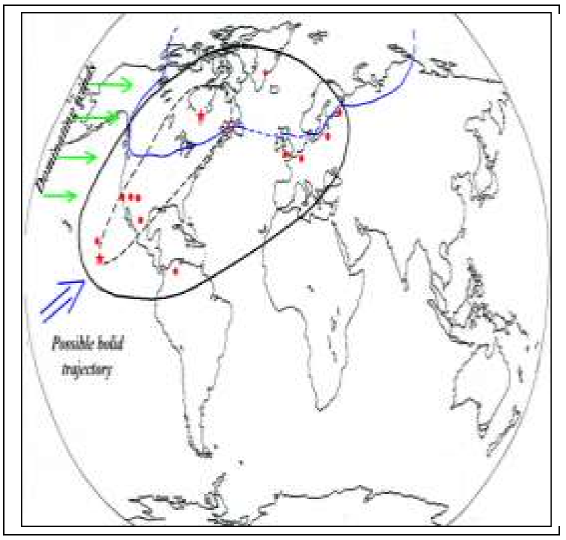

Fig. 2. Distribution of fingerprints (red dots) of the suggested Late Pleistocene ET event (using Firestone et al., 2007; Beets et al., 2008; Kennett et al., 2009; Sharma et al., 2009; Kurbatov et al., 2010; Mahaney et al., 2010; Tian et al., 2010; Higgins et al., 2011; Marshall et al., 2011; Andronikov et al., 2012; Fayek et al., 2012; Israde-Alcántara et al., 2012, and the present study). Red stars, two possible areas of the main impact(s). Outline of the continental Ice Sheet in the Northern Hemisphere (a thin blue line) at the time of the possible ET event is after Thomson (1995) and Svendsen et al. (2004). A possible area of a meteorite strewn field is outlined by a dashed black line.

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POSTGLACIAL PLEISTOCENE ENVIRONMENTS OF THE RUSSIAN NORTH AS COUNTERPARTS OF THE EUROPEAN PERIGLACIATION

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The last glaciation of the Eurasian mainland east of the White Sea terminated 50-60 ka BP (Svendsen et al., 2004). Then followed the pre-Holocene history of the Russian North some 40-50 ka long which has been disputed during several decades. Those believing in validity of \`old finite\` (~35-50 ka BP) conventional radiocarbon dates often describe non-glacial Weichselian formations as mostly marine, lacustrine and fluvial sediments lain in relatively deep water bodies at temperate climates. Lately hundreds of new AMS and luminescence ages of the same order have been obtained from postglacial formations deposited in harsh continental conditions thus falsifying the finite conventional ^{14}C dates from the interglacial waterlain sediments as too young (Mangerud et al., 2002; Astakhov, Nazarov, 2010).

The sedimentary complex related by modern geochronometry to the postglacial Pleistocene is distinctly different from subtill formations of the \`Mid-Valdaian megainterstadial\` or Karginsky interglacial. In northeastern European Russia waterlain facies with reliable finite radiocarbon dates occur but locally as alluvium of two riverine terraces or limnic muds in glacially scoured depressions. The volumetrically dominant mass of the postglacial sediments is represented by subaerial formations of dune sands, niveo-aeolian coversands, loess-like silts, soliflucted diamicts, slopewash, coarse sands left by ephemeral creeks, fine sands and peaty silts deposited by shallow thermokarst ponds. This basically fine-grained complex draping all topographic elements, except floodplains and lacustrine hollows, was deposited in subaerial environments outside of permanent water bodies (Astakhov, Svendsen, 2011). Sedimentologically it is very similar to cover formations of the Weichselian periglacial zone of western Europe deposited in treeless permafrost environments with meager water supply. The closest analogues are in the Russian European Arctic where coversands similar to the European niveo-aeolian formation (Koster, 1988) have lately been described. Such distinct periglacial features as the concentric belts of aeolian sands and loess sheets are readily traceable from Poland across central Russia to the European Arctic (Velichko et al., 2006; Astakhov, Svendsen, 2011) and beyond the Urals.

The all-pervading processes within the subaerial sedimentary system are weathering, wind action and frost-cracking with ice wedges increasing in size and number eastwards. In East Siberia ice wedges, which cannot grow under water, often volumetrically exceed the silty matrix of the Yedoma Formation, also called the \`Ice Complex\`. The geocryologists have traditionally believed in alluvial origin of the Yedoma silts, even for the Late Weichselian time span (e.g. Schirrmeister et al., 2008) although the draping occurrence, grain size, mineralogical composition and organic remains are decidedly in favour of subaerial genesis. Especially important is wind transportation which is felt in all periglacial environments. E.g. the arctic Yedoma silts contain many fragments of volcanic rocks, including ash, which are totally alien to local provenances and can only be explained by long-distance aerial transportation (Tomirdiaro and Chornyenky, 1982). The basically aeolian source of the Yedoma silts was also acknowledged by Péwé and Journaux (1983) who compared them with the Alaskan loess.

The extreme continental environments of periglacial type, inferred for the arctic postglacial Weichselian in the final QUEEN report, were strongly supported by multiproxy data from the Taimyr Peninsula and Lena delta implying not only low precipitation levels but also warmer than present summers concurrent with very cold winters (Hubberten et al., 2004). The ubiquitous presence of xeric tundra-steppe species with a small share of hydrophiles is recorded by different proxies: pollen spectra (Andreev, Tarasov, 2007), plant macrofossils, fossil insects and testate amoebae (Sher et al., 2005). Numerous mammoth carcasses with ^{14}C dates from >53 to 10 ka BP provide a good signature of habitats with very cold winters, dry soils and tall grass. Important evidence of principally subaerial conditions is presented by cryoxeric paleosols in the East Siberian Yedoma. During the interstadials the paleosols formed in semi-arid conditions although with a reduced influx of aeolian dust and wind-blown plant detritus (Gubin et al., 2008).

More humid Weichselian episodes deduced from aqueous processes and mesic plant communities are noticeable only for the interstadial dated to 50–24 ka BP and for the final Weichselian since 15 ka BP. During these interstadials, marked by fluvial activity, abundant megafauna and Palaeolithic artifacts, treeless permafrost environments still persisted. The bulk of the sedimentary mantle was formed in the time span of 24 to 15 ka BP within frozen steppe with reduced biota in Siberia and in almost sterile polar semi-desert leeward of the Barents Ice Sheet (Astakhov, Svendsen, 2011). The extra-dry landscapes of northeastern Europe beyond the Urals were replaced by more hospitable tundra-steppe, providing plentiful forage of frozen grasses and herbs even for Late Weichselian mammoths. In the East Siberian Arctic `the LGM environment was just an impoverished variant of the MIS 3 tundra-steppe` (Sher et al., 2005, p. 564). Appreciable fluctuations of post-glacial climates are recorded only west of the Urals.

The new paleoenvironmental results point out to predominantly subaerial sedimentation at low sea level. The multitude of radiocarbon dates confidently correlates the arctic postglacial Pleistocene with the Middle and Late Pleniglacial of north-western Europe (50–13 ka BP) which was also dominated by subaerial processes and growing permafrost without major temperate events. However, in western Europe the periglacial cover did not contain that much ice as the Siberian Yedoma and the stadial/interstadial climatic contrast was larger. The Pleniglacial environments were generally milder: the January-July temperature difference was 28-33°C (Huijzer, Vandenberghe, 1998) against 55-60°C on the Laptev Sea shores (Sher et al., 2005). Precipitation and waterlain facies were more plentiful in western Europe. The ubiquitous mammoth fauna is the common denominator for all periglacial Eurasia. Thus, non-glacial Weichselian environments of Europe and East Siberia are just opposite end members of the same periglacial system.

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SOUTH-EASTERN BALTIC SEA REGION DURING THE LAST GLACIAL CYCLE: FROM LATE SAALIAN UNTIL LATE WEICHSELIAN

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The presented results of researches cover the Lithuanian part of the south-eastern Baltic Sea Region, or so-called Lithuanian Maritime Region (LMR). The stratigraphy of Quaternary thickness is still an unsolved issue of the LMR. The absence of key sections with reliably detected interglacial sediments is one of the reasons of the mentioned problem. Thus, the complex of inter-till sediments widespread in this region is playing an extremely important role for stratigraphic subdivision and correlation of sediments of the whole Quaternary thickness. From the second half of the XIX century the mentioned inter-till complex was known as Purmaliai-Gvildžiai sediments (Kondratienė, 1967). In the last decade of the XX century, during the geological mapping of the LMR at a scale of 1:50 000, the mentioned Purmaliai-Gvildžiai sediments were detected in more that 150 boreholes. The dating by method of optically stimulated luminescence (OSL) along with traditional palinological and diatom analyses has been used for solving the stratigraphical problems. After the geological mapping, the Purmaliai-Gvildžiai inter-till sediments were renamed as sediments of Pamarys Sub-formation (Satkūnas *et al.,* 2007).

The resent investigations show that the mentioned Pamarys Sub-formation sediments were formed during a few cycles of sedimentation, starting from Late Saalian and ending Late Weichselian. The lowermost part of Pamarys sediments were formed about 160-140 kyr ago. The results of pollen analysis show that the interstadial conditions prevailed during the sedimentation processes. Due to these circumstances, the lowermost part of the Pamarys sediments could be correlated with Zeifeny interstadial sediments. Probably the conditions at the final stage of Saalian glaciation in the LMR were "Younger Drias-style" (Seidenkrantz, 1993), i.e. palaeoclimatic conditions could be comparable with Zifen-Kattegat climatic oscillation (Seidenkrantz *et al.*, 2000). Later, when the Saalian ice sheet completely melted in the Baltic Sea depression and the mentioned basin was drainaged, the LMR was uplifted due to intensive glacioisostatic rebound. As a result, this region was not submerged during the Eemian Sea transgression.

The results of OSL dating maintain that sedimentation in the LMR was renewed about 118-119 kyr BP, i.e. at the very beginning of Early Weichselian. This fact could be explained only by a new glacial advance that occupied the Baltic Sea depression. In the LMR the freshwater basin was damped again, but at the higher level than the Eemian Sea. There were at least two similar cycles of sedimentation-drainage linked with glacier margin fluctuation in the Baltic Sea depression during the Early Weichselian.

The recent researches in the Šventoji harbor (northern part of the LMR) supported with a new series of the infra-red optically stimulated luminescence (IR-OSL) dating revealed that the 2.3-5.5 meters-thick till stratum covers a complex of sediments of the Pamarys Sub-formation. Beneath the mentioned till layer the age of sandy sediments varies from 113.1±8.5 to 83.6±6.7 kyr BP, whereas above – from 48.8±6.2 to 43.7±4.0 kyr BP. According to these data, the mentioned till layer could be formed most probably during MIS 4. The both sand layers beneath and above the mentioned till are not rich in diatoms, but findings of such species as *Hyalodiscus scoticus* (Kutz.) Grun., *Rhabdonema arcuatum* (Lyngb. In Horn.) Kutz., *Rhabdonema minutum* Kutz., *Cocconeis scutellum* Ehr., *Actinocyclus octonarius* Ehr. maintain that they could be formed in marine conditions, or re-deposited from the Eemian marine sediments – the latter version is more likely. The discovered new till stratum could be correlative with Świecie stadial in Poland (Marks, 1998) and Talsi stage in Latvia (Zelčs, Markots, 2004).

The results of geological investigations of the last decade carried out in the Klaipeda Strait and the adjacent onshore show that the complex of inter-till sediments exist in this area as well. According to IR-OSL dating results, these sediments were formed 113.2 ± 7.3 – 76.5 ± 4.9 kyr ago, i.e. fell within the age range of MIS 5d-5a (Early Weichselian). The composition of diatoms and the remnants of mollusc fauna indicated that these sediments were formed in a freshwater basin. The mentioned inter-till sediments are found not *in situ*: they are lying as blocks (rafts) within the till. Thus, the results of the presented investigations have led to the assumption that the Western Lithuania was covered by continental ice sheet during MIS 4 (Molodkov *et al.,* 2010, Bitinas *et al.,* 2011).

The both till layers in the Šventoji harbor and Klaipėda Strait could be of the same age and are linked with the ice advance that started during MIS 4 and, probably, continued during the beginning of MIS 3. In general this assumption is in a good correlation with the standpoint of some researchers stating that during MIS 4 the glacier occupied a significant part of the Baltic Sea depression (Svendsen *et al.* 2004).

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MAGNETOSTRATIGRAPHY OF LATE CENOZOIC SEDIMENT COMPLEX IN THE EASTERN LITHUANIA

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The complex of stratified sand, silt and clay sediments that occur between the Devonian rocks and the Pleistocene glacial deposits are widely distributed in Eastern Lithuania. Based on various lines of evidence (palaeobotany, lithology, sedimetology, palaeomagnetism, etc.), assembled by different investigators, these sediments have been interpreted as having been formed in a few sedimentary basins – ranging in age from Oligocene (Kondratienė, 1971) and to Middle Pleistocene (Baltrūnas *et al.,* 2013). The precise determination of the Neogene/Quaternary boundary by palaeobotanical evidence is problematic as a consequence of the poor pollen content of the sediments (Kondratienė, 1971). In recent stratigraphical schemes of the Lithuanian Quaternary, the sediment complex is subdivided into two parts, the lower to the Anykščiai Formation of Upper Pliocene age and the upper to the Daumantai Formation dating to the Early Pleistocene (Satkūnas 1998; Guobytė, Satkūnas, 2011). This chronostratigraphical position has yet to be confirmed by geochronologicaly evidence.

A new series of palaeomagnetic investigations of the sediment complex was carried out during 2011-2013. Four sections in the Eastern Lithuania were examined for this study: Šlavė-1, Vetygala, Gyliai and Daumantai-1 (Fig. 1). At the last section only the lowermost part was analysed – the uppermost part having been studied previously by Baltrūnas *et al.* (2013). The results of these palaeomagnetic investigations displayed a complex alteration of intervals of normal and reversal polarity which could be characteristic of either the Matuyama or Gauss chrons. Thus, there are some doubts concerning previous opinions whether the Brunhes/Matuyama boundary indeed occurs in the Daumantai-1, Daumantai-3 and Šlavė-1 sections (Damusyte *et al.,* 2012; Baltrūnas *et al.,* 2013). Further examination of the distribution of chemically weathered quartz grains, as well as the estimation of the carbonate content and its composition in the investigated sediment complex could hold a key to the resolution of the sedimenthological and stratigraphical problems.

The measurements of the anisotropy of magnetic susceptibility (AMS) in the sections investigated indicate that the general current directions of the water in all the existing sedimentary basins, despite their differing age, are generally orientated from West to East. The anomalies of magnetic anisotropy in the uppermost part of the Vetygala section can be attributed by post-depositional glaciotectonic deformation (by rotation of a frozen megablock) of the sediments during the one of the subsequent Pleistocene glaciations.

The results of these multidisciplinary investigations, i.e. the combination of the results of the palaeomagnetic investigations with those of palaeobotanical and lithological studies, potentially offers an essential background for the revision of the stratigraphic scheme of Lithuania and surrounding regions, and also for the correction of the pre-Quaternary geological map of Lithuania.

The palaeomagnetic investigations presented were undertaken using a kappabridge MFK-1B, magnetometer JR-6, AF molspin demagnetiser and an ESM QUANTA 250 at the Nature Research Centre of Lithuania.

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DEVELOPMENT OF FLUVIO-LACUSTRINE SYSTEMS IN THE YOUNG GLACIAL AREA IN POLAND

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Most research on fluvial geomorphology is conducted in river valleys located in extraglacial areas in relation to the last glaciation. The river valleys there have a long fluvial history, in the course of which they have achieved the mature stage of their development. Contemporary changes in the fluvial processes in these valleys result from general climatic and vegetal transformations as well as the increasing human impact

The development of river valleys in young glacial areas started only after the Upper Vistulian ice sheet retreated. This did not leave enough time for a full development of valley landforms and, in most cases, the course of fluvial processes was conditioned by the primary morphogenesis of the depressions included by rivers into their fluvial systems.

The studied river valleys of the Wierzyca with the Wietcisa and the valley of the Wda are typical examples of morphologically diverse fluvial forms in the young glacial areas in Poland (Błaszkiewicz 1998, 2005). The Wierzyca Valley is located directly behind the maximum range of the Pomeranian Phase, predominantly amongst morainic plains, while the Wda Valley is located in front of this maximum range within the East Pomeranian outwash plains. Despite differences in both the geomorphological settings and their relation to the maximum range of the deglaciation in East Pomerania, morphogenetically the valleys are very similar. The developing rivers in that area included into their systems a number of genetically diverse depressions, predominantly various systems of subglacial channels. The valley sections between them, mainly of the gap type, beside a narrow floodplain also include two or three erosive terraces.

The course of fluvial systems in the inherited sections was tightly connected with the melting of the buried dead ice blocks and the development of lakes which became local erosion bases in river valleys. They also trapped sediments transported by the river and this way intensified erosion in the gap sections of river valleys. Delta fans which entered lakes became the basis for further development of fluvial processes. In this way in the inherited sections wide meander belts developed, within which rivers had been freely meandering until they were regulated. Some delta forms, especially those which entered bottom deposits of deep lakes, were of the Gilbert type (Gilbert 1890, after Chudzikiewicz et al., 1979). Other deltas, especially those developing in the Late Glacial were fan deltas (Nemec, Steel 1988). A very interesting example of the Late Glacial delta fan which enters bottom deposits of a developing lake was recorded at the contact of the River Wda with the Wieck subglacial channel (Błaszkiewicz 2005).

Diversity of melting processes and, consequently, the asynchrony of the lake development resulted in significant course changes of the river valleys. A good example here is the central section of the Wda valley where in the vicinity of Szlaga a dry unused section of the asymmetric meander valley of about 3 km is recorded. Fluvial structures are clearly visible within this meander. They include an erosive-accumulative meadow terrace and an old floodplain with abandoned channels filled up with biogenic deposits. The results of the research indicate that this form was active during the entire Late Glacial and that it was abandoned by the Wda River possibly at the turn of Younger Dryas and pre-Boreal. The recent river in this area flows within the subglacial channel. The change in the course of the Wda River was connected with the course of the melting processes in subglacial channels, which is indicated by the deposits there: pre-Boreal basal peat covered with the lacustrine and fluvial deposits at the significant depths of up to 20 m below the modern floodplain.

Analysis of the relationships between the lacustrine and fluvial deposits makes it possible to date both Late Glacial and Early Holocene development tendencies in the erosive sections of the river valleys. At that time accumulation dominated in the inherited sections (deltas' growth, the input of material from the shore platforms and primary production of sediments in the lakes) and erosion was limited to small bank undercuttings and gaps creation. At the gap sections in the river valleys, however, erosive processes, mainly downcutting, dominated. In practice, only Younger Dryas was the period of time when the tendency to deepen the river channels slowed down in favour of lateral erosion. At this time the lowest meadow terrace developed in the studied river valleys. The turn of the Younger Dryas and Early Holocene was the last period of time when large changes in the course of the river valleys took place. Simultaneously, after a short episode of deep erosion, erosive-accumulative processes in their bottoms stabilised significantly giving way to lateral migration of the river channels widening the floodplain.

During the Later Glacial phase of the river downcutting, in the valleys in question single river channels of low but growing sinuosity existed (development of slide meanders) in the Wierzyca River valley and, to some point, in the Wda River valley). Constant widening of the floodplain due to lateral erosion, which took place in Holocene, led to the development of a large number of erosive sections of the so-called constrained meandering. The main factor which would limit lateral development of the river along this section was narrowness of the floodplain in relation to the river discharge.

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FIRST CONCEPTION OF COOPERATIVE PROJECT ABOUT BIOSTRATIGRAPHICAL INVESTIGATIONS AND U/TH DATINGS OF EEMIAN INTERGLACIAL DEPOSITS IN MECKLENBURG-WESTERN POMERANIA (NE-GERMANY)

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For the beginning of the Eemian Stage in Europe, the date of 127.2 kyrs from the varved-dated record of Monticchio in Italy (Brauer et al. 2007) can be taken as the best estimate of age (Litt & Gibbard 2008). The warmest stage of the early Eemian falls at about 125-120 kyrs. according to van Andel & Tzedakis (1996).

In the gravel pit Neubrandenburg-Hinterste Mühle (cf. fig. 1) the limnic and telmatic sediments of Eemian interglacial were investigated by Rühberg et al. (1998) and Strahl (2000) at first. At this location were observed several isolated horizons, predominantly peats and lake marls between two tills. The first pollenanalytical investigation shows here a complete late Saalian sequence above a Saalian till. The sequence starts with fine- and medium-grained glaciofluvial and glaciolacustrine sands directly on top of upper saalian till (Warthanian, qs2). The development of a local lake basin was most probably due to dead ice. The Pollen analytical investigation shows a beginning of limnic conditions at the end of the late Saalian. This late Saalian sequence could be subddivided into the Saalian A to C after Menke & Tynni (1984). Within the depression, a short phase of mire formation (peat and peaty mud) was followed by accumulation of silty mud. Fully limnic conditions were probably attained at this site at the end of the late Saalian and in the early Eemian (PZ I after Menke & Tynni 1984). At the beginning of this interglacial, the vegetation was dominated by sparse birch forests. On account of the relatively rapid temperature increase at the transition to the Eemian Interglacial, the final meltwing down of dead ice was probably soon completed. Eemian peat accumulation began in the second half of the pine-rich phase (PZ II). In spite of the progressive alluviation of the lake, areas of open water (mire pools) still remained - they permitted the spread of submerged and floating water plants. The end of the interglacial and transition into the Early Weichselian cannot be clearly identified. However, the abrupt change in the flora shown by the truncation of the top part of the succession and the locally rebedding of older peat lenses on the top of the Eemian peat representing a hiatus, which spanned a period from late Eemian to the Late Weichselian glaciation.

A new evidence of interglacial peat (Eemian?) was found 2011 in a short-time outcrop of NEL pipeline trench near Banzin (cf. fig. 1). The profile is situated in a shallow kettle hole in Saalian morainic uplands. A maximum 0.5 m thick lower peat layer is covered by a redeposited diamict of low gravely loams, with sand lenses and layers and boulders, which representing periglacial reworked parts of sourrounding till morainic hills. The lower peat layer was strongly compressed by overlying deposits. Due to the geological position in top of Saalian deposits we assume an Eemian age for the peat and a Weichselian age for overlying redeposited diamict. In the centre of Saalian kettle hole the whole sequence is covered by 1 m of Holocene peat which demonstrating the calk of "older" structures at recent surface.

The cooperative project of new biostratigraphical investigations and U/Th datings provide upgrading knowledge about the development and timing of Eemian interglacial in Northeast Germany.

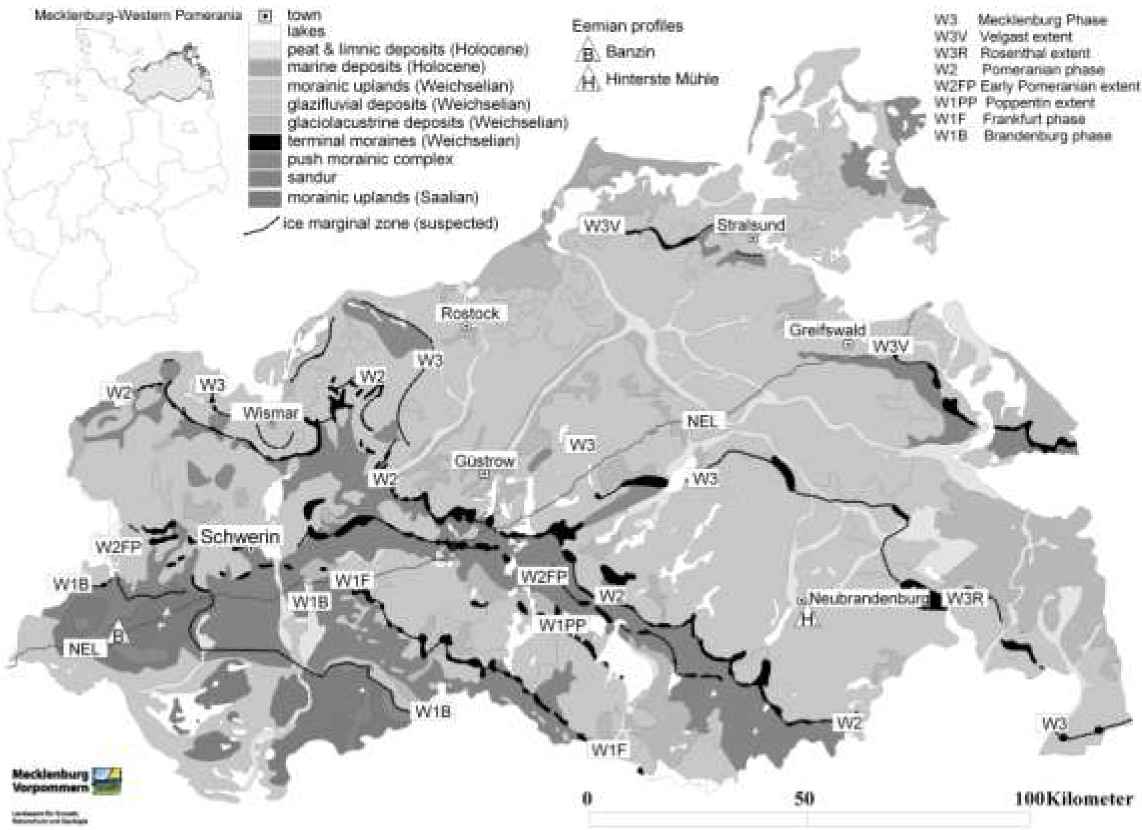

Fig.1: General geological map of Mecklenburg-Western Pomerania with location of investigated Eemian profiles

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GEOLOGICAL SURVEY OF THE HONDSRUG MEGAFLUTE, DRENTHE, THE NETHERLANDS: THE BASE OF A UNIQUE NEW EUROPEAN GEOPARK

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Ice streams always reflects an unbalance between accumulation and ablation in ice sheets and along ice sheet margins they are highly variable and dynamic in space and time. Present-day and Last Glacial examples of ice streams demonstrate a behaviour of switching on and off; acceleration and deceleration, migration and change of direction. The situation at the ice margin provides a main control on the mass (in)balance of the ice stream, for example where melting or calving occurs in ice lakes, seas and oceans. Knowledge on controlling factors and process dynamics of present day ice streams has much grown. For paleo-ice-streams, however less studies truly assess process-relations, especially in NW Europe. We have focussed on the Hondsrug –Hümmling Ice Stream of Saalian age (Drenthe Substage, within MIS 6) in NE Netherlands and NW Germany, glaciated in the penultimate glacial, but not in the last glacial. The best expression is a 70 km long mega flute complex landform, known as 'Hondsrug' (e.g. Rappol, 1984; Van den Berg & Beets, 1987). Because of its unique genesis and preservation, the Province of Drenthe has nominated the Hondsrug to apply to be a European - GEOPARK.

We have importantly updated the reconstruction of phases of the glaciation for the wider region and have collected new data on the paleo-ice stream using road-cut outcrops, boreholes, seismics and ground penetrating radar and "new" till-characterisation techniques (XRPD analyses of clay minerals).

Results are discussed and related to Winsborrow et al. (2010) hierarchy of controls of ice streams. We have strong reasons that ice streams of the terrestrial ice margins of the former Scandinavian ice sheets of the North Sea, German, Polish and Baltic area are controlled in a different way than e.g. Antarctic actuo- and North American palaeo-examples. The ice-streams appear regional initial deglaciation phenomena, affected by substrate and ice-margin control primarily, rather than larger scale expanding ice-cap phenoma. This conclusion opens new approach in understanding the scales and dynamics of ice streaming at the tipping point of maximum glaciation to initial deglaciation, and input for further research between the North Sea and the Baltic.

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THE MORPHOLOGY, INTERNAL STRUCTURE AND DEVELOPMENT OF INLAND DUNES AT NORTH VIDZEME, LATVIA

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Dune formations at North Vidzeme is related with Trapene, Seda and Burtnieku plains, where thick layer of sandy glaciolacustrine sediments were exposed to re-deposition by wind after drainage of ice-dammed lakes between Gulbene and Valdemarpils deglaciation phases (Zelčs et al. 2011).

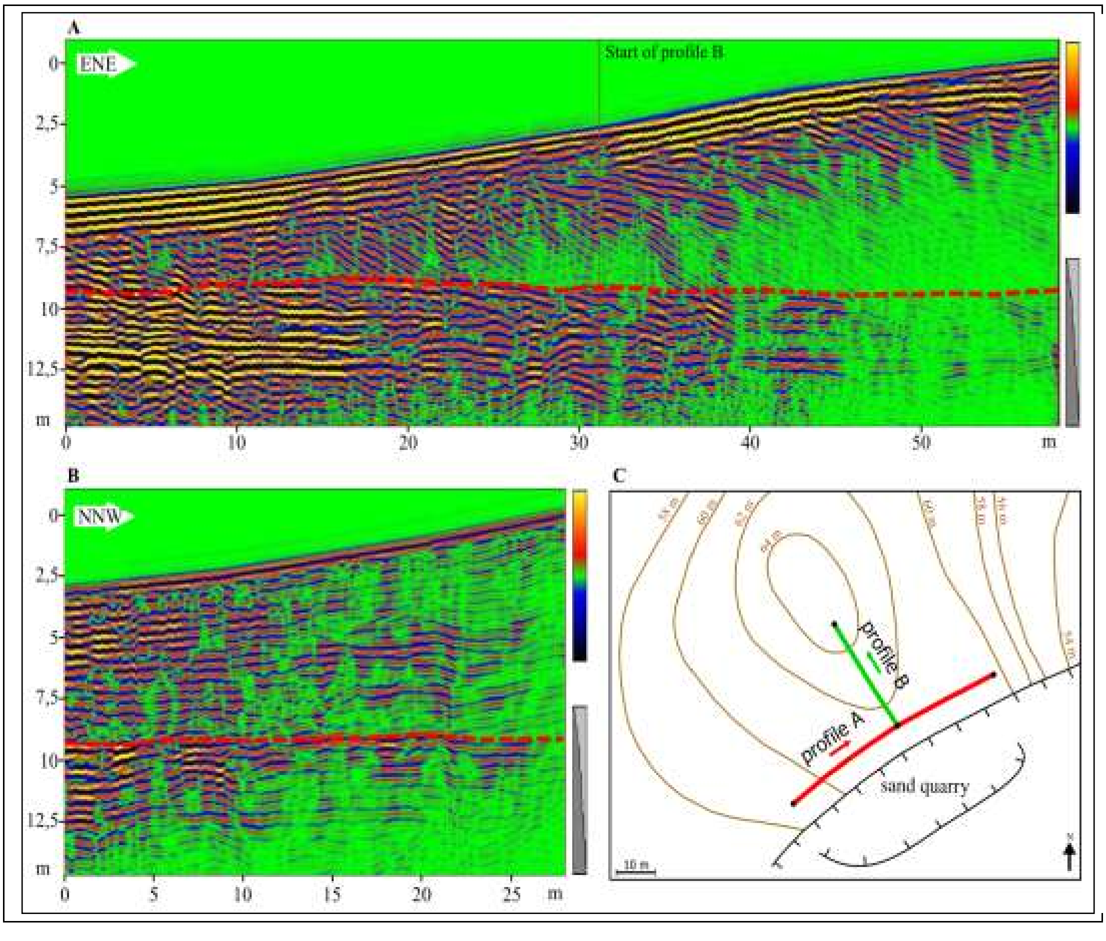

Fig. 1. Radargram from study site Silezers with typical cross-bedding of lee side and sub-horizontal bedding at base of the dune (A), perpendicular profile (B) and schematic plan of location of ground penetrating radar profiles (C).

Various study methods including geographic information systems, ground-penetrating radar and optically stimulated luminescence dating were used during this research.

Dunes spatial arrangement and morphological measurements were made in GIS environment using 1:10,000 scale topographic maps.

Single dunes are rare, most of dunes concentrate in bigger dune complexes. These dune complexes occupies the most part of the Seda plain, while in Burtnieku and Trapene plane only central part of these plains.

Distribution of inland dunes is possible to correlate with area of sandy glaciolacustrine sediments, in areas with clay or silt sediments dunes are rare (Juškevičs, 2002). Concentration of the dunes can reach up to 42 relief units per square km in the north-eastern part of the Seda plain. Absolute heights of the inland dunes vary from 42 m in Burtnieki plain to 136 m a.s.l. in Trapene plain. Relative heights can reach up to 23 m, but on average dunes are 4 m high. Dune patterns mostly apply for simple parabolic dune in Burtnieki plain and compound or comb parabolic dunes in Seda and Trapene plains. It is possible to distinguish varieties in dune patterns between different dune complexes.

Extend and azimuth of the long axis of dunes were analysed to establish main wind directions. Results clear out small variabilities in wind directions between plains. During the phase of the dune stabilization in Burtnieki plain main wind direction were from NNW to SSE, WSE to ENE in Seda plain and W to E in Trapene plain.

For survey of internal structure of dunes ground penetrating radar Zond-12e with 300 and 500 Mhz antenna systems were used. In total 2.5 km of profiles from 16 different study sites were recorded. By analyses of radargrams typical cross-bedding of lee side were recognized for dunes with higher relative height (Fig. 1). Beddings with small inclination are more common for low single dunes. In most of radargrams base of dunes with sub-horizontal bedding can be recognized.

OSL dating results indicate that stabilization for most of dated dunes at North Vidzeme can be relate to the Preboreal, Boreal and Atlantic time (Nartišs et al. 2009).

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POST-GLACIAL RELIEF EVOLUTION OF EAST AND SOUTH LITHUANIAN GLACIOLACUSTRINE BASINS AND IT‘S INFLUENCE ON RECENT GEOMORPHOLOGICAL PROCESSES

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The emergence of periglacial lakes in the territory of Lithuanian was conditioned by recessions and oscillations of the Baltija stage of Nemunas glacial. The slow recession of the glacier edge affected the evolution and drainage of the basins. Establishment of the drainage levels and analysis of the sections of glaciolacustrine sediments allows revealing their relationships with the recession phases of degrading glacier. The last stage of East and South Lithuanian glaciolacustrine basins – full drainage – was very important in their evolution. The intensity of glaciolacustrine drainage could be slow or cataclysmic.

For structural analysis of the littoral sediments of glaciolacustrine basins samples were taken from the quarry outcrops and ad hoc excavations. The granulometric composition of sediment layers was determined by screening of sediment samples were taken in the quarry outcrops and excavations situated in the eastern and western littoral parts of glaciolacustrine basins and in the basin bottoms.

In Late Glacial (Weichselian) a one time existed seven large glaciolacustrin basins. The oldest existed in Brandenburg Stage. It‘s occupied glaciodepresions between Neris Middlestream, Vilnia and Dainava ice-tongues. Small and shallow basins were in high level: the eastern basin which affluent by Neris Middlestream and Vilnia ice-tongues shoreline was fixed in 220 m and western basin which affluent by Vilnia and Dainava ice-tongues – in 200 m AMSL.

In Frankfurt Stage cascade of glaciolacustrin basin existed in East Lithuania. The highest level basins had in north part an lowest – in south. The Žeimena glaciolacustrine basin was in 155–160 m AMSL, the Labanoras – 150–155, the Vilnia – 140–145 m, the Merkys Middlestream – 135 m. The shoreline altitudes coherently sink from north-east to south-west (Fig.). The lowest Katra basin was in contemporary Lithuania – Belarus border. In south-east Lithuania extant some shoreline terraces, which was in 135, 130, 125 and 120 m AMSL .

For determining the arrangement of the shores of the former glaciolacustrine basins and distribution of terraces, large-scale topographic maps and aerophotographs were used. Relief forms were investigated by the cartographic, descriptive and granulometric analysis of sediments (Česnulevičius, Švedas, 2010, Seiriene *et al.* 2008). It enabled to define relief evolution in the South-East Lithuania glaciolacustrine basins zone by permafrost, erosion, aeolian, fluvial and organogenic formations (Stancikaite *et al.* 2002). Two different shoreline type zones are determined in investigation area: upper eastern and lower western. In eastern part dominated periglacial erosion, which embody by gullies, ravines, meltwater valleys. In western part predominated gullies and ravines, which joined in complicated network thermokarst holes and kettles.

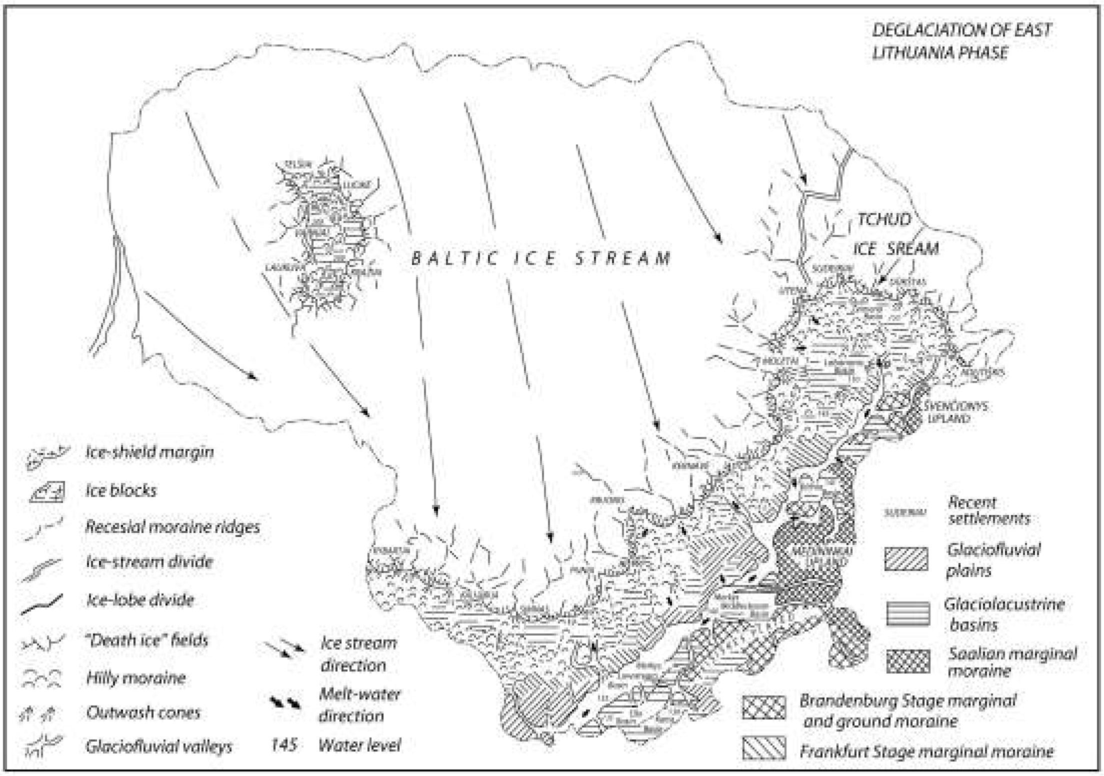

Fig. Ice – sheet deglaciation during East Lithuania Phase.

The important reason, which evidence to glaciolacustrine basin existence are old gullies network. The gullies which mouth opened in glaciolacustrin basins have complicate structure: multi-arms, volatile longitudinal section. Long time of existence decided different possibilities in gullies evolution: when basins water level sink, the longitudinal section of gullies followed them. The mouths part of gullies in time become in convex form.

Epigenetic processes substantially changed the glacial and glaciolacustrine relief forms. During the periglacial epoch, sculptural hilly-ridges and hills were formed, which show more complicated and epigenetically transformed glacial relief complexes. Nival holes and kettles underwent epigenetic transformation: the forms became shallower and their slopes flatter. After epigenetic transformation, typical glaciofluvial forms – stream valley – became shallow, with flat bottom and slopes. Erosion relief form dissected glacial moraine hills and glaciolacustrine basin shores. In dells, three layers of different lithology were distinguished. They show that the climatic conditions fluctuated and thus for influenced the activity of geomorphological processes in warm periods. Dells and periglacial gullies had a complicated structure: their upper parts reached the lower watershed, and their mouth opened into the glaciofluvial basins bottom.

The sediments changes illustrated evolution of glaciolacustrine basins. In old shoreline levels (135, 130, 125 and 120 m AMSL.) are fine-grained and coarse-grained sediments layers. Coarse-grained layers are thin and oblique, it show that stable shorelines level was exist only short time.

The glaciolacustrine basins were stretched among two uplands belt: Saalian Ašmena Upland in east and Weichselian marginal Baltic Uplands in west. Distance between it's uplands are only 10 – 60 km and this fact had essential importance for evolution all urstrom.

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GLACIAL TILL PETROGRAPHY OF THE SOUTH PODLASIE LOWLAND (E POLAND) AND STRATIGRAPHY OF THE MIDDLE PLEISTOCENE COMPLEX (MIS 11-6)

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The Middle Pleistocene Complex is still an arguable stratigraphic unit of the Pleistocene in Poland, correlated with MIS 11-6 (Lindner & Marks 2012; Lindner et al. 2013). Controversies refer a. o. to the number of glaciations and their rank. In the newest scheme, three glacial periods are distinguished: Liwiecian Glaciation (MIS 10), Krznanian Glaciation (MIS 8) and Odranian Glaciation with three recession stadials, including the post-maximum one – Wartanian (MIS 6) (Fig. 1A,B).

According to the extents of the ice sheets of the Middle Pleistocene Complex, they seemed to cover the central-eastern part of the South Podlasie Lowland (Fig. 1B). Their undisputed, lithostratigraphic key unit is a basal till from the Wartanian stadial of the Odra Glaciation, the maximum extent of which is marked by well visible in morphology set of marginal forms. They mark also the southern boundary of the occurrence of numerous sites of the Eemian Interglacial (MIS 5e) (a. o. Pidek & Terpiłowski 1993/1995).

In order to establish the number of the Middle Pleistocene basal till layers and their stratigraphic position in the South Podlasie Lowland, petrographic research was carried out, i.e. the analysis of indicator erratics (Lüttig 1958, Czubla 2001), in 5 sites: Neple & Mielnik (lower and upper till layers), Kol. Domaszewska & Kaczory (one surficial till layer) and Wólka Zagórna (one till layer with pedogenesis and periglacial morphogenesis traces, separating glacifluvial series) (Fig. 1C).

Proportions between erratics originated from the various regions of Fennoskandia and location of Theoretical Stone Centres allow to distinguish only two main till lithotypes in the central-eastern part of the South Podlasie Lowland.

Lithotype A (Kol. Domaszewska site and lower till layer in Neple and Mielnik sites) comprises fairly numerous rocks from the southern Sweden and Dalarna region, whereas erratics from the Åland Islands and eastern Fennoskandia occur in it in little number.

Lithotype B (Kaczory, Wólka Zagórna sites and upper till layer in Neple and Mielnik sites) comprises, in comparison with the lithotype A, much more Åland and central Sweden rocks, and much less rocks originated from the southern Sweden. In the Wólka Zagórna site (lithotype B-1), this till lithotype is distinguished by a higher proportion of rocks from the Dalarna region than in the Neple, Mielnik, Kaczory sites (lithotype B-2), what results in shifting of Theoretical Stone Centre to the west.

Differentiation of alimentary areas of the distinguished in the South Podlasie Lowland till lithotypes, is very similar to that observed for tills in central Poland (Czubla 2001), which in the light of newer papers (a. o. Balwierz et al. 2006, 2008) and reinterpretation of the Middle Pleistocene Complex stratigraphy (Ber et al. 2007, Lindner & Marks 2012) can be related to two main periods of ice-sheet transgression:

1. Lithotype A has features of tills originated from the South Pleistocene Complex. Its relation with the Sanian 2 Glaciation (MIS 12) in the Kol. Domaszewska site is unequivocally indicated by the alluvial series of meandering river from the Mazovian Interglacial (MIS 11) inserted in the till level (Terpiłowski et al. 2012).
2. Lithotype B has features of tills originated from the Middle Pleistocene Complex. The differences between the lithotypes B-1 and B-2 probably indicate their different age. The till lithotype B-1 in the Wólka Zagórna site could be connected with the Krznanian ice-sheet advance, and the till lithotype B-2 in the Kaczory site – with the Odranian-Warthanian ice-sheet advance. This interpretation can be justified by the traces of pedogenesis (warm Lublin period? – MIS 7), which was followed by strong periglacial modifications (dated to the Odranian Glaciation (MIS 6) by the IRSL method), documented in the till lithotype B-1 in the Wólka Zagórna site.

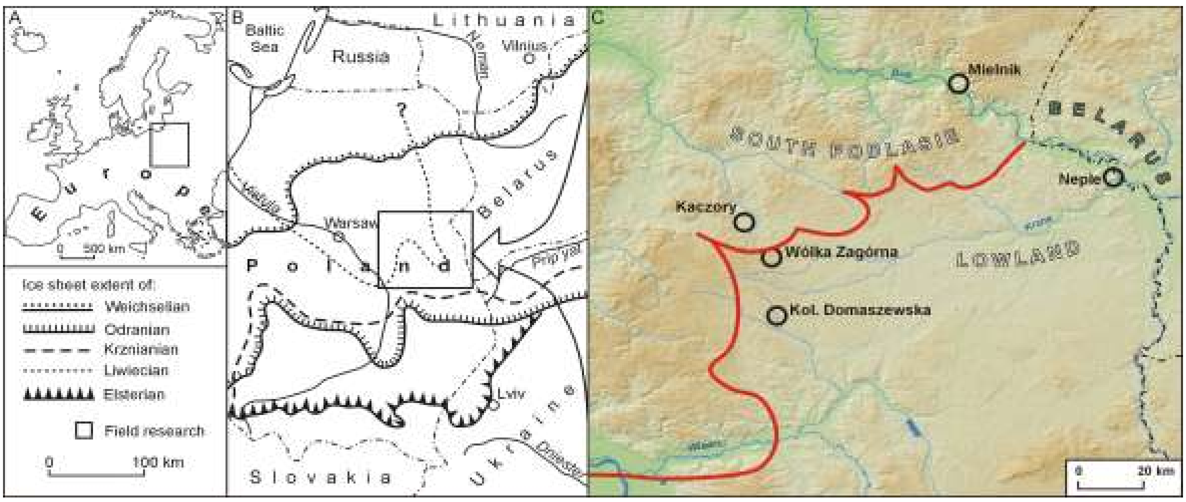

Fig. 1. The examined area: A) against a background of map of Europe; B) against a background of the extents of the Pleistocene ice sheets in eastern Poland (after Lindner & Marks 2012); C) location of the examined sites at the background of the Warthanian ice-sheet extent (after

Marks et al. 2006)

This lithostratigraphic view, received from the basal till in the South Podlasie Lowland, allow to claim that only two till layers (B-1, B-2), much less spread than it is commonly accepted, belong to the Middle Pleistocene Complex. Additionally, the older till layer – from the Krznanian Glaciation (thought to be the pre-maximum among the Middle Pleistocene Glaciations) seems to extend much further to the south than the younger till layer – from the Odranian Glaciation (regarded as that having the maximum extent among the Middle Pleistocene Glaciations). The latter generally corresponds to post-maximum extent of the Middle Pleistocene Glaciations, i.e. the Warthanian (compare Fig. 1B with 1C). This lithostratigraphic view of tills of the Middle Pleistocene Complex suggests the need of revision of the distinguished glacial units, their nomenclature and accepted ice-sheets' extents.

Acknowledgements:

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UTILISATION OF HIGH RESOLUTION LIGHT DETECTION AND RANGING (LIDAR) DATA AND GROUND PENETRATING RADAR (GPR) IN GEOMORPHOLOGY - AN EXAMPLE FROM SWEDEN

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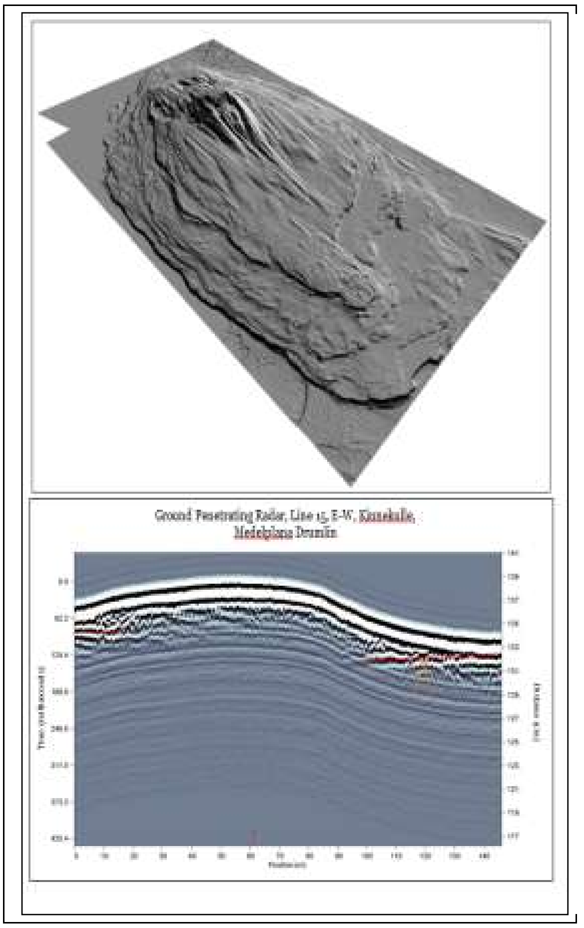

Fig 1.0 illustrates one of the fastest and most effective uses for the NNH in geomorphology, hillshading of the terrain. As the starting point of any landform based study the hillshade output can be used a means of rapidly mapping glacial landforms, particularly in conjunction with other data sets such as digitised quaternary geology deposit maps. Fig 1.0 also illustrates a GPR cross profile taken from one of the drumlins on the Kinnekulle plateau. As can be seen in the figure this was not entirely successful. However it does suggest that these landforms are indeed not bedrock cored, and that therefore further sedimentological investigations are suitable. The hillshade is useful in both identifying the streamlined feature in the first place, and in the placing the feature in its spatial context. That is identifying other glacial landforms that form the concurrent glacial landsystem before, during and after formation.

The advent of national scale, high resolution LiDAR DEMs (digital elevation models) radically changes the approach taken in in investigating historical glacial environments. In the past spatially extensive studies of landform distribution and form have relied upon a combination of aerial photography and topographical maps, the quality and extent of which is highly dependent on national policies and industrial interest. Not only does this bring problems with consistency and quality control in mapping and analysis, but takes a lot of time to collate and produce a statistically significant data set (Hättestrand, 1998). This is set to change with the gradual adoption and roll out of national scale high resolution LiDAR data sets that are made available to researchers on a free at the point of use basis. When these spatially extensive LiDAR data sets are combined with detailed field studies, such as GPR and field sedimentology, a new appreciation of the glacial landscape is born in which spatial extent does not mean a loss of detail and detail does not mean a loss of extent (Margold & Jansson, 2012). Here we outline how access to a high resolution LiDAR data set in Sweden, along with GPR, is being exploited in the study of streamlined landforms, as part of the on-going international effort to investigate the formation processes and characteristics of drumlins.

The New National Height (NNH) model is a LiDAR derived DEM that by 2015 will cover the entire landmass of Sweden (Läntmeteriet 2012). For technical details in English see Dowling, *et al* (*in press*), however in short; the NNH DEM is delivered orthorectified and geo-referenced to the projection SWEREFTM99 with a horizontal resolution of 2.0 m and a vertical resolution of 0.10 m. Data is downloaded directly from a password protected web-portal. The DEM was manipulated in the ArcGIS software suite for all of the outputs shown here. The GPR used in the field example given here was tried at frequencies of 150 and 200 MHz in an attempt to test penetration vs resolution in the sediments under evaluation, 200MHz was found to give some penetration. However there were significant issues with gaining any penetration due to high clay and moisture content in the quaternary deposits attenuating the signal. The unit, along with technical expert L.V. Jakobsen, was hired from Universitetet for miljø- og biovitenskap (UMO), Norway.

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NEW DATA ON PALAEOENVIRONMENT OF SOUTH-EASTERN BALTIC REGION: RESULTS OF 2012 – 2013

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Introduction

The processes of settling by southeastern Baltic primitive tribes against the background of environmental changes were studied since 2009 (the projects ‘The Evolution of the Baltic Sea and the Stages of the Earliest Human Settlement in the Southeast Baltic’, “Evolution of environment of the Southeast Baltic on the border Pleistocene – Holocene and the Stages of the Earliest Human Settlement, RFBR). Aims of the investigations are to obtain new archaeological and palaeogeographic data (variability of climate, vegetation and geological, geomorphological and hydrological processes over the last ~13000 years), and to approach the reconstruction of the Late Glacial and Holocene climate and landscapes as the natural basis of settling processes in the southeastern Baltic Sea.

Methods

Methods of research include:

1. The complex palaeogeographic analysis of lake and bog deposits, using data for reconstruction of climate and in-continental hydrological net fluctuations, changes of vegetation
2. Archaeological prospecting and excavations, studying of key archaeological sites within palaeogeographic approach

3. C14, AMS, OSL dating
4. Geological and geomorphological studies for the reconstruction of ancient relief and topography

Studying area

From 2011, paleogeographic studies have taken place in a group of small lakes of Vishtynetskaya highland (Kaliningrad region, RF), and include drilling and sampling of bottom sediments of Kamyshovoe lake, one of the most interesting hydrological objects of this territory. Comparisons of palaeogeographic characteristics of this lake with the ones of moraine hills of Lithuania and Poland indicates that the reservoir may be one of the oldest in the region, and its formation should be related directly to deglaciation processes of the Vishtynetskaya highland territory.

Results

The obtained samples confirm the assumption about the relative age of the lake. Sediment cores are presented by both stages: late glacial and the column of Holocene sediments. Sediment cores were obtained with a total capacity of about 10 meters; 200 samples are in the process for complex palaeogeographic analysis - magnetic susceptibility, pollen, diatoms and analysis of isotopes (δ18O, δ13C), AMS, 14C dating. For the present moment, preliminary results of the analysis of magnetic susceptibility and radiocarbon dating of part of samples have been obtained. The earliest dating for now (LU-6980) has been received from a depth 830-840 sm from water surface (8740+-160). Complete data are expected in the end of 2013. It will be possible then to reconstruct the Late Glacial and Holocene climate and the landscapes of the southeastern Baltic territory.

Acknowledgements:

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PALAEOLANDSCAPE OF THE YOUNGER DRYAS IN CENTRAL POLAND

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Well recognized climatic cooling of the Younger Dryas influenced the functioning of geosystems. The better geological recognition of rules govering the relief evolution the better background to conclude about short geological periods, such as the Youner Dryas, which morphological evidences are difficult to record. For Łódź Region (Central Poland) such a background is well known, because of a long tradition of Weichselian periglacial investigations.

The picture that emeges from the review of the Younger Dryas-age sites and from the latest studies, shows the Younger Dyas the most privileged time to increased activity of geological processes and their effectiveness during the Late Glacial termination. The transformation in rebuilding of mophogenetic realms from periglacial into moderate was disturbed. Such a catastrophic event had a noticeable impact on geomorphologic systems. The analysis of available evidences from slope, river and aeolian sedimentary environments indicate return of phenomena typical of cold conditions, not excluding permafrost reestablishment.

The sedimentary slope archives point to the formation of the over-snow deposits. The over-snow deposition was a composite process, in which mineral material was gathered as a result of slope wash, mud flow and aeolian activity. On the snowy slope surface the deposited material was able to survive a long time, especially when was trapped into local depressions of the slope. A summer rise in temperature might have resulted in a snow decay and in producing of distinctive collapse deformations. From the series position it is possible to correlate its stratigraphically with the Younger Dryas low terraces of some Łódź Region rivers (e.g. Mroga river). The Younger Dryas was considered as a time of an ultimate correction of the valley relief in the region when the shape of the slope has changed, became smoothed and extended upslope. Taking into account the large dynamics of the processes in the Younger Dryas environment it may be assumed that apart from sediments filling these local slope depressions, more material was transferred outside the slope system.

Fluvial sedimentary systems of the Łódź Region reacted differently to the Younger Dryas climatic deterioration, depending first of all on the morphological properties of the surrounding area. Generally this period was marked by an enhanced fluvial activity, reflected in the fluvial sediment succession. In most cases analysed for the Łódź Region, the rivers maintained their meandering pattern, nevertheless both meandering rivers, braided river systems and multi-channel anabranching ones existed during this period. Due to enhanced slope processes a significantly higher sediment supply into the rivers, resulted in some systems in aggradation. The studies in the Warta River valley in Koźmin Las indicate periodic intensifications of floods which finally resulted with high energy flows, morphologically expressed as the low terrace in form of a widespread landform.

The sedimentary and morphological aeolian archives of the Younger Dryas indicate the transformation of the older inland dunes, the process which is well-recognized and well-documented in the Łódź Region. Recent data from the northern part of the region allowed to complete the Younger Dryas aeolian evolution with the formation of coversands, which create the substratum for the Holocene dunes. They were formed as a result of short-distance transport of sand derived from the flood plains adjoining them from the west, i.e. material being quickly deposited by the YD-age anabranching Warta River system.

LATE GLACIAL SEDIMENTARY ENVIRONMENTS OF THE ŪLA RIVER BASIN: ON AN EXAMPLE FROM ŪLA 2 OUTCROP

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The basin of Ūla River, the left tributary of Merkys River, flowing along the outer foot of the Baltic Upland – the marginal ridge of the Last Glaciation, is one of the most complex sites for Late Glacial environmental history investigation in south-eastern Lithuania (Fig. 1). Presently the majority of outwash plane area is covered by cover sands, blown to high dunes in many places, which hide the landforms originated during the deglaciation. Also the onset of Late Glacial organogenic sedimentation there was always under discussion due to difference in the results of absolute dating and interpretation of pollen diagrams (Blažauskas et al., 1998; Sanko and Gaigalas, 2008). The postglacial lake sedimentation had been stopped by aeolian one at different time points in various sites depending on local setting and development of aeolian processes (Seibutis, 1974). The results of the new study are expected to provide some deeper insight into post glacial environmental history of the area.

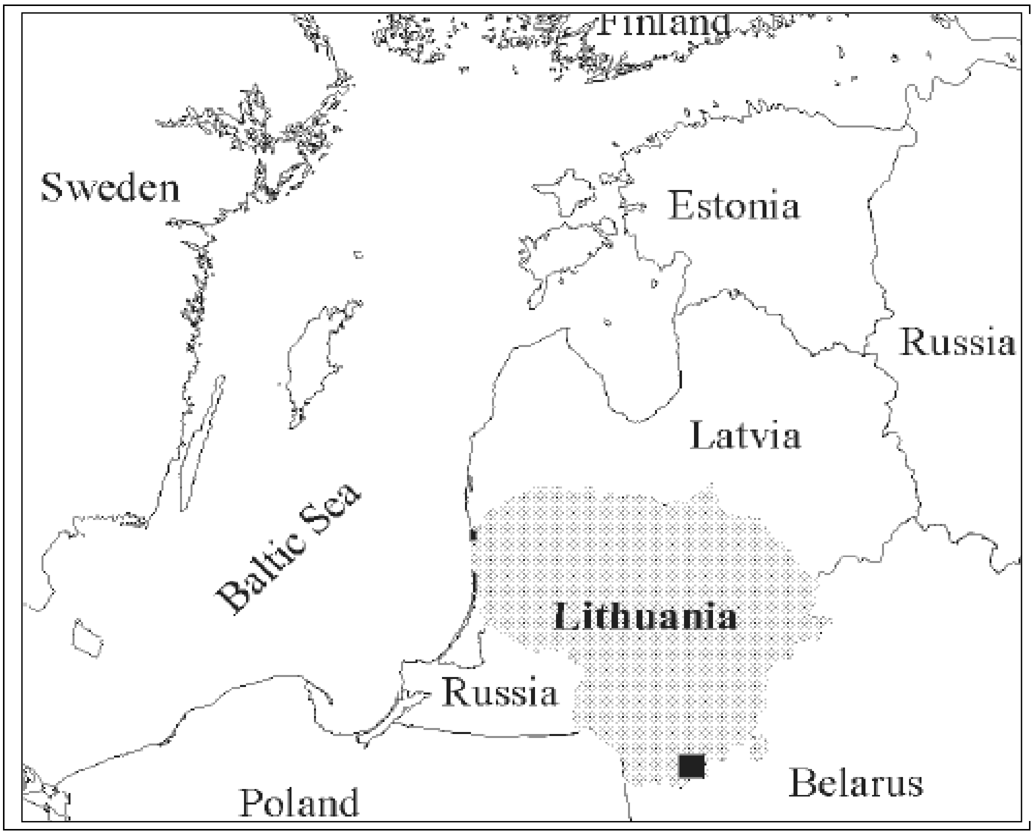

Fig.1. Location of the study site

The investigated sediment section in Ūla 2 outcrop (54°06`34.1``N, 24°28`44.4``E) lays at 11.10 m depth under the aeolian sands. It consists of 0.7 m thick gyttja covering the sand and 0.1 m thick silty clay with organic matter on top of gyttja (Fig. 2). Such lithological change points to an abrupt alteration of the sedimentation environment. The lacustrine sand underlying aeolian sediment thickness has an admixture of drifted sand. Layer of sand below the gyttja is also deposited under the lake conditions and is underlain with glacial outwash sediments (Blažauskas et al., 1998; Sanko and Gaigalas, 2008).

The origin of the lake, according the results of earlier studies, was related with melting of the dead ice block started just before the Older Dryas (DR_1) and ended probably in Alleröd (Blažauskas et all, 1998).

New AMS date obtained at Poznań Radiocarbon Laboratory from the gyttja at the depth of 11.90 m — 15200-14650 cal. yr BP proposes new timing and interpretation of environmental change. Together with absolute dating the abundance of open ground, cold tolerant plants such as Poaceae, *Artemisia*, Chenopodiaceae at the lowermost part of pollen spectrum (LPAZ 1) indicates sediments correlated to Bölling, at least to the end of it, when water basin was already formed. The decline of NAP and an increase of AP, especially of pine in LPAZ 2 and 3 show Alleröd warming. At LPAZ 4 and 5 transition, at the depth of 11.25 m — 13630-13300 cal. yr BP according to the result of AMS dating, some instability in pollen diagram is observed. Abundance of cold tolerant plants shows colder and dryer climate determined a thinning of the forest cover and expansion of different herbs. The slight increase in birch pollen, the spread of juniper on sandy habitats is recorded here. Also steep drop in the amount of $CaCO_3$ and in organic content is stated in the LOI diagram. According to last results these sediments were deposited during the GI-1b/Gertsenzee "climatic event" (Lowe et al., 2008). These new records show that investigated sediments are about 1000 year older, than it was thought before and climatic instability that caused infilling of this sedimentation basin started during the Alleröd Interstadial respectively.

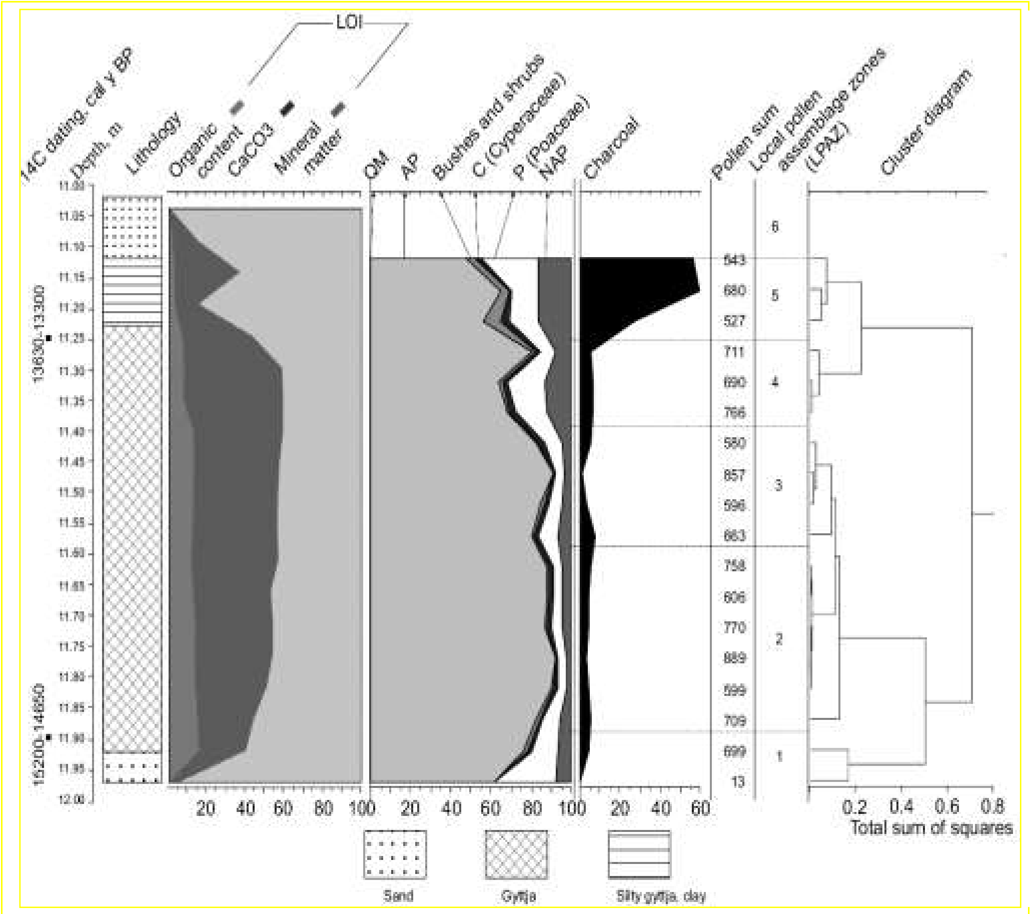

Fig. 2. Summarizing pollen and LOI diagrams from Ūla2 outcrop: LOI – loss in ignition; QM –Quercetum mixtum, AP – arboreal pollen, NAP – non arboreal pollen; analysed by Gedminienė and Stančikaitė (2013)

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POST-GLACIAL ENVIRONMENTAL VARIATIONS IN VERPSTINIS LAKE, EASTERN LITHUANIAN

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Interdisciplinary investigations (pollen, plant macrofossils, ^{14}C dating and loss-on-ignition measurements) were carried out in the Verpstinis Lake (55º11′38″N, 25º52′26″E) providing new data on the post-glacial environmental history of the Eastern Lithuania. The ^{14}C results indicate the deposition of the investigated layers during the earliest stages of the Holocene and the biostratigraphical subdivision of the strata indicates a Late-Glacial age of the oldest sediments. According to the data, the oldest sediments represents the Allerod Interstadial. During the Allerod, *Pinus-Betula* forest was growing around the lake. Meanwhile in the Young Dryas the forest cover thinned and mixed herb-shrub vegetation expanded. In Preboreal, birch forest predominated and then was gradually replaced by pine. Simultaneously, the pollen and plant macrofossils show *Picea* immigration into the region. At that time the abundance of *Chara* oospores in the sediments implies low eutrophication level of the investigated lake as well as high content of carbon. The latter drop in *Chara* representation alongside with the expansion of *Potamogeton natans, Potamogeton pusilus, Potamogeton coloratus, Nymphaea alba* indicates increasing intensity of eutrophication process. The early Holocene climatic warming was followed by the introduction of new deciduous species. *Corylus* arrived at 10 200–10 000 cal yr BP and was followed by *Ulmus* at 10 000 cal yr BP. *Alnus* arrived and started to expand at 8200–8000 cal yr BP. Furhermore, the *Tilia* appeared at 7700–7400 cal yr BP while *Qeurcus* were established later at 5200 cal yr BP. During the Subboreal the intesive grow up of the paleobasin started. Water plants dissapeared and the wetland plants started to prevail.

QUANTIFICATION OF TERRAIN RUGGEDNESS FOR LANDFORM AND MATURITY ANALYSIS IN PALEOLANDSCAPES FROM SAALIAN TO WEICHSEELIAN, SOUTH WESTERN DENMARK

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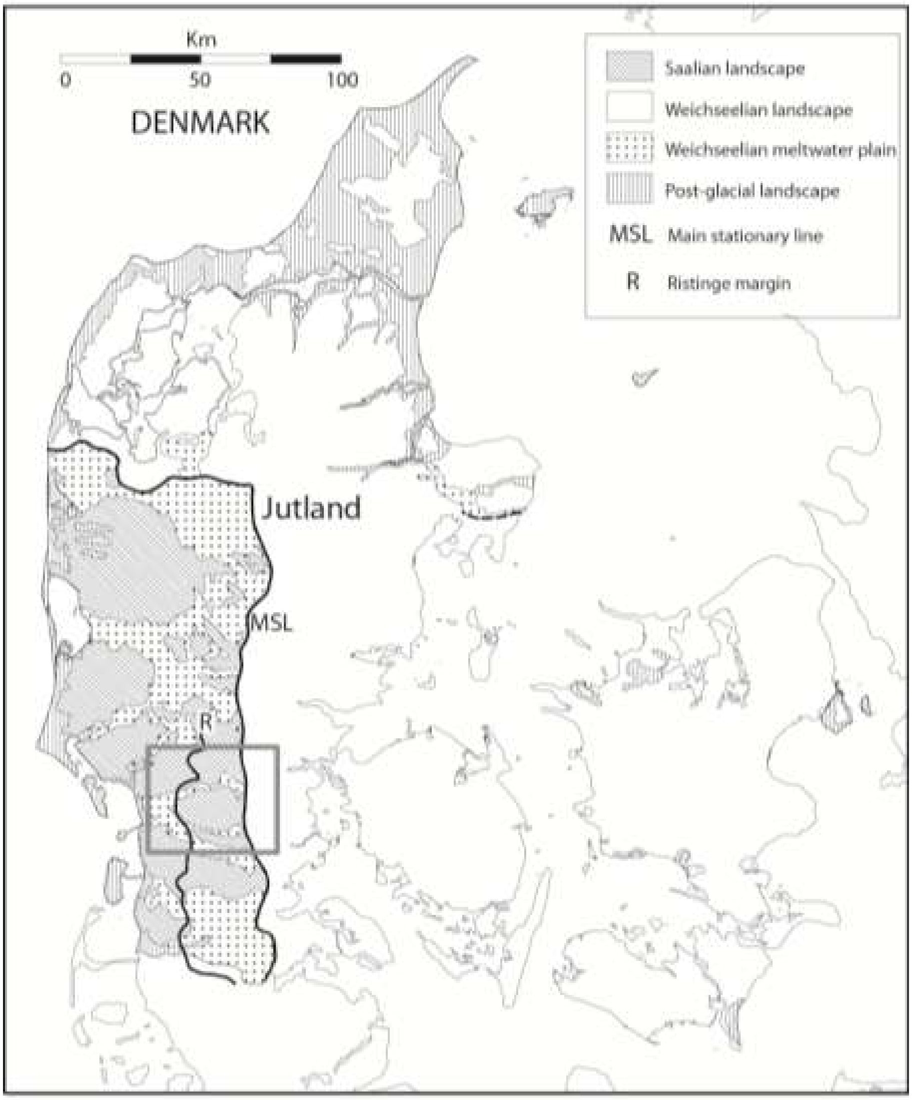
The glacial landscape west of the Main Stationary Line (MSL) in the South-western part of Jutland, has traditionally been regarded as a Saalian or older, periglacial smoothened, glacial landscape rising above the flat melt water plains surrounding them. In Denmark these landforms are called Hill Islands as they rise above the flat plains. However, the Ristinge ice stream reached, at about 50 kyr BP, about 50 km further to the west than the MSL (Houmark-Nielsen, 2007, 2010). This implies that part of the Hill Island landscape is of Weichseelian age. This paper presents a GIS based analysis of the paleolandscapes in this region in order to give an estimate of the maturity of the landscape.



Terrain ruggedness analysis, as described by Sappington et. Al (2007), has been applied in order to quantify the topographic heterogeneity, and thereby to describe the character of the landscape and divide it into units with comparable characteristics. The ruggedness analysis was performed in ArcGIS using spatial analyst. The analyses were performed on 1.6 m and 30 m digital elevation models (DEM). The 30 m DEM is a resampled version of the 1.6 m DEM.

The 1.6 m DEM was too detailed as anthropogenic features, such as roads, contributed to the ruggedness index and too many non relevant details blurred the picture. The 30 m DEM was chosen as it gave a more general picture, and only larger terrain forms where shown.

Landform units with dead ice topography show a very distinct ruggedness pattern and it is easily recognised and outlined. The melt water plains have of course a very low ruggedness index.

Within the Hill Islands there is a slight difference in the ruggedness index and pattern and it is possible to differentiate a western and eastern part with similar characteristics. The separation of these units coincides well with the maximum extension of the Ristinge ice stream. The difference of the ruggedness is interpreted as reflecting the maturity of the landscape with the lowest ruggedness values in the older landscape west of the maximum extention of the Ristinge ice stream.

On the geomorphological map of Southern Jutland inland dunes and larger bogs are often affiliated with the Ristinge margin as it is the case along the MSL. It therefore seems to be a general feature that inland dunes and larger bogs to some extend are characteristic features along ice marginal lines

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LIDAR DATA AND ELEVATION MODEL USED TO PRODUCE INFORMATION OF GEOLOGICAL LANDFORMS AND DEVELOPMENT OF ICE LAKE STAGES

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High-resolution digital elevation maps generated by airborne LiDAR are spreading to geological mapping and palaeohydrological research in northern Finland. LiDAR (Light Detection And Ranging) or laser scanning is an optical remote sensing technology based on laser pulses transmitted by an active sensor, or a laser scanner and on accurate location information. LiDAR data is typically used to produce elevation models, as the technique is particularly well suited for providing elevation data of the ground beneath the vegetation canopy. LiDAR-derived products can be easily integrated into GIS for analysis and interpretation.

At Saariselkä mountain area a combination of aircraft-based LiDAR and GIS has evolved into an important tool for detecting different kind of geological landforms and development of ice lake stages. During the deglaciation stage of the last glaciation about 10 500 years ago an ice lake was dammed in the Kiilo-oja river valley between the slope of the fell and the ice margin. Because the glacier margin was receding to the southwest to lower elevations the ice lake had to discharge its waters over the fell range towards opposite direction.

In the field studies the existence and history of the ice lake were studied using the information of the shore marks and spillways and their heights. There are very few immediately recognizable shore marks in the terrain. They include washed bedrock surfaces and indistinct stone belts. They are hard to detect at close range. It is only an elevation model which makes these horizontal lines apparent. The surface level of the ice lake is also reflected by the termination of lateral drainage channels at the same level, as well as by the flat surfaces of the esker ridges and marginal drainage deltas. The spillways were formed on the lowest points between the fell tops. The meltwater eroded 5 - 10 m deep and 100 – 500 m long channels into the bedrock. Although the channels are clearly eroded by running water, their formation was also favoured by existing fractures and crush zones in the bedrock.

There are seven channels north of the Fell Kiilopää at different threshold level. They functioned one after the other as spillways of the ice lake. On the basis of the shape and dimensions of the spillway, it is possible to get an idea about the strength and duration of the former stream in it. The oldest channel lie at 461 m level and it formed at a location where subglacial meltwater erosion had taken place earlier. As the ice margin receded, the ice lake started to form at the mouth of a subglacial meltwater conduit. The formation of the lake was favoured by strong melting of the ice and by a large volume of meltwater coming from the subglacial meltwater conduit. The part played by the subglacial meltwater erosion was certainly more significant than that of the proglacial one, because it served as the spillway for only some years before the second spillway opened, situated some 200 m north at 446 m level. Meltwater erosion was at its most marked when a new spillway opened and the level of the ice lake dropped to that of the spillway threshold. The third spillway was formed as the ice thinned and its margin receded down the slope of the fell. The opening of the third spillway led to a lowering of the water level at 418 m level. The spillways led the waters to the northeast to the Lutto river valley and the Barents Sea.

The following spillways (404 m, 402 m, 388 m and 336 m) formed marginally at the contact between the ice margin and the slope. Although they are situated on the slope like the lateral drainage channels, they can be distinguished on the basis of their considerable size and irregular mode of occurrence. They were formed as the ice thinned and its margin receded down the slope of the Fell Ahopäät. The opening of new spillways under the margin of the ice sheet, below the preceding ones, led to a successive lowering of the water levels. If the ice margin retreated approximately 100 – 140 m per year, it is estimated that each ice lake stage lasted some 5 – 15 years. The younger spillways joined to form a more than 15 m deep extramarginal channel, collecting the water and leading it northwards to the Tolosjoki valley and further to the Barents Sea.

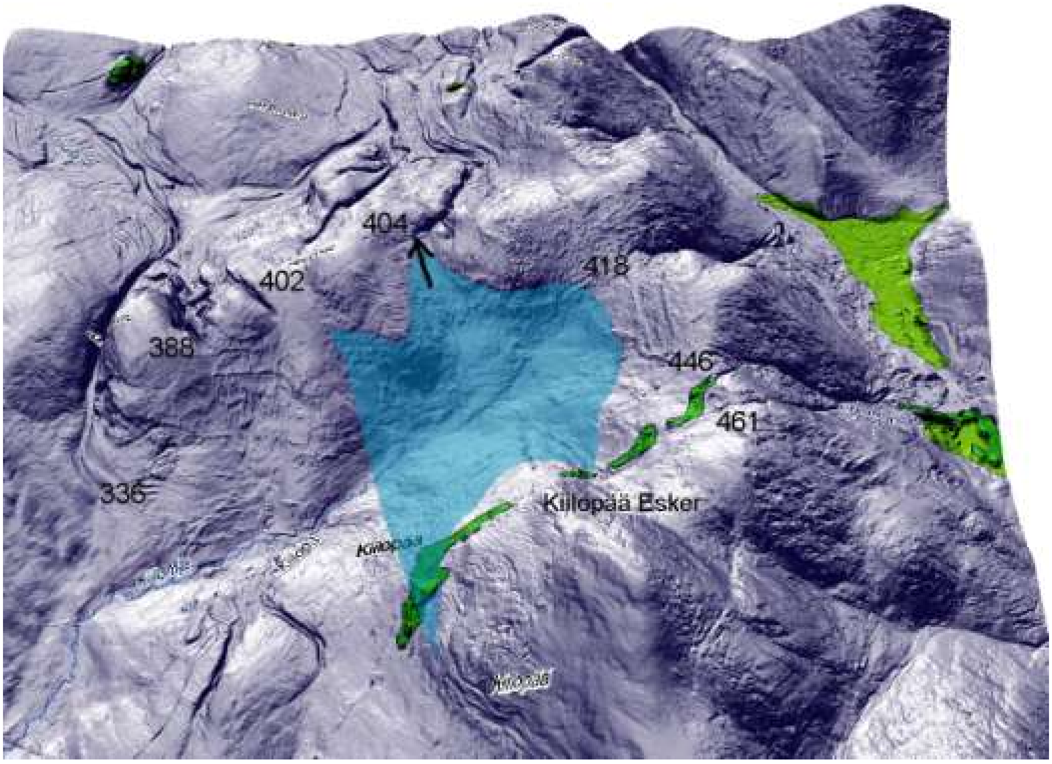

Figure: Ice lake stage 404 m (blue area) in the Kiilo-oja valley. Digital elevation model processed from the laser scanning material of National Land Survey of Finland.

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OSL DATING AND SEDIMENTARY RECORD OF AEOLIAN SEDIMENTS IN THE CENTRAL AND EASTERN PART OF LITHUANIA

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Four sediment sections located in the eastern, central and south-eastern Lithuania were selected to provide a sedimentary pattern and chronology of aeolian environment history. The Inkliuzai, Mikieriai and Gaižiūnai sites are located slightly in the foreland of the Middle Lithuania glacial limit (Guobytė, Satkūnas, 2011). The Rūdninkai site is situated in the foreland of the Baltija glacial limit, and slightly within the maximal extent of Weichselian (Vistulian) glaciation (Guobytė, Satkūnas, 2011). All sites are located within the smaller (Inkliuzai and Mikieriai) or the bigger (Gaižiūnai and Rūdninkai) dune fields underlied by the glaciolacustrine sediments. Only the Mikieriai site lies on the right high bank of Merkys River, where dune sediments are underlied by the fluvial sediments of the higher river terrace. Previous IRSL–dating results, involving i.a. the southern Lithuanian Dzūkija dune field revealed the timeframe between 3.2±0.5 to 11.3±1.4 ka (Molodkov, Bitinas, 2006).

Eighty five samples for textural features analysis, as well as six for OSL dating were taken from the dune forms. Grain-size analysis was performed by sieving. Two sandy fractions: 0.5–0.8 and 0.8–1.0 mm were selected to perform the quartz grains rounding and frosting analysis according to Mycielska-Dowgiałło and Woronko (1998), as well to determine the mineralogical-petrographic composition. For OSL samples, equivalent doses were determined using a single-aliquot regenerative dose (SAR) protocol (Murray and Wintle, 2000; Wintle and Murray, 2006). After obtaining 180–250 µm fraction, samples were chemically treated to remove carbonates and organic material, and any feldspar grains. The quartz extracts were checked for purity, and were considered sufficiently pure, when the natural and regenerated signal ratios of the IRSL to the blue stimulated luminescence were ≤ 10%. A dose recovery test (Wallinga et al., 2000) was run on 36 aliquots from six samples (6 aliquots for each measured sample). The OSL SAR protocol contained following steps: (1) irradiation with the regenerative beta dose D_i, (2) preheat at the temperature 260°C for 10 s, (3) blue light stimulation at the temperature 125°C for 40 s, (4) irradiation of the test dose D_r, (5) preheat at the temperature 220°C for 10 s for 0 s, (6) blue light stimulation at the temperature 280°C for 60 s. Equivalent doses were obtained for 9–15 selected aliquots using Risø Luminescence Analyst v. 4.20. The OSL signal was integrated from channels 1–2 and the background was taken from channels 3–6. Recycles points were used to both exponential and linear fitting and the growth curve was forced through the origin. The external beta and gamma contributions to the total dose rate D, were estimated in the laboratory from the contents of natural radioactive elements ^{238}U, ^{226}Ra, ^{210}Pb, ^{232}Th and ^{40}K.

Fine- and occasionally medium-grained sandy deposits yield general enrichment into aeolian-type grains, both well-rounded (RM), and with the aeolian abrasion visible only at the edges (EM/RM). Grains classified as NU/M, representing *in-situ* (frost) weathered conditions without effect of transportation (Woronko and Hoch, 2011), cracked (C) one, with the lack of at least 30% of grain (Mycielska-Dowgiałło & Woronko, 1998), as well as, the totally fresh quartz grains (NU/L) with no signs of rounding in any transportation environment, nor evidence of any-post depositional weathering (Dąbski et al., 2011; Woronko, 2012), present a relatively high share. The results of presented study suggest, that the grains were in direct contact with each other, leading to cryomechanical chipping (Woronko, 2012). Hence, aeolian – frost–weathering interaction and/or the inheritance after the surrounding/substratum sediments could be reflected in the investigated profiles.

Three OSL dated profiles reveal consistent ages: 11.59±0.77 ka (Risø123096; Mikieriai site), 12.92±0.85 and 13.18±0.77 ka (Risø123098 and H230100; Rūdninkai), 14.19±0.77 and 15.12±1.01 ka (Risø123097 and 123099; Gaižiūnai site). Hence, according to the INTIMATE protocol (Blockley et al., 2012) the oldest results could be correlated with upper part of the Greenland Stadial 2a (GS–2a) and the lowest part of the Greenland Interstadial 1 (GI–1), the middle one – with upper part of the Greenland Interstadial 1 (GI–1), and the youngest – with the Preboreal Oscilation. Fourth dated profile (Inkliuzai) perform probably only partially bleached grains of quartz and provide the age 46.01±4.40 ka (Risø123095). Simultaneously, results based on infrared stimulation (IRSL) agree with the results obtained from quartz with OSL, which suggest, that the sediments of that profile have been affected by light only in short time while transporting and depositing.

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RELATIONSHIP BETWEEN FOLK AND WARD (1957) INDICATORS AS A TOOL FOR ANALYSING THE AEOLIAN SEDIMENTARY ENVIRONMENTS

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Grain-size is considered as the most fundamental property of sediments (Román-Sierra et al., 2013), and provides important clues to transport history and depositional conditions (Flemming, 2007; Folk and Ward, 1957) as well as a basis for the study of the other textural features of the deposits (Mycielska-Dowgiałło & Ludwikowska-Kędzia, 2011). The transportation and deposition history of fluvial sediments (Ludwikowska-Kędzia, 2000) could be reconstruct by applying the relationships between granulometric parameters regarding the mean grain size (Mz) vs. the standard deviation (σ_1), the skewness (Sk) vs. mean (Mz), and the standard deviation (σ_1) (Mycielska-Dowgiałło, 2007a). Bivariate scatter plots have been also successfully employed into the interpretation of the environments and mechanism of sediment deposition of a coastal area (Alsharhan and El-Sammak, 2004), and have been based on the assumption that these statistical parameters reliably reflect differences in a fluid/air–flow mechanism of sediment transportation and deposition (Sutherland and Lee, 1994).

A total of three hundred eleven samples at three locations (Central Poland, Eastern Latvia and Western and North-Eastern Estonia) with twelve profiles (Plecewice, Kan

i, Girjantari, Majaks, Mieļupīte, Pērtrupe, Silezers, Smilškalni, Iisaku 1, Iisaku 2, Varesmetsa and Kanaküla) were examined by the same processing methodology to make the results comparable. Ca. 200 g of each sample were dry sieved for 20 minutes according to the recommendation of Syvitski (1991) and Mycielska-Dowgiałło (2007), using the sieve sizes of: 4.0, 2.0, 1.0, 0.8, 0.5, 0.315, 0.25, 0.2, 0.125, 0.1 and 0.063 mm. The individual sieve fractions were subsequently weighted with ±0.001 precision. The mean (Mz), sorting (σ_1) and skewness (Sk) were calculated with Folk and Ward (1957) logarithmic graphic method provided by customized version of R package "rysgran" (Gilbert et al., 2012).

The diagram of standard deviation (σ_1) against mean (Mz) allows two groups to be separated. First one, representing Pērtrupe and Silezers sites, have a high values of mean (in phi), the lower values of standard deviation (sediments are the better sorted), and with a specific trend line lowering into the better sorting values and the coarser sediments ("overbank deposits" distinguished by Ludwikowska-Kędzia (2000)). Second group involves worse sorted sediments, and represents the opposite inclination of the trend line: worse sorting of sediments is noted in the coarser fractions. Group of points from Plecewice site (Central Poland) have grain size consisting of medium sand shifted towards the coarser fraction.

The plotting of skewness (Sk) against standard deviation (σ_1) designates a big scattering of points, presenting not only clusters around near symmetrical field of skewness, but also the "tails" running into positively or negatively skewed values. Smilškalni, Pērtrupe and Kani (Latvia) sites reveal the domination into positively skewed, Majaks (Latvia) and Kanaküla (Western Estonia) – into negatively, while the rest sites perform the "symmetrical character". These populations may be due to variable sources and the selective enrichment in the optimal fraction (Mycielska-Dowgiałło, 2007).

The diagram of mean (Mz) against skewness (Sk) reveals two scattered groups of sites. First one, including Silezers (Latvia) and

Plecewice (Central Poland) points are shifted towards coarser fraction. The second one, involving the rest of sites, runs as an almost vertical line, with the most positively skewed sediments on the top (i.e. Pērtrupe and Kani sites), and the most negatively one in the bottom part of diagram (i.e. Kanaküla and Majaks sites).

It is concluded that the variations between different sample sites are triggered by: (1) the diversity in the source of the sediments, or/and (2) geological history of the particular setting.

The study was funded by the Postdoctoral Research Grant ERMOS (FP7 Marie Curie Cofund the "People" programme) "Age and climatic signature of coversands deposits distributed on glaciolacustrine basins along the Scandinavian Ice Sheet margin southeast of the Baltic Sea".

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DEVELOPMENT AND INFILL OF GLACIOLACUSTRINE BASIN UŽVENTIS (WEST LITHUANIA)

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The object of this study is glaciolacustrine unit in Western Lithuania, close to the towns of Upina, Patumšiai, Užventis, Vaiguva, villages Šalteniai, Šaukenai. It covers an area of 65 km^2. The aim of this study was to establish the depth of sediment thickness and lithological peculiarities of the basin. The most characteristic feature of these sediments is the rapid vertical changes of sedimentary facies. The investigations enabled to reconstruct the sedimentary environment and the reasons of facial changes. Those investigations combined with geomorphologic studies of the area, forms the basis for a new interpretation of the glaciolacustrine sedimentary conditions in studied glaciolacustrine lake.

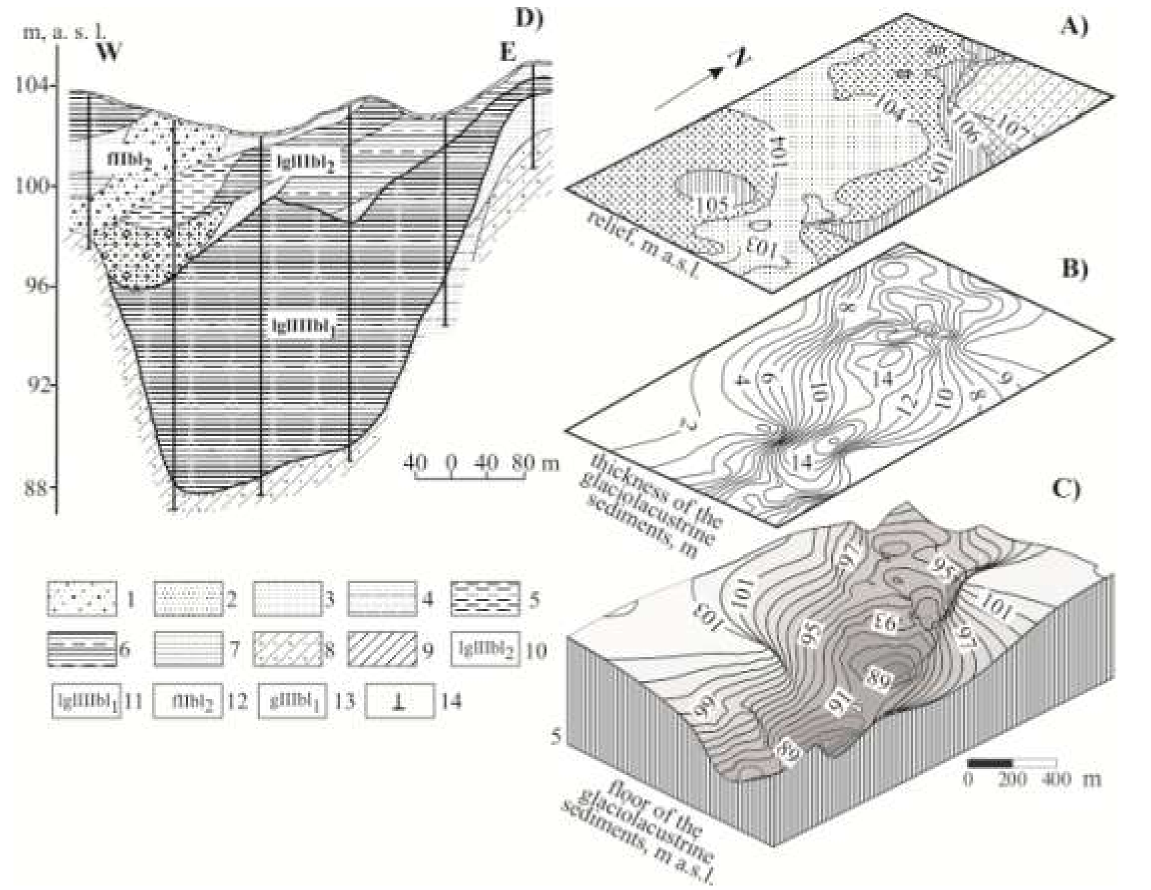

Fig. 1. Diagram of the surface relief (A), thickness of the glaciolacustrine sediments (B), floor of the glaciolacustrine sediments (C) and geological cross-section (D) of Aukseliai area (Aunuva valley): 1 – sand with gravel; 2 – coarse and middle grained sand; 3 – fine grained sand; 4 – clayey fine grained sand; 5 – silt; 6 – silty clay; 7 – clay; 8 – till; 9 – soil; 10 – glaciolacustrine proglacial sediments of Middle Lithuanian phase; 11 – glaciofluvial sediments of Middle Lithuanian phase; 12 – glaciolacustrine proglacial sediments of South Lithuanian phase; 13 – till deposits of South Lithuanian phase; 14 – borehole.

The absolute altitude of the Užventis glaciolacustrine basin varies from 100 to 115 m reaching 120–125 m in its peripheral part. The surface of glaciolacustrine plain is undulating and slightly sinking towards the south-eastern direction. The west borders of the basin are morphologically very clear-cut. The north–east border of the Užventis basin is morphologically harsh and coincides with the marginal relief of South and Middle Lithuanian phase. In the east, the area is bordered by the slope of the Kurtuvenai glaciolacustrine kame terrace, which is considerably steep. The southern and west border coincides with the basal till plain and marginal till formations of South Lithuanian phase. In the middle of the Užventis basin the marginal formations are present reaching about 10–20 m height above the basin surface as well as the hills up to 5-10 m of height. A longitudinal Pašilėnai–Lykšilis ridge in the eastern part of basin stretches from North to South direction. Ridge separates Užventis basin into two parts: the western - Knitojas depression and eastern - Gansės depression.

The geological material from boreholes and clay quarries points on that the sediments exposed in the Užventis basin lie on an uneven till surface. The absolute altitude of the bottom surface usually ranges from 98 to 100 m a.s.l. However somewhere, especially in the central and southern parts of the basin, the bottom depress to 87–96 m a.s.l. The lithological composition and thickness of glaciolacustrine sediments depend on the depth of glaciolacustrine basin and deposition area. The thickness of sediment layer mainly has been predetermined by the uneven surface of the bottom of the periglacial lake and the amount of transported material. The thickness of sediment layer in the basin is rather uneven. The dominant thickness is 5–10 m. The bottom of the Užventis glaciolacustrine basin is furrowed by deep trough-shaped old valleys and depressions used by Venta, Knituoja, Aunuva and Ubesiukas rivers.

The Aunuva valley is trough-shaped and reaches 0.8–1.5 km width (Fig.1). Its upper part is composed of sandy silt clay with scarce gravel somewhere merging into silt or fine-grained sand with gravel. Silt and various grained sand indicate a shoaling basin. The thickness of these sediments ranges from 3 to 8 m. They overlie brown, greyish brown, dark brown and greasy varved clay. The varves are represented by clay and silt or silt clay interlayers. Clay layers are dominant. The thickness of silt layers varies from 0.5 to 2 cm and the thickness of clay layers from 1–2 to 5 cm. The content of clay particles is rather high and comprises about 60–70 % or somewhere even 85 % of the total composition and increases in the lower part of the layer. The thickness of clay layer is uneven and ranges from 1.7 to 14.0 m. It tends to increase in the direction of the confluence of Aunuva and Venta rivers reaching of 21.7 m.

SPECIAL FEATURES OF PETROGRAPHIC COMPOSITION OF UNEVEN-AGED MORAINES ALONG BALTIC GLACIAL STREAM ROUTE IN WESTERN BELARUS

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Today of current interest is study of the material composition of coarse moraine deposits with the purpose of their stratigraphic differentiation and palaeglaciologic reconstructions of the Scandinavian Ice Sheet glaciations. Sector of Baltic glacial stream that encompasses entire Western Belarus is preferable for identification of changes and features of glacial deposit material composition. Here Baltic glacial stream stood apart in the dynamic structure of Dnieper (Saale), Sozh (Warthian) and Poozerje (Weichselian) glaciations, more fully and extensively uneven-aged ground and terminal moraines are represented.

Data on moraine petrographic properties on the territory of western Belarus was collected and analyzed by many researchers [1, 3]. Yet purposeful comparative characterization of coarse material of uneven-aged moraines along Baltic glacial stream route was not undertaken until now.

Analysis of petrographic composition of gravel-pebble fractions (over 5 mm) of morainic samples (0.5 m^3) with exposure of governing pebbles and boulders was performed by the world-known method [2]. In order to reconstruct more detailed picture of ice motion one had to take into account direction vectors reconstructed by measurement of pebble orientation, flaggyness of basal moraines, dislocations by a glacier, glacial valleys and terminal moraines.

Baltic glacial stream during different glaciations originated on the territory of middle Sweden and south-east Finland had close to sub-meridional motion direction and was rather wide. For its motion it used large topographic low. At the time of Dnieper glaciation the Baltic glacial stream on Upper-Prypyats lowland formed West-Polessje lobe and ended up in Ukraine. During Sozh and Poozerje glaciations restraining influence of the western Belarus uplands manifested itself, with its maximal boundaries marked by Middle-Niemen and Ozersk lobes. The eastern boundary with Chudskoe glacial stream passed across Estonia-Latvia strip of island uplands, Bujvidjaisk, Myadinkay and Novogrudok uplands.

On the territory of glacial stream expansion the most widely represented are ground moraines with thickness from 1 to 5–12 m. Uneven-aged ground moraines rest at small inclinations and submerge to the north. At that more fresh moraines overlap older ones, and often cut them and under-moraine quaternary deposits going deeper in bed rocks. Dnieper moraine comes out to the day surface in the southern part of Baltic glacial stream, is underlying fluvioglacial sediments and often lacustrine-boggy accumulations of Alexandrian interglacial period. Sozh moraine is the first from top horizon in the area Middle-Niemen lowland. Within glacial valleys and along their sides moraine is strongly dislocated, contains erratic masses of chalky and Paleogene deposits. At the bottom of Poozerje moraine rockmass of Sozh formations is developed, and only in Lithuania and further to north rockmass emerges to bottom layer.

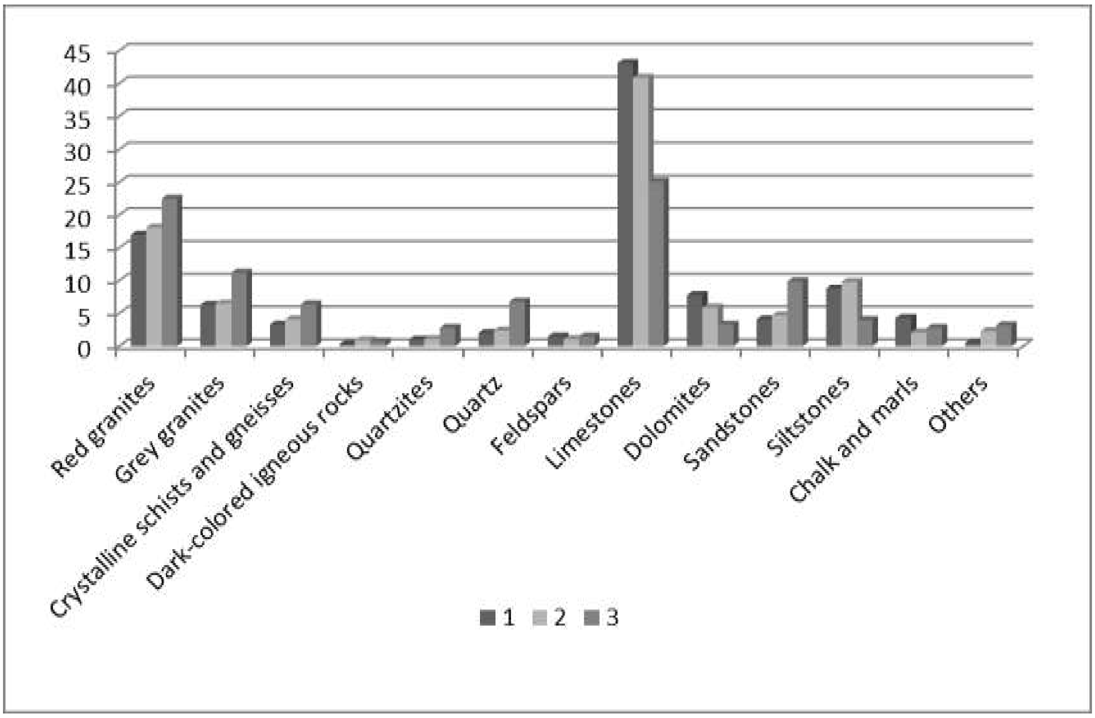

Fig. 1. Ratio of fragmentary material composition in uneven-aged moraines of the Baltic stream: 1 – Poozerje moraine, 2 – Sozh moraine, 3 – Dnieper moraine

The main suppliers of clastic material for Baltic glacial stream served exaration kitchen areas in the middle part of Fennoscandia, the Gulf of Bothnia, on Aland Islands and adjacent areas of the Baltic sea bottom, in Gulf of Riga and lowlands of south-east Lithuania and western Belarus. Location of head of glacial stream route reflect crystalline rocks of middle Sweden, south-west Sweden, Aland Islands and bottom of Baltic sea northern part. These are granites, gneisses, diorites, gabbro, diabases, porphyrites, crystalline schists, quartzites etc. At the segment of stream between south Baltic and south Lithuania Vendian sandstones and siltstones, Ordovician and Silurian limestones, marlstons and Devonian sandy-argillaceous and carbonate rocks of transient group were subjected to exaration. In western Belarus in moraines of the Baltic glacial stream important place is taken by Cretaceous system fragments of local rocks: chalk, marls, concretions of flints and phosphorites.

Uneven-aged moraines quite differ from each other by petrographic properties of gravel and pebbles (fig. 1). Samples of Dnieper moraines contain maximum quantity of Scandinavian rocks (granites, gneisses, quartzites) – up to 51.9 %. Share of transit rocks – limestones, dolomites, sillstones is minimal – 42.3 %. The homeland rock assumes 2.8 %. Ratio of crystalline pebbles to sedimentary pebbles equals 1.1, and limestones and dolomites – 7.6.

In Sozh moraine the amount of Scandinavian rocks, crystals of quartz and feldspars reduces down to 34.2 %. Content of transit rocks – limestones, dolomites and sillstones increases, and that of sandstones –

decreases. In a quantitative sense the leaders are limestones – (40.9 %). Share of homeland sedimentary rocks – 2.3 %. Ratio of crystalline rocks to sedimentary rocks equals 0.5, and limestones to dolomites – 6.9.

In Poozerje moraine the share of Scandinavian rocks and north part of the Baltic sea is somewhat decreased down to 31.4 %. Maximum content is reached by transit group rocks (limestones and dolomites) – up to 50.9 %. Quantity of homeland sedimentary rocks increased up to 4.3 %. As for the rest, Poozerje moraine is similar to the Sozh one.

The established features of moraine fragments' petrographic composition consist in that direction of the Baltic glacial stream motion changed in different glaciations. In Dnieper glaciation the Baltic glacial stream for considerable extension was in contact with Devonian bed rocks, was enriched with dolomites and sandstones, and transgressed from north to south. During Sozh stage it was saturated with carbonate and terrigenous Lower Paleozoic deposits of western Estonia and Baltic, and protracted to south-east. During Poozerje glaciation regional depressions within Lithuania determined south-east orientation of the Baltic glacial stream.

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LATEGLACIAL ENVIRONMENT IN NORTHERN LITHUANIA: AN APPROACH FROM LIEPORIAI PALAEOLAKE

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The multiproxy data (pollen, plant macrofossils, stable $\delta^{18}O$ and $\delta^{13}C$ isotope, magnetic susceptibility, loss-on-ignition measurements (LOI) and AMS ^{14}C dating) obtained from the sediment core (Lieporiai) representing N Lithuania have allowed reconstruction of the Lateglacial and early Holocene environmental changes. A chronology of the sediment core was established on the basis of AMS 14C dates and correlation of $\delta^{18}O$ and NGRIM $\delta^{18}O$ isotope curves suggests the onset of sediment accumulation 14000 cal yr BP. Treeless herbaceous tundra with dwarf shrub *Betula* and *Salix* predominated in the area during the initial stage of the palaeobasin formation. Finds of cold-tolerant plant *e.g.* *Selaginella selaginoides* (L.) Link and *Potamogeton vaginatus* Turcz. in the sediments suggests severe climatic regime typical for the Older Dryas. At the same time content of minerogenic material in the deposits was high due to intensive erosion processes and terrigenous material inwash into the palaeobasin from the surrounding bare ground. At about 13700 cal yr BP, the AP value slightly increased (especially pine pollen), and was accompanied by tree birch finds in the macrofossil evidence. The corroborating evidence of both analyses for Lieporiai indicates the presence of forest-tundra type vegetation with birch and scattered pine during this period. In our study, the value of mineral matter slightly rises at 170 cm depth and synchronizes with sharp drop on the $\delta^{18}O$ curve. This may be coincided with a cooler episode GI-1d (Lowe et al. 2008).

The Allerød is characterised by significant changes of vegetation composition. Warmer and more humid climate determined spread of *Pinus* predominating forest and degradation of herbaceous cover. Rise of organic constituent in the sediments suggests stabilization of the vegetation cover. The climatic conditions were favourable for carbonate accumulation which gradually reached the maximum at this time. This Allerød warming streak determinated around 13700-13200cal BP could be correlated with GI-1c event (van Raden et al. 2012, Lowe et al. 2008).

Considerable changes recorded in sediment structure (changes of $CaCO_3$, organic and minerogenic matter values) started at the 140 cm depth. It coincides with climatic transformation which is visible in the vegetation composition as well. According to pollen records the pine forest was exchanged by forest tundra vegetation with *Pinus* and *Betula*. The plant macrofossil diagram reflects considerable fall in total plant macroremains concentration and rise in number of cold-tolerant species finds. It suggests transition to colder Younger Dryas conditions.

Data obtained from the Lieporiai sequence indicate instability in vegetation composition and sedimentation regime, suggesting cooler and warmer intervals as well as humidity changes during the lateglacial in the area. These variations could be correlated with climatic events fixed in Greenland ice cores, European lacustrine and Atlantic Ocean sediments during the Lateglacial period (Yu and Eicher, 2001).

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DENDROCHRONOLOGICAL STUDIES OF BURIED OAKS AND THEIR IMPLICATIONS FOR PALEOGEOGRAPHIC RECONSTRUCTIONS

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Introduction

Under certain favourable conditions buried trees remain undeformed. These tree trunks may be used for dendrochronological researches. These researches are applied in order to identify the environment of the age and growth period of buried trees according to the annual tree rings in the section. In different years tree growth as well as annual tree ring thickness varies due to different air temperature, sunbeams, humidity and different soil fertility. When the age of the tree is established, the age of the sediment is also identified and the composed dendrochronograma characterizes the shift of palaeographic conditions.

Research methods

When making the dendrochronological

measurements of tree trunks and tree species, the following methods and devices have been used: in order to identify the species of a buried tree, a visual description together with a loupe and a microscope have been used. The name of a species was established while researching wood structure in various sections, when, identifying the age of a tree, the rings of the examined tree have been counted, they were recounted for 3-5 times, various sliders have been used when identifying the thickness of a tree ring. The thickness of a tree ring was measured with 0.01 mm accuracy, repeating the measurement for 2-4 times. In order to identify the growth period, radiocarbon (^{14}C) dating for tree trunks have been carried out.

Data of research

The buried oak trunks have been discovered in the outcrops of Dubysa River, Kelmė district, Zakeliškiai village and in Kartena district, Gintarai village (Lithuania), Minija gravel-pit. In the outcrops of Dubysa River, two buried tree trunks have been found to which dendrochronological and radiocarbon (^{14}C) dating research have been carried out. Three buried oak trunks to which dendrochronological research has been carried out, have been found in Minija gravel-pit. All tree trunks were well-preserved, hence it was established that it was a common oak *Quercus robur L*.

According to research data, the climate, at the time of the examined trees' growing, was unstable and often changed. The growth ages of the examined buried oak trunks range from the end of Atlantic climate to the period of sub-Atlantic climate.

During the Atlantic climate, the average temperature of summer months in Europe was 2.5 – 3.5°C higher than now (Gudelis, 1973). At that time, much more broad-leaved trees grew in the forests. At the end of Atlantic period, the climate cooled off; therefore, the climate was less favourable for the broad-leaved trees to grow. When analysing the dendrochronological research results (figure 1) of the oldest oak sample (No.7) 5365 + / - 35 years (A.Gaigalas and others), which grew at the end of Atlantic climate, it was noticed that at about 80 years' period the climate ranged because the thickness of tree rings always changes. Besides, the diameter of this 77 years old tree is relatively thin, only 9.5 cm.

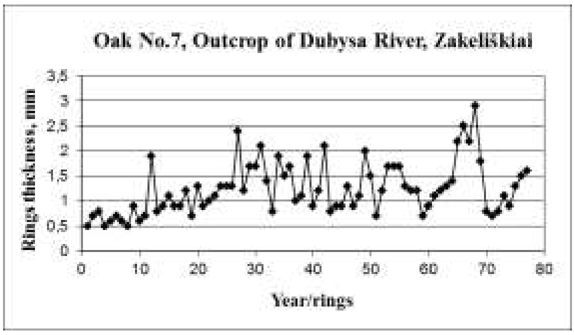

Figure 1. Dendrochronograms of Oak Quercus robur L trunk No.7.

In Dubysa River, the wood of Atlantic climate period oak trunk is thicker and its colour is the darkest (Charcoal) different than other examined buried oak trunks. While comparing this example to another oak trunk No. 8 which was found in the old riverbed of Dubysa, it is clearly seen, that it is from considerably later period than the trunk example No. 7 from the Atlantic climate period. The identified age of the oak example No. 8 is 1750 +/- 30 years (A. Gaigalas and others) and its growing age corresponds to sub-Atlantic climate period. The trunk colour of oak example No. 8 is not smooth from the edge towards the pith – in the edges it is black, closer to centre the colour lightens to grey. Its colour particularly differs from the Atlantic climate period oak as it is black and smooth. According to this data, it may be claimed that depending on the colour of a buried tree trunk, the smoothness of its colour and thickness of the wood, it is possible to approximately identify the growth period of a tree. On the basis of the previous information it may be also claimed that the oaks No. 1, 2, 3, examined in Minija gravel-pit, grew in sub-Atlantic climate period, they are similar to the example No. 8 for their colour lightening from the tree bark towards the pith and the thickness of their rings is similar too (figure 2).

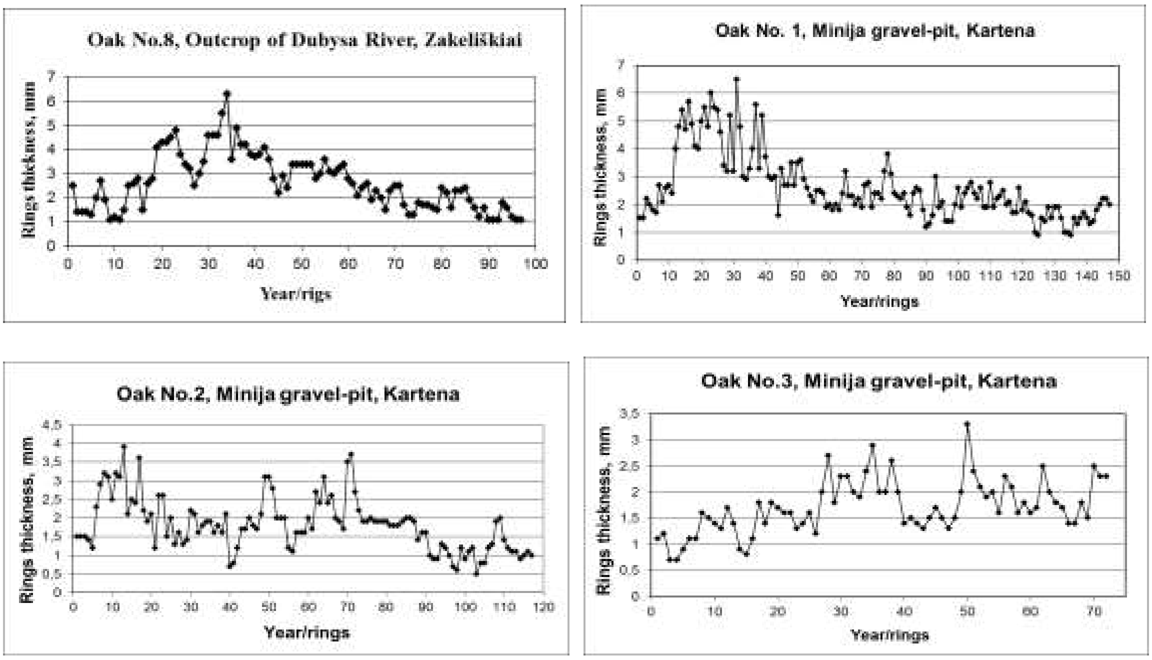

Figure 2. Dendrochronograms of Oak Quercus robur L. trunks No.8, No.1, No.2, No.3.

Conclusions

After having carried out the dendrachronological research of a buried tree trunk section, having identified the age, the thickness of tree rings and having compared them among themselves, it is possible to re-create the specific climate features of the tree growing time. The results of this research are significant while reconstructing the palaeographical conditions.

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A MODEL OF GLACIODYNAMIC DEVELOPMENT OF THE POOZERIE GLACIATION IN BELARUS

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In study of the Poozerie (Weichselian) Glaciation on the territory of Belarus palaeoglaciodynamic reconstructions are extensively used. Usually they come in the form of icecap cartographical representation. Presently, the models of glacier structure of Poozerie period in northern Belarus have been already proposed [1–3, 5]. Usually different authors reconstructed ice sheet proceeding from study of one-three natural constituents (ancient forms of relief and deposits, composition of moraines, space geological investigations, and others) and reported them in terms of generalizations. Whereas glaciodynamic build-up of structure and dynamics of glaciations development through the extensive use of geotectonic-geologic, geomorphological, lithologic-and-petrographic data has not evolved yet.

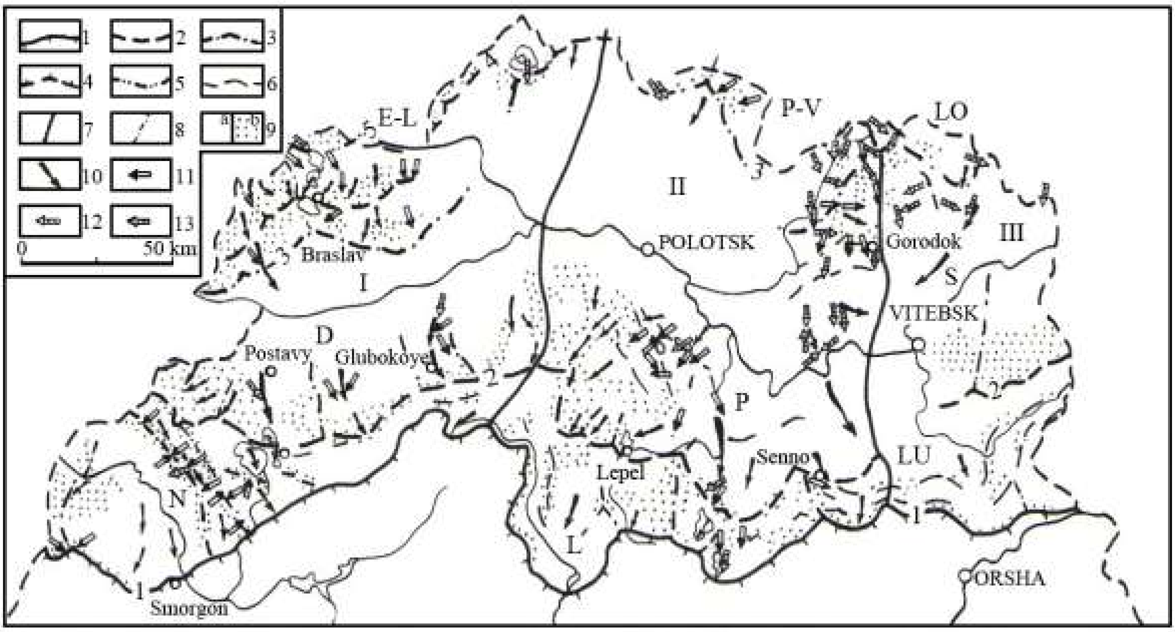

Fig. 1. Map of dynamics of the Poozerie Ice Sheet on the territory of north Belarus:Icecap boundaries: 1– Orsha stage, 2 – Vitebsk phase, 3 – Braslav stage, 4 – Slobodka phase, 5 – Kraslava phase, 6 – oscillations, 7– glacial divides of streams, 8 – iceshedes of lobes and tongues, 9 – zone of viscoplastic ice creep (a) and ice creep along internal splits (b). Direction of ice motion according to data of: 10 – orientation of exaration palaeo-valleys, 11 – glacial structures and glacial dislocations, 12 – textural elements of basal moraines, 13 – coarse-grained material of basal moraines. Glacial streams: I – Riga, II – Chudsky, III – Ladozhsky. Glacial lobes: N – Narochanskaya, L – Lukomlskaya, LU – Luchosskaya, D – Disnenskaya, P – Polotskaya, S – Surazhskaya, E-L – East-Latvian, P-V – Pskovsko-Velikoretskaya, LO – Lovatskaya

A model of glaciodynamic development of the Poozerie Glaciation in northern Belarus was suggested on the basis of comprehensive interpretation of geological and geomorphological data (Fig. 1). It presents the structural and dynamic differentiation of the Belarusian sector-peripheral zone of the Poozerie ice sheet on the transgressive stage at Riga (Baltic), Chudskoje and Ladoga glacial streams which ended in lobes. In the regressive phase the ice sheet was characterized by intermittent areal reduction accompanied with necrosis of bands and fields of peripheral ice of different width, the deep down retreat of the active ice edge and its oscillations on the dead remnants of ice in the retro-transgressive stages and phases. On the basis of interpretation of geological and geomorphological materials in the process of degradation of the last glaciations in Belarusian Poozerje area are distinguished three main marginal zones of repeated glacial advance: the maximum (Brandenburg) zone of stadial rank along the southern boundary, the Vitebsk (Frankfurt) phasial zone in the center, and the Braslav (Pomeranian) zone of stadial rank in the north.

The common laws of deglaciation of the Poozerie glacier and its specific features at different stages have been reconstructed. The general laws include: the active areal nature of deglaciation with vibrations of the ice edge of different rank, higher level of dynamism of the Poozerie glacier and growing intensity of the associated geological processes from the maximum phase to the Vitebsk and their decrease in the Braslav zone, the relative instability and shifting of ice divide into major phases and stages; synchronism in the manifestation of phases and stages, and autonomy in the development of individual glacial streams, lobes, and tongues; glaciodynamic adjustment, position of certain elements and complication of the structure of marginal zones; control by large unevennesses of glacial bed of dynamics and structure of icecap at different stages.

The basic stages of glacier retreat have their characteristic features. At the maximum stage the marginal zone of the glacier experienced a relatively short-term stabilization and contacted the periglacial zone. Active areal deglaciation in the sector of Naroch lobe was mostly replaced with the frontal one with two oscillations in the area of other lobes.

In the Vitebsk phase, the marginal zone developed on the boundary of active ice fields with dead ice fields over 6–8 oscillatory motions. The Desna lobe and the western flanges of the Polotsk and Surazh lobes as well as their ice divide zones exhibited higher activity.

We have reconstructed three active phases in the formation of the marginal zone of the Braslav stage. The key feature of the Poozerie Glaciation dynamics was the appearance of a host of small separate outlet glaciers in later phases, which say for hypothesis of the pulsing nature of glacier degradation [4].

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RECONSTRUCTION OF PALEOTOPOGRAPHY BASED ON LIMNIC AND SLOPE SEDIMENTS ANALYSIS IN THE CZECHOWSKIE LAKE (NORTH CENTRAL POLAND)

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Czechowskie Lake is situated in north-central Poland in Tuchola Forest. It is located about 100 kilometers away from Gdańsk. It occupies the dividing position between Wda and Wierzyca catchments, local tributaries of the Vistula river. Czechowskie Lake has the area of 76,6 ha. Actual water level is at the height of 109,9 m a.s.l. The average depth is 9,59 m, maximal 32 m. Recently it has the volume of 7 350 000 m^3. The lake occurs in a large subglacial channel, now reproduced within the glacifluvial sediments of the Pommeranian phase of the last glaciation (Błaszkiewicz 2005, 2011). In the widest place it has the width of about 1 kilometer. The maximal depth of the channel (counting from the channel edges to the reconstructed deepest lake mineral floor (after removal of the limnic sediments)) may reach near 70 meters. Inside of the channel some throughs and small hills do exist which are built of outwash sediments but, considering internal structures, they bear some similarity to the dead ice moraines and kames. The vicinity of the channel consists of two outwash plain levels. The lower one was created on the dead ice blocks therefore after its melting the lower topographical level come into being. Toward the north a vast morainic plain does exist with dispersed kame hills which are also poking out of the outwash sediments in the transitory zone to Czechowskie Lake. In direct vicinity of the lake absolutly dominate the dead ice kettles with various sizes and morphology. Generaly the larger forms comprise even smaller forms.

In the deepest parts in the lake there are hidden laminated sediments which holds the Late Glacial and Holcene climatic record. These deposits are subject of ongoing, detailled work within the framework of joint german-polish Virtual Institute of Integrated Climate and Landscape Evolution (ICLEA) of the Helmholtz Association. Aiming to determine the topography of the primordeal lake floor there was undertaken the boring campaign which delivered over 160 profiles made with the use of Instorf corer as well as the Livingstone corer (in modification of Więckowski) in the most interesting places. The analysis of the derived field material has revealed the graet lithological diversity of the sediments. Spatial analysis of them have lead to following conclusions:

1. The maximum infilling with the limnic and telmatic sediments reaches over 12 m. In the bottom of the lake there is marked the presence of many overdeepenings with the diameter of dozen or several dozen meters and the depth of up to 10 m with numerous, distinct throughs between them. They favoured the preservation of the lamination in the deepest parts of the lake due to waves hampering and stopping of the density circulation in the lake waterbody.
2. The glaciolimnic phase of the sedimentation begann with the accumulation of the several centimeters or decimeters thick bed of often laminated clay or silt gyttjas or just simply clays and silts. Numerous flexures, deduced from the cross sections, indicate widespread subsidence, because of the subsequent dead ice blocks melting which propped out the accumulated sediment masses. At the transition between the glaciolimnic phase to the typically limnic phase there is a layer or in some places two layers of basal organics, mainly peat sometimes plant detritus, with the thickness of up to some centimeters. The peat was accumulated over the melt-out moraine which covered still existing dead ice blocks.
3. The typic, limnic phase began with the deposition of calcareous gyttja having the thickness of a dozen or several dozen centimeters. In deeper places gyttja is laminated. Palinologically it was ascribed to Allerőd times. In our opinion this sediment marks the maximum stage of the lake development which was about 1,5 meters higher than today.
4. Bottom parts of the lake sediments, excluding the gyttja from Allerőd, are composed of: algal, algal-calcareous, silty-calcareous, calcareous-algal gyttja. The top parts of the profiles are built of often pink, massive, calcareous gyttja. Additionaly within it occurs some thin algal and calcareous-algal gyttja intercalations. The lithofacial development of limnic sediments is strongly dependent upon the place in the fromer waterbody and upon the actual depth in the lake while the deposition. In the small, isolated overdeepenings the gyttja has more organic, detrital component, whereas the gyttja in more open basins has more calcareous component.
5. The gyttjas in the shore zone and in the vicinity of former lake islands are generally enriched in unsorted sands and gravels which apart from waving indicate periods of sediment sliding and slumping within the lake bottom.
6. In the lower parts of the lake sediments there appers zones of distinct lamination. At least three such zones were found. They allow to suppose the existence of at least three periods of the hightened water level. This high water stand caused the temporary rise of the wave base in the waterbody creating favourable conditions for lamination preservation.
7. In respect to the composition and the thickness the surface peat layer is very variable. Its maximum value reach 2,5 m but is strongly dependent upon location in the former paleolake plain. The peat consists from the following types: sedge (dominating), sedge-reed, reed-moss, sedge-moos and moos one. What interesting the peats are better developed on the northern banks of the paleolake as on the southern ones. This may be linked to diminished light and warmth delivery in the northern expositions which indeced the growth of the peat building plant species.
8.

Acknowledgements:

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ON THE INTERNAL STRUCTURE AND EVOLUTION OF THE THIRD TERRACE OF THE RIVER GAUJA DOWNSTREAM OF VALMIERA

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Between Valmiera town and Murjāņi village the River Gauja valley span, known as the Gauja spillway according to Āboltiņš (1971), is about 110 km long. The valley has asymmetrical cross-sectional profiles with prevalence of erosional terraces (Āboltiņš *et al.* 2011). These terraces represent the Sigulda terrace spectrum of the River Gauja valley. On the basis of geomorphological and geological investigations Āboltiņš (1971) has distinguished seven terrace levels at the town of Sigulda.

Formation of the River Gauja spillway began after ice retreat from marginal zone of the North Lithuania phase at least about 15.2 cal. ka B.P. (Āboltiņš *et al.* 2011). Terraces VII to IV apparently are formed before Allerød. Terraces VII and VI were formed by meltwater streams which flowed from melting dead ice and small proglacial basins located adjacent to the upper reaches of the spillway into the Silciems ice-dammed lake. Terraces V and IV were produced as a result of the water drainage from the Strenči meltwater basin into the Zemgale ice-dammed lake. Terraces III and II are formed during Allerød and Younger Dryas. They relate to levels of stage Bgl II and phase Bgl IIIb of the Baltic Ice Lake. Terrace I is aggradational and conjugated with the Littorina Sea phase Lit a level. The lower part of the river valley is occupied by an aggradational flood plain (Āboltiņš *et al.* 2011). Up to now there are different views on sedimentological record of the terrace III (Ābolkalns et al. 1960; Āboltiņš 1971).

Near the Līči sanatorium terrace III is located 38-40 m a.s.l., and 11-14 m above the River Gauja level. This terrace is traceable in 1500 long and 300 m wide span of the river valley. During test drilling and pitting in the beginning of sixties 400 m south of the main building and 100 m south-east of the new residential building of the Līči sanatorium, in fine grained sand 38.5 m a.s.l. inclusions of plant remains were found (Ābolkalns et al. 1960). Geological cross-section which depth reaches 4.35 m consists of fine grained sand and silt. Plant remains were found in depth from 2.91 m to 3.16 m, and from 3.47 m to 4.35 m from ground surface. In this location samples of plants were collected to determine macroscopic remains and their possible age using radiocarbon dating method. Obtained results shows that age of plant remains collected in the River Gauja terrace III are 10,535±250 (Ri-33) and 10,282±250 (Ri33A) ^{14}C years BP (Stelle et al. 1975 a, b) or by calibration using IntCal09 radioactive carbon age calibration curve (Bronk Ramsey 2009; Reimer et al. 2009), age of macroscopic plant remains are in range from 11,013 to 9460 and 10,659 to 9312 years before nowadays.

Recent studies have been carried out in summer 2012 to supplement the information on the riser of the River Gauja terrace III composition and structure, as well to collect new samples containing plant macroscopic remains, and to complement the data on terrace age with AMS ^{14}C dating method. Before field studies according to literature sources, interview with O. Āboltinš (pers. comm.) and photo fixations earlier study location were established. In order to reveal the internal structure of terraces new hand-drilled test boreholes were made.

Obtained geological cross-section consisted of fine grained sand with silt and silt admixture. Highly scattered macroscopic plant remains were found in almost all boreholes in depth from 3.19 m to 4.19 m and from 6.93 m to 7.21 m from the ground surface, or 35.39-34.39 m and 30.92-30.64 m a.s.l. From boreholes resulting plant macroscopic remains were not in sufficient quantity to determine age using AMS ^{14}C method. Removal of sample, taking account the groundwater level, would be possible in dry summer only by test pitting.

Formation of the sediments forming the River Gauja terrace III is still questionable. In order to reveal the internal structure of the terrace hand-drilled test boreholes were made, lithological composition and textures of sediments were studied, and facies analysis of the sediment units was performed. Outcrop lithological composition at the Dukuļi farmhouse on the terrace III of the right bank of the River Gauja pronounced numerous characteristics that indicate rather glaciolacustrine origin of sediments. Outcrop is situated 4.1 m above river level and 33.40 m a.s.l. Thickness of glaciolacustrine sediments reaches up to 4.5 m. The lower part of the section is built by fine grained sand interbedded with silt and clay admixture. An upper part of the section consists of silt and fine grained sand with weakly unvoiced ripple cross-lamina. Lithological composition, textures and facies analysis of the sediment units give evidence on accumulation of these sediments in basin, supposedly in glaciolacustrine environment but not alluvial origin as it was interpret in previous studies (Ābolkalns et al. 1960; Stelle et al. 1975a, b).

Still unanswered is question about genesis of the River Gauja terrace III. In previous studies (Ābolkalns et al. 1960; Āboltiņš 1971) both highest terraces of the lower complex (terrace III and II) are related to levels of the stage Bgl II and phase Bgl IIIb of the Baltic Ice Lake. Sediment depositional environment was interpreted as oxbow lake and floodplain members (ibid.). The latest studies of the outcrop exposing internal structure of the "riser" of terrace III on the right bank of the River north of the farmhouse "Dukuļi" testify sediment deposition in palaeobasin contacting with dead ice. Such interpretation is also supported by evidence of ablation moraine lenses located in the lower part of the outcropped section. Only upper part of the cross section testifies sediment accumulation environment as alluvial or alluvial-lacustrine which produced as a result of the water drainage from meltwater basin. After palaeobasin leaking, the River Gauja valley cutting and erosion terrace formation started. According to geological and geomorphologic evidences (Āboltiņš, 1971), then river cut and its bed gradually narrowed.

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CLIMAT VARYABILITY IN SOUTH-EAST PART OF BALTIC REGION IN HOLOCENE BY ANALYZ OF TOTAL ORGANIC CARBON CHANGES

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Paleogeographical investi-gations of south-east part of Baltic region in Holocene started in 2009. In this year we investigated the peat-bog Velikoe. In 2011 we started to study the lake bottom sediments of Lake Kamyshovoe. More than 7 meter of sapropel was taken for research by radiocarbon, palyinology, geochemistry and grain-size methods. At the present we obtained first results about the total organic carbon concentration along the sediment sequence. Concentration of total organic carbon depends of bioproductivity of lake, which depends of climate dynamic. Than more high concentration of the total organic carbon in layer, then more favorable climatic conditions dominated in this period. Thus, percentage of total organic carbon can be used as proxy data for investigation of climate variability.

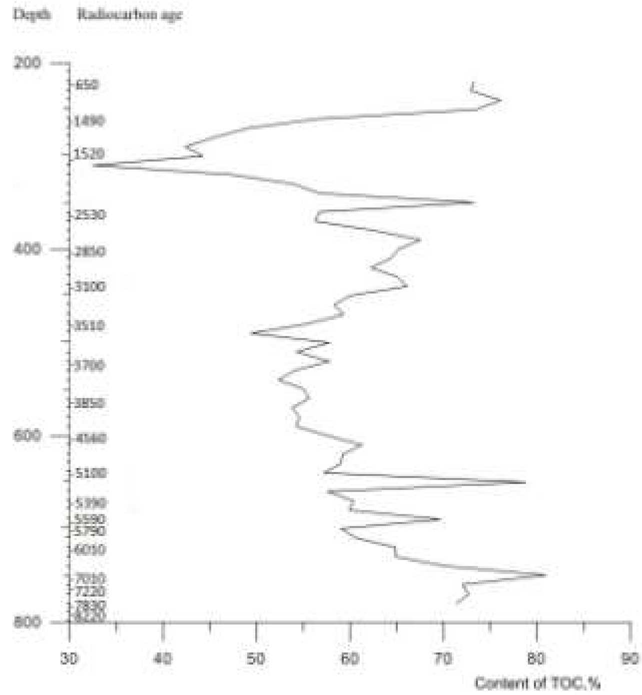
Paleogeographical investigations of south-east part of Baltic region in Holocene started in 2009. The main goals of our research is nature-climatic changes in Late Pletstocene and Holocene. Our research are based in paleogeographic and radiocarbon investigation cores from peat-bogs and lake bottom sediment. . In 2009 we investigated the peat-bog Velikoe (N 54º 57’ 06’’, E 22º 20’ 28’’; 34 m. above Baltic basin; area about 2000 ha.), it located in Eastern part of Kaliningrad region in watershed of Sheshupe river. The results of this research already are published (Arslanov Kh.A and others 2010).

In June 2011 started new expedition in Vishtynets highland for taking cores from lakes with different position of Baltic basing. During this expedition we investigated Kamishovoe lake (54º22’531’’N, 22º42’750’’E, 189 м. над у.м.). This is small lake – maximum length 1200 m., width – 600 m., depth – 2.2 m. In result of boring was taken 7,3 meters of bottom deposit presented from top to bottom highorganic sapropel, brown-grey clay sapropel and dark-grey clay alevrit. All deposits were selected by Russian borer diameter of sampler 7 cm and 5 cm, 1 meter length. Total was taken 9 cores 1 meter length each other. In the laboratory every core was divided on 10 cm samples, with were investigation by lithological, palynological, grain, carbon dating and geochemical analyzes (Kublitskiy and others 2012). In the present time perform palynological analyzes and grain-size analyses and provided the first data on the content of total organic carbon (TOC), dynamics of this element we will be discussed in this article. TOC reflects the biological productivity of the reservoir in time, which is directly dependent on climatic parameters, especially on the air temperature. Then higher summer temperatures, the higher the content of TOC in a particular layer of sediment section.

If we investigate changes in the percentage of TOC in time, it is possible to draw conclusions about the dynamics of the climate. These data are not precise, and using them will not be able to enter the specific numbers, however, allow us to understand the direction in which climate change is taking place

Below is a graph of the TOC in the content of sediment Kamyshovoe lake (Fig.1).

TOC changes in the content of sediment Kamyshovoe lake



As can be seen from the graph, the study area of about 7830 years ago, the contents of the TOC was same with present time.7100 years ago there was a slight increase in TOC, which can be associated with the time climatic optimum. The content of TOC started gradually to decline, but the 5600 and 5200 years ago concentration of TOC was increase. 3,800 years ago a sharp change in the concentration of TOC was not observed, but 3800 and 3500 years ago, it may be noted TOC reduction, which may indicate the cold weather. After this peak, the concentration gradually increased, reaching 2,400 years ago up to the next peak and then abruptly went into decline, reaching a minimum for the entire study period of about 1600 years ago, after which the content of TOC quite sharply went up and adopted modern values. The high content of TOC in the period 7830-5600 years ago can be due to the Holocene climatic optimum. Reducing the concentration of TOC 3500 BP coincides with the sub-boreal period, which is characterized by coldness and dryness. TOC increase occurring in 2400 BP, corresponds with warm climate of sub-Atlantic period. However, such a sharp decline in the percentage content of TOC to 1600 yr BP it is difficult to explain, this may be due to regional climatic conditions. Further studies will answer this question. Except for a sharp decrease in the concentration of TOC in the Sub-Atlantic period, for the other part of the studied section of sediment dynamics of the percentage of TOC in the sediments is well correlated with the climatic conditions of the Holocene.

When the study of palynology, geochemistry and grain size for the object will complete, then we can more accurately describe the dynamics of the natural environments in the South-Eastern part of the Baltic region Holocene.

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THE ^{230}TH/U AND ^{14}C DATING OF THE LATE PLEISTOCENE ORGANIC-RICH DEPOSITS FROM THE NORTH-WESTERN RUSSIA

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The Vychegda-North Dvina fluvial system is situated in the North-East of Europe in the area of influence of the last ice cover. A new geochronological data obtained in recent years for this region are given in this paper.

The ^{230}Th/U radioisotope dating method may be applied to Holocene and Pleistocene Interglacial (Interstadial) deposits in the range from 1-2 to 300-350 kyr. Age data for a number of buried peat and gyttia samples, as well as travertine and wood, have already been obtained (Heijnis, 1992; Kuznetsov et al., 2002, 2011; Kuznetsov & Maksimov, 2003, 2012; Gaigalas et al., 2007; Laukhin et al., 2007, Kuznetsov, 2008; Razjigaeva et al., 2011; Maksimov et al., 2006, 2011, 2012; Nikitin et al., 2012). Some of these dates are disputable, however, so it is increasingly vital to obtain reliable ^{230}Th/U ages for further palaeogeographical, palaeoclimatic, and stratigraphic reconstructions.

From this point of view, the reliability of ^{230}Th/U dates can be confirmed by applying simultaneously a complex of dating methods: e.g. ^{14}C and ^{230}Th/U dating of organic sediments with ages less than 50 kyr and OSL dating of the overlying and underlying sediment layers.

We carried out such investigations of sediments from the Tolokonka profile (61^{0}46,25' N, 45^{0}26' E) located on the right bank of the North Dvina River (North-Western Russia) (Kuznetsov et al., 2011; Maksimov et al., 2011). The profile of 30 m thickness studied in 2010 and 2012 is composed of (from the bottom to the top): A) alluvial sands; B) thick peaty loams with plant remnants, possibly of the Eemian age and lacustrine origin; C) alluvial sands; D) a strata of interlayering sands and silts with ice wedges (D1), southwards this horizon is replaced by pure sands (D2); in the upper part of D-layer there is a loamy peat horizon of 20-80 cm thickness; E) thick layer of alluvial sands; F) laminated loam with gravels; G) alluvial sands; H) loamy silts; I) sand; J) loam with gravel at the bottom and a dropstone ø 0.5 m.

The ^{14}C ages 42.5±0.6 cal BP and 38.5±0.4 cal BP were determined for the bottom and the top of organic sub-layer in the upper part of D-layer respectively. Content of the mineral fraction was in the range of 55-69% in the analyzed loamy peat samples. Two ^{230}Th/U dates 39.1+/-7.6/6.6 kyr and 42.5+/-2.8/2.7 kyr obtained for the same layer were calculated according to the new version of isochron approximation. This approximation is based on agreement of isochron-corrected ^{230}Th/U ages (Geyh, 2001) obtained for the same duplicate samples, which had been analyzed by the "leachate alone" (L/L) and "total sample dissolution" (TSD) techniques (Kuznetsov & Maksimov, 2003, 2012; Maksimov et al. 2006). The OSL dates 12-16 kyr for the overlying G-layer and 73±10 kyr and 78±10 kyr for the underlying C-layer were determined. The results of ^{14}C and ^{230}Th/U methods are in a good agreement and all the dates (OSL, ^{230}Th/U-, ^{14}C) fit to the stratigraphic sequence (Kuznetsov et al., 2011; Maksimov et al., 2011).

The results of the cross ^{14}C and $^{230}Th/U$ dating of buried soil layer from the Kur'jador profile (61^{0}46,25' N, 45^{0}26' E) located on the right bank in the upper reaches of the Vychegda River (North-Western Russia) confirmed the reliability of the $^{230}Th/U$ ages. The calibrated ^{14}C age in the range of 43.6-41.6 cal kyr BP corroborated the isochron corrected $^{230}Th/U$ dates 47.8±2.3 kyr (according to the L/L technique) and 42.8±4.0 kyr (according to the TSD technique) (Zaretskaya et al., 2012). Content of the mineral fraction of the analyzed samples in the range of 86-97% was higher than in the loamy peat samples from the D-layer of Tolokonka profile.

The application of multiple independent methods to the dating of organic-rich samples, in combination with radiometric dates of both overlying and underlying sediments, allows us to increase the reliability of geochronological data significantly. Therefore, we applied the $^{230}Th/U$ method to date peaty loam samples from the B-layer in the Tolokonka profile. The U and Th isotopes were purified and separated using analytical technique described earlier (Kuznetsov et al., 2002; Kuznetsov, Maksimov, 2012). The alpha-spectrometric measurements were made for several days applying the alpha-spectrometer "Alpha Duo" (ORTEC). The $^{230}Th/U$ ages 120.4±11.9/9.2 kyr (L/L-technique) and 104.0±9.4/8.0 kyr (TSD-technique) were calculated according to the new version of isochron approximation. Content of the mineral fraction was in the range of 88-91% in the analyzed peaty loam samples. These dates as well as previous radiometric data obtained for the profile samples confirm the Eemian age of the B-layer and reflects their correct stratigraphic sequence.

The $^{230}Th/U$ ages obtained according to the new version of $^{230}Th/U$ isochronous dating of buried organic-rich sediments allow us to consider these radiometric data quite reliable. A new possibility of $^{230}Th/U$ method in dating organic-rich sediments with a high degree of mineralization such as loamy peat, peaty loam and soil opens up the prospects of its application in geochronology of the Late and Middle Pleistocene.

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GROUND PENETRATING RADAR SURVEY OF SOME KAME HILLS, CASE STUDY

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The paper presents the results of a ground penetrating radar (GPR) investigations carried out in the south and central parts of Chelminska morainic plateau, wich are built up of the numerous dead-ice forms (Niewiarowski 1959, Wysota 2007). Among them are the Owieczkowo kames together with a sequence of eskers (Lisewo esker) between Golub-Dobrzyn and Kowalewo, create the compact complex recording their course the direction of the outflow of melt-out waters, extending further north in the direction of kames in Piatkowo and Zapluskowesy. All kame hills are located in the surroundings of the basale moraine, among the south and northern part of the Lisewo esker. The numerous meltout depressions exist in the neighbourhoods of the esker and kames. Georadar studies were supported by geologic data from exposures and mechanical drillings (up to 18 m).

GPR studies in stratigraphy of the quaternary sediments are widely used (Davis, Annan 1989, Huggenberger et all 1994, Jol et all 1996, Lamparski 2001, Lamparski 2004, Neal 2004, Van Overmeeren 1998). GPR was used to examine the sedimentary structure and thickness of fine sandy and silty sediments that built the hills. All kame hills were crossed by several GPR profiles with ranges 100-500 ns, using 400, 300 and 35 MHz antennae. Correlation between patterns of radar facies and drillings is quite good and allows to recognize structure of the sandy and silty sediments up to 17-18 meters depth as well as to recognize some faults. Possibilities to recognize the internal structure of the kame hills by GPR method will be discuss with an example of investigation of two kame hills near Owieczkowo, kame hill near Zapluskowesy and another one near Piatkowo.

The study confirmed the existence in the kame hills silty-clayey layers, falling towards the center of kames and outgoing upward at the edges of the forms. The image of the structures, which have shown by GPR survey was very detailed and included several categories of facies (in the sense of GPR facies). Was observed supposed quiet zone of plain sedimentation limited horizontal by the zones of occurrence of numerous geophysical anomalies interpreted as boulders and flow matrix. In the entire mass of sediment was observed numerous discontinuity of geophysical line anomalies, interpreted as a plane of fault. The faults came down to the bottom sediments. The presence of faults in the entire mass of sediment indicates sedimentation of the lake sediments on the ice. The pattern of the geophysical anomalies on GPR profiles take the form of concentric macrostructures. The structures are horizontal in the central parts of the plateau, go up into the air concentrically with the distance from the culmination. Anomalies interpreted as flow material are observed mainly in the marginal parts of the hills. In the culmination of the western Owieczkowo kame hill thickness of the sandy sediments was determined at approximately 17 m.

Studies were also carried of the eastern Owieczkowo kame hill. The system of geophysical anomalies imaging most likely the sequence of sandy silty sediments. Here again in the central part of the kame, GPR anomalies are arranged horizontally. Relatively shallow beneath the surface of the hill, in some places, there are significant elevation of sediments in the form of a highly disordered structures. From the beginning of the profile, up to 130 running meters in the ground occurs, typical for clays, pattern of overlapping each other reflections generated by gravel and boulders. There is no doubt in this area the horizontal line represents the limits of sandy clay sediments with bottom moraine.

In both of the Owieczkowo kame hills occurs a different system of the macrostructures. West kame hill shows a quiet arrangement of layers, typical for the glacilacustine kames. The east one seems to have a different origin. In the culminating part system of layers takes the horizontal position. Eastwards layers arranged in clearly as sloping, perhaps in the shape of delta. This is undoubtedly related to the close proximity of water outflow from the former lake in the direction of the eastern and south eastern direction of the lisewski esker.

The GPR studies of the Zapluskowesy kame hill have shown its internal structure in the form of the geophysical anomalies pattern. Especially clearly were distinguished the structures that represent the layers of silt in the fine-grained sands. These layers at the edges of the hill go up in the air.

The GPR researches of the Piatkowo kame hill were carried out close to a large quarry. Comparison of the pattern of geophysical anomalies on radargrams with this quarry allowed to determine the interpretation of the recorded anomalies

In all kame hills were measured dielectric constant by Frequency Domain Reflectometry method (FDR).

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GLACIAL LINEATIONS IN THE CENTRAL LATVIAN LOWLAND AND ADJOINING PLAINS OF NORTH LITHUANIA

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Glacial lineations in the Central Latvian Lowland CLL) and adjoining plains of North Lithuania are represented as drumlins, megaflutes and mega-scale glacial lineations (MSGL). In some places glacial lineations are superimposed by ribbed moraines and eskers. Drumlins in CLL are studied since 30 years of the 20th century (Dreimanis, 1936; Straume, 1968; Āboltiņš, 1970; Ginters, 1978; Straume, 1979; Zelčs et al., 1990; Zelčs, 1993; Zelčs & Dreimanis, 1998) and more recently are investigated by Lamsters (2012) and Lamsters & Ošs (2012).

Glacial lineations were identified and mapped from the topographical maps of scale 1: 10,000 in Latvia and from hillshade images of the digital elevation model (DEM) with a resolution of 5 m (created from Lithuanian LIDAR data) in the North Lithuanian plains (NLP). In total 3500 glacial lineations and 2500 superimposed Zemgale ribbed moraines (Lamsters & Ošs, 2012) were mapped and their morphometric parameters obtained and included in the database that contains the largest amount of glacial lineations ever reported (e.g. Zelčs, 1993; Guobytė & Satkūnas, 2011) from the area under consideration.

The formation of studied glacial lineations occurred during oscillatory retreat of the Late Weichselian Scandinavian Ice Sheet in the Middle Lithuanian and North Lithuanian glacial phases by the main body of the Zemgale ice lobe (ZIL). The largest Pra-Zemgale drumlin field (Zelčs et al. 1990) formed during North Lithuanian glacial phase was disintegrated later by superimposition of Zemgale ribbed moraines, and only parts of it are preserved as Zemgale and Iecava drumlin fields. These drumlin fields also extend in NLP, in places up to the North Lithuanian marginal ridge (Fig. 1A). The most elongated drumlins occur in the central and distal part of CLL and NLP suggesting the fastest ice flow of the ZIL during the North Lithuanian glacial phase.

The ice flow direction of the main body of ZIL changes from WNW- ESE in the Madliena drumlin field (Lamsters, 2012) to SSE-NNW in the Vadakste drumlin field, so we assume that ZIL during Middle Lithuanian glacial phase was divided in several ice tongues but the fastest ice flow was sustained in the main central body of the ZIL as it is evident from glacial lineations. These lineations are preserved in the NE part of the Middle Lithuanian Lowland, towards the west they are buried beneath sediments of ice-dammed lakes and destroyed by fluvial activity. The morphology, arrangement and elongation of these glacial lineations resemble MSGL (Fig. 1B) that are discovered under Pleistocene and modern fast flowing ice beds (e.g. Clark, 1993; King et al., 2009). Identified MSGL are characterized by high parallelity, their height usually does not exceed 5 m, length is up to 24 km and elongation ratio up to 50, so they are longer than MSGL reported in the Dubawnt Ice Stream in Canada (Stokes & Clark, 2002) that are up to 13 km long, have elongation ratios of up to 43:1 and are evidence to fast flowing ice streams.

The internal structure and composition of drumlins were studied in several sand and gravel pits. In all cases cores of drumlins consist of glacioaquatic sediments with different level and depth of glaciotectonic deformation. All cores of studied drumlins are capped by a few meters thick layer of till, but in some places sandy sediments are exposed at the surface. Units of till that form imbricated thrusts on the flanks of some drumlins and on radial segments of the Zemgale ribbed moraines are formed by the ice stress from the inter-drumlin depressions. The internal structure of some drumlins was also changed during the final stage of the deglaciation by the transverse ice stress.

At least four steps can be recognized in the formation of subglacial bedforms in the CLL. At the first step Rogen type ribbed moraines are created as suggested by several authors (Zelčs, 1993; Zelčs et al., 1990, Zelčs & Dreimanis, 1997). These moraines were almost completely destroyed during the second step, only some of them survived in the Zemgale and Vadakste plains proximally from North and Middle Lithuanian marginal ridges. At the second step melting ice bed accelerates extensional ice flow and facilitates drumlin formation. At the third step ice flow regime changes to compressional in the SE part of ZIL and Zemgale ribbed moraines forms. This leads to the SE part of ZIL shutdown that corresponds to the model elaborated by Stokes et al. (2008). The absence of the Zemgale ribbed moraines in the central and W part of ZIL might suggest that these parts of ZIL remained active longer. At the fourth step ice margin retreats, subglacial drainage is sustained in R-channels as inferred from the presence of eskers.

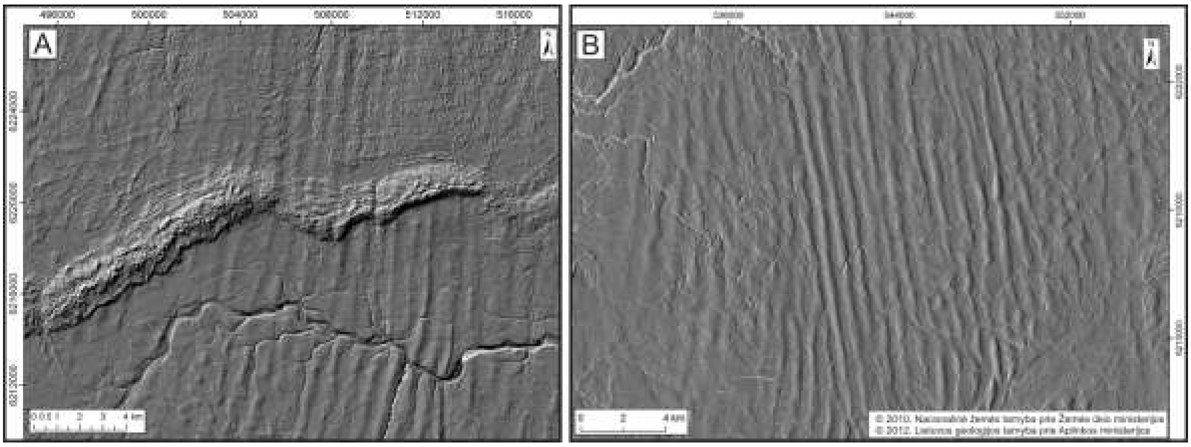

Fig. 1. A: The most impressive part of the North Lithuanian marginal ridge and accompanying glacial lineations; B: Mega-scale glacial lineations in the NE part of the Middle Lithuanian Lowland.

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MIDDLE-WEICHSELIAN ICE-FREE INTERVAL NEAR LGM POSITION AT KILESHINO IN VALDAY UPLAND, RUSSIA

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The investigated outcrop is located in Valday Upland, Russia - in the marginal part of modelled last Scandinavian Ice Sheet (SIS) during its maximum extent in southeastern part (Kalm 2012). The area at Valday is not very well examined, yet holds great importance while suggesting the limit and timing of LGM, whereby opinions vary between Early Valday and Late Valday (Arslanov, 1993)

The outcrop of Kileshino (56.88033°N, 33.45834°E) was described and photographed in the field and the samples for absolute dating (4 OSL, 6 ^{14}C) were taken below glaciogenic sediments with the main purpose to determine the timing of SIS advance. Based on lithology and datings five main sedimentary units were determined (Fig. 1.). First unit comprises two layers of laminated silt and sand, with genesis of varved clay under periglacial sedimentation conditions. Layers of laminated silt and fine sand with diffused organics and 2 peat interlayers form the second unit and indicate the change of sedimentation conditions, as glaciolimnic sediments change to typical nonglacial limnic-fluvial sediments. Third unit show rhythmic sedimentation, laminated silt and sand layers interchange throughout the whole unit and are typical to fluvial sedimentation system. Bedding planes of the layers in unit 3 are mostly wavy and contorted. Forth unit comprises layers of diamiction and sand with pebbles, what refers to glacial sediments. The topmost layer is soil. Based on datings (>43.5 ^{14}C ka BP) and the genesis of sediments, unit 1 is a transition of Early-Valday stadium to Middle-Valday interstadial. Unit 2, with age range of 57.5 OSL ka to 33.81 cal ^{14}C ka BP could correspond to Middle-Valday Krasnogorsk (Rokai) interstadial (Arslanov, 1993). The datings (72.2-40.8 OSL ka) from unit 3 are inconsistent with other datings below it and considering also the fact that layers are contorted, we have reason to believe that the whole unit has been redeposited to Kileshino site by last SIS advance. The unit 3 could be characterized as transition of Early-Valday Shestikhino stadial sediments to Kransogorsk (Rokai) interstadial sediments (Arslanov, 1993). The till found from unit 4 can correspond only to Late-Valday glaciation, while the SIS reached to the study area during Valday only twice and the till cannot be older than the dated sediments below it.

In conclusion SIS reached Kileshino site only once during last 57 ka - in Late-Valday, not before 33.81 cal ^{14}C ka BP. Based on dated sediments, there were limnic-fluvial sedimentation conditions at Kileshino site between 57 and 33.81 cal ^{14}C ka BP, together with dated fluvial sediments (72-41 OSL ka) orginated from NW of Kileshino, it can be concluded that there were ice-free conditions during 72 - 33.91 cal ^{14}C ka BP at Kileshino site.

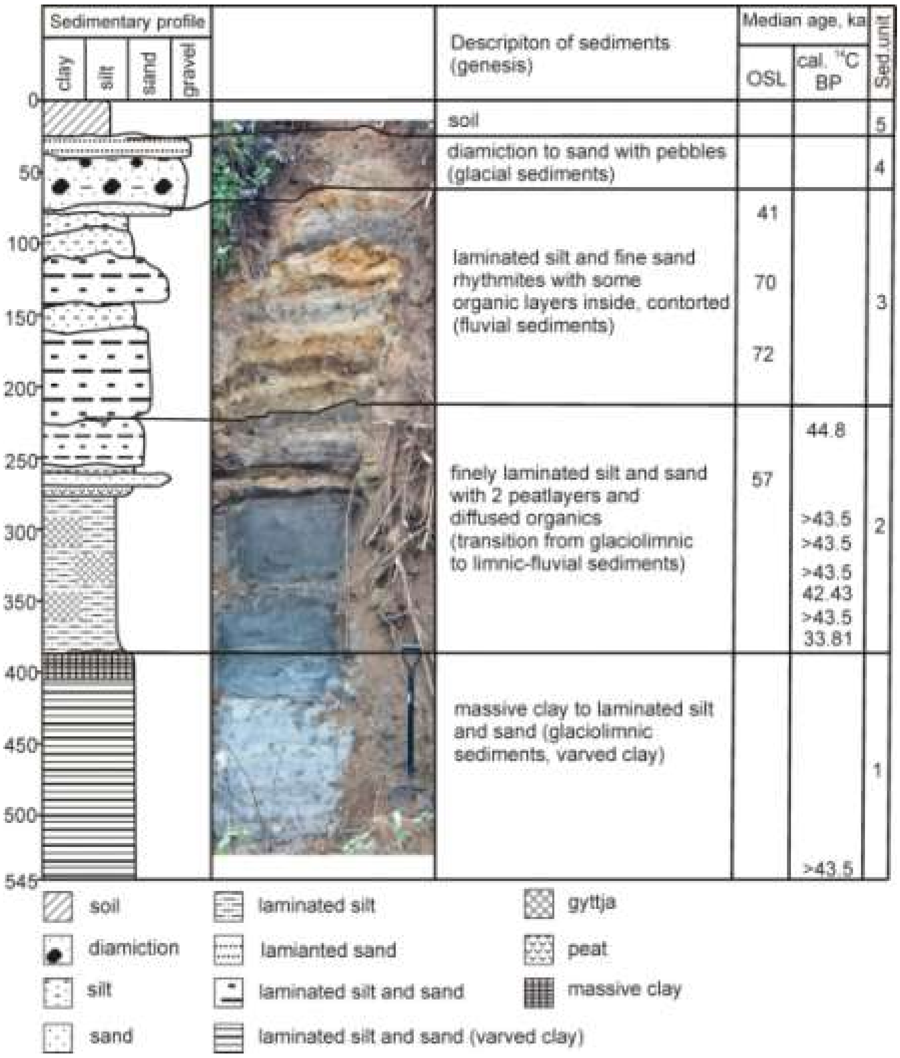

Fig. 1. Description of Kileshino outcop

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FORMATION OF CARBONATE CEMENT IN LATE GLACIAL OUTWASH SEDIMENTS IN SOUTHERN ESTONIA

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Secondary carbonate precipitates as a cement in primary unconsolidated glacial sediments can precipitate in a variety of geomorphic and hydrologic settings by a variety of mechanisms that lead to dissolution and reprecipitation of carbonates. In glacial settings the carbonate precipitation is mostly a result of inorganic process, such as regelation, evaporation, and freezing-thawing processes. Carbonate cements have been recorded in glacial sand and gravel deposits from several places in Estonia, Latvia and Lithuania which are associated with ice-marginal glaciofluvial forms, end moraines, eskers, drumlins and beach formations accumulated during the Late Weichselian deglaciation about 18-12 ka BP. In southern Estonia cementation is observed as vertical cemented piles and patches or thin layers within glacial outwash deposits beneath the upper till layer in Otepää upland. Ice-marginal landforms on the accumulative insular height mark the ice-marginal position of retreating ice.

The cement is mostly distributed uniformly in the sediment matrix filling almost overall intergranular porespace as a massive cemented fine sand and silt with few coarser particles. In cemented piles and patches the degree of cementation is decreasing from centre to the edges. Thin cemented layers are uniformly consolidated throughout the layer. The majority of cement is present as micritic (≤4 µm) calcite composed of randomly oriented calcite crystals or simply occuring as a cryptocrystalline coating. Micrite is usually concentrated at grain contacts and boundaries forming isopachous coatings or rimming detrital grains and filling all smaller interganular pores. The crystal size is increasing towards the centre of intergranular voids and micritic calcite is occasionally going over microsparite (4-10 µm) and sparite (≥10 µm) indicating that micrite precipitation was dominanting and the formation of the cement continued with sparite precipitation in the presence of continuous free porespace in the sediments.

The chemistry of cold-climate carbonates is controlled by the isotopic composition of the parent water from which calcite precipitation occurred and temperature at which the precipitation took place. The isotopic composition of studied calcite cement varies in a narrow range - $\delta^{18}O$ values between -9,0 to -7,2‰ (VPDB) and $\delta^{13}C$ values between -11,4 to -6,4‰ (VPDB). $\delta^{18}O$ values indicate that the parent water does not directly represent the influx of the last glacial meltwater. ^{18}O-depleted compositon of the solute bearing water was controlled by the $\delta^{18}O$ of groundwater and surface waters related to the $\delta^{18}O$ of meteoric water. This is supported by the isotopic composition of meteoric water measured nowadays and the composition of modern groundwater. Likewise, during evaporation the $\delta^{18}O$ of water progressively increases because of the removal of the lighter ^{16}O into vapour. $\delta^{13}C$ values of the cement indicate a mixture of different source of carbon and different precipitation mechanism. Vegetation and decomposition of organic matter in soil system could lead to depletion in ^{13}C, whilst anaerobic bacterial decay, evaporation and influence of atmospheric CO_2 could lead to enrichment in ^{13}C. In case of the studied cement, the important factor that could have affected the isotopic composition is probably dissolved atmospheric CO_2 in surface waters (atmospheric CO_2 with $\delta^{13}C$ values around -7‰). Likewise evaporation in an open system which removes lighter isotopes from the parent water and leads to enrichment of ^{13}C.

The spatial distribution of calcite cement forming piles and layers is attributed to specific hydrologic conditions in limited areas. Formation of vertical piles and patches refers to groundwater circulation in the sediments induced by partially frozen sediments or upper till layer acting as a barrier to water movement. Occasionally the upper part of the cemented piles is distributed more laterally forming a layer or lense refering to circulating water which was later flowing laterally induced by some barrier to the flow. The occurence of thin cemented layers beneath the till layer could indicate lateral water movement along this boundary or a certain water table.

PALAEOHYDROLOGICAL CHANGES IN LAKE TIEFER SEE DERIVED FROM LITTORAL SEDIMENTS AND POLLEN DATA (MECKLENBURG-WESTERN POMERANIA, NE GERMANY)

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According to the elongate and N-S aligned shape of the deep Lake Tiefer See (LTS, max. depth = 64 m), its lake shore is characterised by a narrow littoral zone which is rapidly descending to a steep basin slope. The presence of partly laminated sediments in the lake centre has initiated high resolution, multiproxy studies on climate-landscape interactions within ICLEA (www.iclea.de). Present study focuses on littoral sediments as a record of past hydrological changes expressed by lake level.

Due to its steep slopes, littoral deposition is largely limited to three bays with a typical aggradational fringe of peatlands, alder carrs, reed and shallow water with lake sediments. We drilled 14 cores along 3 transects up to 7 m water depth, considering wind exposed and sheltered lake shores for comparison. All cores reach the minerogenic basis, but most cores are only 2-3 m long. Cores were sampled in 5 cm intervals; analysis includes grain sizes, loss on ignition (TOC), $CaCO_3$ (TIC), dry bulk density and pollen analysis; for peat samples additionally degree of decomposition (by spectral photometer).

The main transect in the SE bay includes three cores from peatlands (TS00, TS2 andTS3) and four cores from the 'open water' (TS1, TS4, TS5, TS6). No core shows a complete Late Glacial/Holocene record. In TS2 and TS3 sedimentation of lacustrine deposits starts in the Allerød period but switches to peat accumulation in the earliest Holocene, suggesting that the lake level during that time was about 5 m lower than today. Peat accumulation proceeds until ~ 3000 cal. BP. Several embedded black, more decomposed layers (partly with hiatuses) underline that the water level was fluctuating also during that period, but still well below the recent level. Continuous sedimentation of lacustrine deposits again starts ~3000 cal. BP, which is related to an increasing lake level. In TS4 and TS5 (in 3-5m water depth) we only find lacustrine deposits younger than ~ 4000-5000 cal. BP, in TS1 (in 1,5m water depth) only sediments younger than 3000 cal. BP, reflecting a step like lake level increase in the late Holocene. Older sediments possibly eroded during low lake levels prior to these dates.

Overall, the results suggest that the lake level of LTS fluctuated strongly over the Holocene, with rather low levels in the early and mid Holocene and higher lake levels after ~3000 cal. BP. Maxima were possibly at least 1 m above the present water level, minima at least 5 m below.

DEPOSITS OF ODRANIAN GLACIATION (=SAALIAN) IN THE KIELCE-ŁAGÓW VALLEY (HOLY CROSS MOUNTAINS, POLAND)

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The origin and age of the Quaternary deposits in the Holy Cross (Świętokrzyskie) Mountains is a disputable issue which has not been thoroughly settled yet. The difficulties in investigating those deposits are due to: the complex litho-structure of the sub-Quaternary bedrock, the fact that the process of Pleistocene glaciations is inadequately recognized, and the extent of the transformations that the forms and deposits underwent as a result of the periglacial denudation processes. The present relief of the area does not provide the basis for the full identification of the glacigenic relief.

The examined research sites of the glacigenic deposits in Mąchocice and Napęków are located within the synclinorium of the Kielce-Łagów Paleozoic core of the central part of the Holy Cross Mouintains, manifested in the relief as the lowering of the Kielce-Łagów Valley. According to the established findings on the Quaternary paleography (Marks 2011, Lindner, Marks 2012), both sites are located to the south of the borders of the Odranian glacier.

Both in Mąchocice and in Napęków the glacigenic deposits are represented mainly by a series of glacial tills, laying on top of the sandy and fluvio-glacial gravel series. Those sediments were deposited in the area of the sub-Quaternary bedrock upheaval made from Devonian limestones and locally Carbonian shales and marlites.

The objective of the investigation is to define the depositional environment of deposits and their age. The sedimentological analyses focussed on structural features (macro-and microstructure) and textual ones (the grain size, the composition of heavy minerals, the rounding and frosting of quartz grains, the petrography of gravels, and the content of carbonates). The geochemical analysis of tills with respect to their elemental composition and the composition of silty minerals was conducted as well. The age of the fluvioglacial series was identified by means of the OSL method.

The analysis of the macro- and microstructural features revealed that in Mąchocice site the fluvioglacial deposits are represented by massive sands and gravels. The glacial deposits, interpreted as the sediments of the end moraine, take the form of the flow till, diamicton facies: 1) diamictons with silty matrix and banks of silty sands formed as a result of cohesive flows, 2) diamictons with sandy matrix formed as a result of cohesionless debris flows. Moreover, there is to be found a gravel-sandy faction in the form of packets of incorporated bedrock material. In Napęków site the fluvioglacial deposits are represented by layered sands and gravels, whereas glacial deposits manifest the features of soft lodgement till, i.e. the till accumulated under the foot of ice in the sufficiently hydrated sub-glacial environment. The roof of the analysed sediments in both sites is distinctly deformed, transformed by periglacial cryogenic processes.

The varied relief of the sub-Quaternary bedrock and its diversified permeability (karstified, fault-cut limestones) determined the deposition location of the glacigenic sediments complex. The heavy mineral composition of the analysed glacigenic deposits is characteristic of the particular genetic type of Quaternary deposits to be found in Poland, however, in both sites there is a noticeably high content of resistant minerals. That is a characteristic feature of the regional mineralogical background of the examined area, not to have been effaced by the activity of the Pleistocene glaciers

(Ludwikowska-Kędzia 2013). The deposits were found to contain a significant content of highly aeolized quartz grains, which indicates intensive aeolian processes forming the sediments in the Holy Cross Mountains. The results of geochemical and petrographic analyses imply indirectly the direction of the glacier movement. They also indicate a connection of clays/tills with Trias clays and Miocene limestones to be found in the NW and SE border of the Holy Cross Mountains.

The OSL age of the sandy series deposits underlaying the tills ranges from 210 to 180 ka BP, which permits classifying the glacigenic complex of deposits within the Odranian Glaciation. The obtained results of the sedimentologic and stratigraphic investigations imply the necessity to verify the established findings with regard to the age and origin of the Quaternary deposits and the views on the range of the Pleistocene glaciation in the central part of the Holy Cross Mountains. In the case of the Odranian Glaciation, these investigations confirm the suggestions of certain scholars of the Quaternary in the region, that its range could have reached further south

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GLACIER LAKE AND ICE SHEET INTERACTION – THE NORTHEASTERN FLANK OF THE SCANDINAVIAN ICE SHEET

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The Arkhangelsk region in the northwestern part of Russia hosts a complex ice sheet and glacier lake history as this area was influenced by three different ice sheets during Weichselian. These ice sheets expanded from the Scandinavia in the northwest, from the Barents Sea in the north and from the Kara Sea in the northeast. Growths and decays in time and space of the different ice sheets were asynchronous, leaving behind a rather complex glacial stratigraphy (Larsen et al. 2006). Associated large proglacial lakes add to this complexity (Lyså et al. 2011).

The area shows a smooth, low-relief terrain raising from the sea-level up to about 160 m a.s.l. Wide north-northwestern oriented river valleys cut through 20-30 m thick Quaternary sediments, although sediment thicknesses up to 120 m are demonstrated from boreholes in over-deepened valleys (Apukthin and Krasnov, 1966). The sediments consist mainly of different glacial, fluvial, lake and marine deposits, the oldest of which are of Saalian age (Larsen et al. 1999; 2006; Lyså et al. 2001; Jensen et al. 2009). Distal to the LGM ice-marginal limit, terraces and sediments related to ice-dammed lakes are demonstrated (Lavrov and Potapenko 2005; Lyså et al. 2011).

Twice during the Weichselian, the river of Severnaya Dvina was blocked by ice sheets expanding into the mainland (Larsen et al. 2006). This took place during the Late Weichselian when the Scandinavian Ice Sheet spread far out into the Severnaya Dvina valley (the LGM Lake), and earlier in Weichselian when the ice expanded into the mainland from the Barents sea (the White Sea Lake) (Lyså et al. 2011). The LGM Lake reached its maximum at about 17-15 ka, and was constrained by the ice sheet in the west-northwest and thresholds

(130-135 m a.s.l.) in the east-southeast. During its maximum phase, water likely spilled over into the Volga basin in the south, as also suggested by Lavrov and Potapenko (2005), and further into the Caspian Sea (Arkhipov et al. 1995). Drainage of the LGM Lake took place stepwise within 700 years, controlled by thresholds and opening of new spillways both into the Volga basin and northeast into the Kara Sea as the ice sheet retreated. Probably small volumes of fresh water reached the White Sea during the final lake drainage (Lyså et al. 2011), this runoff likely corresponding to the increase in smectite delivery in the White Sea during the last deglaciation (Pavlidis et al. 1995). The White Sea Lake was much larger (water volume) than the LGM Lake although not reaching higher water level than about 115 m a.s.l., due to different ice sheet configuration (Lyså et al. 2011). New data indicate that this lake likely existed between 67-72 ka (Lyså et al. in prep).

Morphological mapping based on a new DEM and Landsat imagery combined with detailed sedimentological and stratigraphical studies have led to a new reconstruction of the Last Glacial Maximum, both regarding the extent and the behavior of the Scandinavian Ice Sheet in the northwestern part of Russia (Larsen et al. in press). Long, extremely low-gradient ice-lobes (ice-streams) extended for some 300-400 km up the wide river valleys. Both glacier advance and extent were largely controlled by proglacial lake levels and topographic thresholds, and evidence for ice-bed decoupling is abundant from *in situ* waterlain sediments within diamictons and clastic sills running along the ice-bed interface. Accordingly, the weight of the ice lobes were, to a large extent, carried by pressurized water in the subglacial sediments with thicker ice far upstream providing the gravitational push.

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WAS THE MIDDLE GAUJA LOWLAND ICE FREE DURING LINKUVA TIME?

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The Middle Gauja Lowland is located in the northern part of Latvia next to the border with Estonia. It is enclosed by Alūksne Upland in the north-east, Vidzeme Upland in south-west and Karula Upland in the north. The Gulbene Interlobate Ridge separates the lowland from the Eastern Latvian Lowland in the south-east and the Aumeisteri Interlobate Ridge disjoins it from the North Latvian Lowland in the north-west.

The deglaciation of the Middle Gauja lowland at the end of Late Weichselian glaciation has been discussed in many publications devoted to deglaciation history of Latvia and Estonia or regarding to development of surrounding uplands. Due to lack of absolute age dates ice decaying has been considered in connection with regional deglaciation phases. Nevertheless, there are two different interpretations of the glacier retreat from the lowland. The first one is that lowland became ice free and contained large ice dammed lake after ice retreated from the Middle Lithuanian (local name – Gulbene) phase position marked by the Gulbene Rigde to the ice marginal formations of North Lithuanian (local name – Linkuva) phase. Such opinion is provided by Meirons et al. (1976) and Straume (1979). According to more recent interpretation by Zelčs and Markots (2004) most of the lowland (up to Velēna end moraine ridge) was occupied by ice still during Linkuva phase and ice retreated only after Linkuva phase. Such view is also supported by Kalm (2006, 2012) and Kalm et al. (2011). Last research by Saks et al. (2009) has already questioned presence of ice during the Linkuva phase in the Middle Gauja lowland and, based on it, Zelčs et al. (2011) mark the lowland as being ice free.

As stated in most recent overview published by Bitinas (2012) the Middle Lithuanian phase has been considered to not be present in Estonia, North Lithuanian phase has to be correlated with Haanja phase, and North Latvian or Valdemārpils phase – with Otepaa phase in Estonia. Although Zelčs et al. (2011) has suggested to correlate Middle Lithuanian phase with Haanja and consequently North Lithuanian (Linkuva) with Otepää phase. Still such cross border correlation mostly relies on correctness of interpretation of the morphological features in the near border area between Latvia and Estonia, mainly in the Middle Gauja lowland and its surroundings.

In terms of absolute age, the Gulbene phase has been put to be older than 15.5 (Zelčs et al., 2011) and Linkuva phase – based on dates at the Raunis site – 13.2-13.4 ^{14}C ka BP (Punning et al., 1968), although reliability of Raunis datings as Linkuva age markers has been recently questioned (Raukas, 2009). Recent OSL dating of glaciofluvial deposits on western slope of the Alūksne upland within the suspected Gulbene marginal formations have yielded age of 16.9±3.1 (Zelčs et al., 2011) thus suggesting earlier retreat from the Gulbene marginal line within territory of the Middle Gauja lowland. Accumulation of glaciolacustrine varved clays in the Tamula lake, located northerly of the retreating Middle Gauja ice lobe, started before 14.7 ka (Kalm et al., 2011).

As water levels of the Middle Gauja ice dammed lake are above levels of the Smiltene ice-dammed lake and no evidence of drainage along the western slope of the Vidzeme upland has been found, existence of the Middle Gauja ice dammed lake requires an ice border at Linkuva ice marginal position, as suggested by Zelčs et al. (2011). Active ice stand still at the Velēna end moraine ridge, as suggested by Zelčs and Markots in (2004), should have happened before ice started to retreat from its so called Linkuva position on the western side of the Vidzeme Upland. Thus morphological and age evidence both support the idea of ice free conditions of Middle Gauja lowland in the Linkuva time. Such interpretation supports correlation of the Haanja deglaciation phase with the Gulbene phase and the Otepää – with the Linkuva phase on Latvian side.

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LITHOLOGY AND CORRELATION POSSIBILITIES OF LITHUANIAN MARITIME PLEISTOCENE DEPOSITS

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Despite the numerous geological surveys carried out in Lithuanian maritime area, the stratigraphic subdivision, structure and consequently the sedimentation history of Pleistocene deposit is still complicated there. One of the reasons of this was the lack of reliable criteria for the correlation of widely spread till beds. The scarcity of biostratigraphical data and absolute dating results also do not contribute to solution of the problem. There are only two sediment sections identified as of Butėnai (Holsteinian) Interglacial in studied area. Another quite spread inter-till sediment sequence of sandy deposits containing organic matter pretends to serve as an important marker for subdivision of Pleistocene deposit. However according to OSL dating results it requires to be attributed to the end of Medininkai (Warthanian) glaciation (Satkūnas et al., 2002), but also to Early Weichselian (Molodkov et al., 2010, Bitinas et al., 2011) according to IR-OSL data, or even to

Snaigupėlė (Drenthe-Warthe) on palynology (Kondratienė et al., 2009).

For to better understand the structure of Pleistocene deposit of maritime area the 3D digital model of it was compiled on a base of log descriptions of over 200 boreholes. The stratigraphic subdivision and correlation of deposit is base on lithological characteristics, paleobotanical data and absolute age dating results available for Pleistocene sequence of maritime area. Statistical canonical ordination of petrographical and mineralogical composition data was used for subdivision and correlation of Pleistocene deposit beds, mainly tills.

Principal component analyses (PCA) used had displayed a certain relation between spread of pre-Quaternary sedimentary rocks of different lithology and till composition. All tills at maritime area are enriched with limestone, especially Silurian one and crystalline rocks, but are characterized by relatively lower amounts of dolomite debris. PCA displayed that, the most informative till pebble rock types for subdivision and correlation of till beds in Lithuanian maritime area are Silurian limestone, crystalline rocks and dolomite. The oldest till in area attributed to Dainava (Elsterian) glaciation has sporadical distribution and is commonly spread in depressions of pre-Quaternary surface and paleoincisions. It is characterized by higher amounts of Silurian limestone, sandstone and marl, but shows relatively lower quantities of dolomite, and Mesozoic limestone in comparison with overlaying Žemaitija (Drenthe) till. Dainava till also has higher amounts of Fe oxides and hydroxides, pyrite and ilmenite in sandy fraction. Petrographic composition of widely spread Žemaitija and Medininkai tills rather well differ along the line which coincides with the Baltic Sea coast. Here the pebble composition of Žemaitija till is enriched with dolomite, meanwhile Medininkai till shows the increase of Silurian limestone and crystalline rocks. However further to the upland the pebble compositional differences of these tills strongly decline. The middle and upper Pleistocene tills are separated with broadly spread inter-till sediment sequence of sandy deposits containing organic matter. According to the OSL dating results its age is 140-160 ka BP, so it can be attributed to the end of Medininkai glaciation (Satkūnas et al., 2002). The results of recent investigations in the vicinities of Klaipėda and Šventoji (Damušytė et al., 2011, Bitinas et al., 2011, Molodkov et al., 2010) show that coastal zone or even whole western Lithuania was affected by ice advance which deposits are named as Melnragė till attributed to early Weichselian (Nemunas) glaciation. Pebble petrographic composition of it respectably differs from upper Nemunas (Grūda) till by rather higher amounts of Silurian limestone, sandstones and crystalline rocks, but the difference from underlaid till is rather imperceptible. However mineral composition shows rather good differences between these tills. Melnragė till is enriched with rather higher amounts of epidotes, apatite, garnet and amphiboles in comparison with underlying Medininkai till. The youngest till of Baltija stage of Nemunas glaciation slightly differs from Grūda till by higher amount of dolomite and crystalline rocks.

The obtained study results show quite small till composition differences, what complicate the correlation possibilities of Lithuanian maritime Pleistocene deposits. Also the reincorporation of sediment beds of older glacial advances in to younger ones should be taken into account.

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ASPECTS OF THE PALAEOGEOGRAPHY OF CENTRAL POLAND DURING MIS 3

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Conclusions on climate fluctuations during Middle Plenivistulian – MIS 3 in Central Poland were formulated on the grounds of palaeogerographical researches, among which the most important are: pollen analysis, dynamic of the river environment, analysis of periglacial phenomena. That basis allowed to create an image of the MIS 3 as the period characterized by a cool and humid climate with relatively slight climate warmings. Some researchers have even suggested that dividing that period into interstadials based on the ^{14}C datings and palynology does not give the expected results, because the dating covers almost entire period and differences in vegetation cover could reflect local conditions. The progress in knowledge about climate change during MIS 3 resulting from Greenland Ice Cores research shows that this was a period distinguished by distinct climate shift. The climate changes had a strong impact on the North Atlantic region, what is documented in many sites in Scandinavia and Western Europe. Localization of Poland in the middle part of Europe may cause that this impact is less intensive and thus less marked in the paleoenvironment.

Nowadays it is possible to calibrate ^{14}C dates to 50 ka BP, which in turn improves the ability to relate to the stratigraphy constructed based on ice cores, luminescence datings and other methods. Calibrated ^{14}C datings obtained in different sites in Central Poland show that the dates are grouped into two ranges: about 30-34 ka BP and 35-39 ka BP, but it should be keep in mind that a lot of datings, especially those made several decades ago have large ranges of error. Dates come from thin organic layers which separate sediments of the river valleys or topmost parts of infilling of the reservoirs located in the valleys. Pollen analyzes point to results typical for interstadial periods and do not allow to the stratigraphic assignment. The largest part of MIS 3 deposits is represented by sandy or sandy-silty series infilling valleys of Central Poland, which textural properties provide very important information about palaeoenvironment - in mineral deposits systematically increases amount of wind-abraded grains up to a maximum value in extraglacial deposits of LGM period. It is also noted that there are several levels of ice-wedges pseudomorph and involution which existence may indicate levels formed in the colder periods of MIS 3. Unfortunately, there is a shortage of datings of mineral deposits that could help in more accurate recognition of paleogeography of the period.

Valuable information about MIS 3 provide the Koźmin site located in the middle section of the Warta River valley. In that area thick Quaternary deposits were accumulated including several meters of Weichselian extraglacial sediments. Combination of ^{14}C datings, OSL datings, pollen analysis, examination of textural and structural properties allow to distinguish differences in palaeoenvironment, including periods of climate deterioration. It should be noted that changes in the river valley environment had a quite subtle chrakter.

MELTWATER UNDER THE SCANDINAVIAN ICE SHEET: VOLUMES, DRAINAGE MECHANISMS AND CONSEQUENCES FOR ICE SHEET BEHAVIOUR

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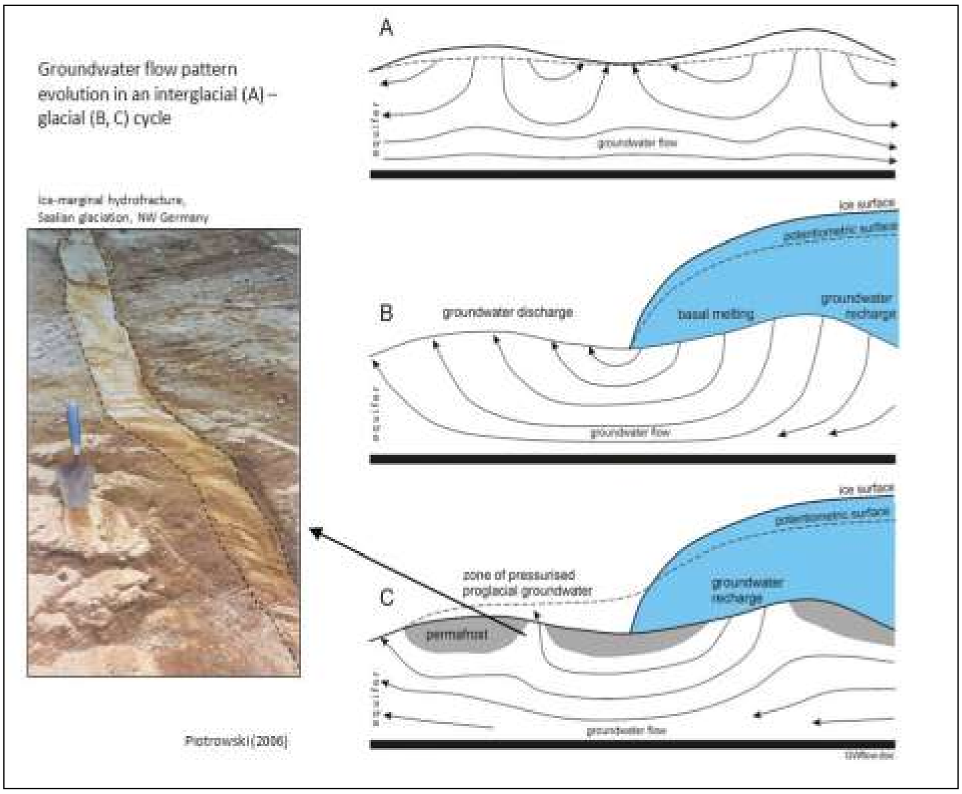

Meltwater under ice sheets originates from melting of basal ice, recharge from the ice surface and recharge from subglacial groundwater systems. The relative importance of these processes depends on a combination of glaciological, climatological and hydrogeological parameters. Water at the ice/bed interface (IBI) is of crucial importance for ice sheet stability, movement mechanisms, sediment transfer and the production of specific landforms. Under slowly melting ice sheets resting on thick, permeable beds basal water will be escaping into the substratum. Such ice sheets are firmly coupled to their beds, move slowly, transfer little sediment and exert little geomorphic impact on their beds. The opposite situation, i.e. where water recharge at IBI exceeds the drainage capacity of the bed leads to a highly dynamic ice sheet characterized by weak basal coupling, efficient sediment re-distribution, production of fast-flow subglacial landforms and glaciotectonism. We synthesize results of numerical modelling of water flow through subglacial aquifers under the marginal part of the Scandinavian Ice Sheet in Poland, Germany and Denmark during several glacial cycles to illustrate that these aquifers lacked the capacity to evacuate meltwater from IBI.

Meltwater typically accumulated under ice sheets leading to ice streaming and the formation of specific landform/sediment assemblages created in subglacial cavities and channels before catastrophic drainage through tunnel valleys removed the surplus meltwater. The results confirm distinct relationships between the hydrogeological properties of the substratum and ice sheet behaviour at both local and regional scales.

PALAEOENVIRONMENTAL IMPLICATIONS OF MARKOV CHAIN ANALYSIS IN SANDUR (WEICHSELIAN GLACIATION OF POMERANIAN PHASE), NW POLAND

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The study area (Woliczno site, NW Poland) is located in the proximal part of one of the largest, coarse-grained sandur in Poland – the Drawa sandur. Its stratigraphic position is correlated with the Pomeranian Phase of Weichselian Glaciation (approx. 16 ky BP). Conventional sedimentological analysis did not include the statistical approach to the vertical sequence of lithofacies. The Markov chain analysis enables to recognise general regularities in vertical succession of lithofacies. Wide diversity and sandwich-like occurence of glaciofluvial sediments force to use a statistical tool as Markov chain analysis. On the base of statistical analysis of Markov chain five cycles and five rhythms have been recognised in the proximal part of sandur. As the rule, rhythms are thinner than cycles. The cycles are represented by three- or four-member successions, and rhythms by 2-mumber successions.

The cycles dominated by Gt and St lithofacies are typical for the lower part of sandur succession, whereas the cycles with diamictic gravel GDm prevail in the upper part. Studied sandur cycles are fining-up successions deposited in braided channels during large ablation floods. Cycles and rhythms have been analysed in regarding to erosion/deposition, sediment transport, progradation/aggradation of depositional forms, together with hydraulic conditions.

Three genetic groups of cycles have been distinguished On the base of mentioned above features. First group is formed by cycles recording the temporal sequence of processes: erosion ⇨ deposition from traction carpet ⇨ suspension settling. In the course of cycle formation, the aggradation ratio gradually decreased and the flow evolved from upper to lower regime. This group comprises the thickest four-member cycles, which represent the most pronounced grain-size grading (from gravels and boulders to silty fine sand upwards): GDm ⇨ Gh ⇨ Sh ⇨ STh and B ⇨ Gh ⇨ Sh ⇨ STh. Both cycles represent complete records of channel sheet evolution during large flood: from extensive erosion up to avulsional channel abandoning. The next group is formed by cycles: Gp ⇨ Sl ⇨ Sh and Gl ⇨ Sl ⇨ Sh reflecting initial accumulation from progradation of barforms, to their aggradation. Simultaneously, deposition from saltation changed to deposition from traction carpet due to flow evolution from lower through transitional to upper regime. We interpret the mentioned cycles as the record of braid bar development during initial and advanced receding of flood waters. A cycle B ⇨ Gt ⇨ St is qualified as the third type. Erosion phase was prior to deposition from dunes. They were the parent bedforms for majority of this succession. This indicates that the third type cycle was formed in the channel zone where bed configuration, sediment transport, and deposition were in equilibrium with the flow parameters. It was the deepest subenvironment of cycle formation – thalweg or interbar channel.

The assemblage of cycles forms one large-scale coarsening-up succession ('outwash megacycle') which correspond to ice-sheet advance. The environment of lower part of succession is the deepest part of the gravel-bed braided river where the major and minor channels, bar surfaces, and the floodplain occured. The lowest level of lower part of succession is that of the active channel. Higher levels are active only during flood stages, and accumulate deposits of element SB and GB (i.e. dunes). Lateral migration of channels is accompanied by aggradation of abandoned channels. Significant depth of braided channels in the zone located more distally to ice-sheet margin can be explained by the fact that the most volume of sediments were deposited close to ice masses, and aggradation of channel bed decreased towards the middle outwash zone. The deep, gravel/sand-bed braided river sedimentation style has changed in effect of ice-sheet advance into shallow, gravel/sand-bed braided river. Architectural elements GB, SB, GS and SU predominate in the middle part of succession. Channels may be abandoned at low stages, in which sand may be deposited, comprising element SB (ripples). These rivers can be braided only during low and mean discharge stages. At times of high discharge there may be a single, very broad, but shallow streamway occupying most width of the braidplain. As a result, fine-grained overbank deposits constitute a minor part of succession. The main architectural components are extensive sheets (element GS and SU). Progressive advance of ice-sheet caused environmental change from the shallow, gravel/sand-bed braided river into shallow, gravel-bed braided river with sediment-gravity-flow deposits. In the upper part of succession two styles of lithologic arrangement are typical, high-energy gravel sheet (element GS) and sandy upper plane bed (SU) prevail in the first style, whereas sediment gravity flow (SG) is indicative for the second one. On the surface of sandur there are numerous remnants of thick debris flow deposits with nonerosional bases.

The following conclusions can be drawn:

- The Woliczno succession represents three stages of glaciofluvial sedimentation in proximal part of 'transgressive' sandur. Deep, gravel/sand-bed braided river evolved into shallow, gravel/sand-bed braided river with episodic high-energy flows, and finally into gravel-bed braided channels which were occasionally filled with sediment-gravity flow deposits.
- three genetic groups of cycles have been distinguished. The first one records the channel sheet evolution during large flood, from extensive erosion up to avulsional channel abandoning (GDm ⇨ Gh ⇨ Sh ⇨ STh and B ⇨ Gh ⇨ Sh ⇨ STh). The second one records the braid bar development during initial and advanced receding of flood waters (Gp ⇨ Sl ⇨ Sh and Gl ⇨ Sl ⇨ Sh). The third one evolves in the channel zone – thalweg or interbar channel (B ⇨ Gt ⇨ St).
- All fining-up channel cycles were caused by meltwater floods. Cycle origin was controlled by avulsion of braided channels most often. The assemblage of cycles built coarsening-up outwash megacycle which correspond to ice-sheet advance.
- We conclude that the rising phase of floods was connected with erosion (the presence of gravel lags in some cycles confirms this interpretation), followed by accumulation flood maximum
- A Succession of most proximal part of 'transgressive' sandur characterises by increasing grain size, cycle thickness, flow competence, aggradation rate and mass flow component. Decreasing tendency is observed in frequency of erosional surfaces and cross-stratified beds, erosion phases and episodes, fluvial sorting, redeposition and channel depth.
- Application of the Markov chain analysis shows that sandur deposits are strongly cyclic, especially in proximal part. We consider the Markov chain analyses as a good tool for reconstruction of glaciofluvial sedimentation conditions.

OCCLUSIVE MORPHOLOGY AS EVIDENCE OF ENVIRONMENTAL CONDITIONS: LOWER PLEISTOCENE SPERMOPHILUS SEVERSKENSIS (SCIURIDAE, RODENTIA), NORTHERN UKRAINE

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Novgorod-Seversky is one of few examples of small mammal faunas from the Ukrainian Late Pleistocene that may be considered as the periglacial one. This fauna is characterized by presence of lemmings (*Dicrostonix torquatus, Lemmus* cf. *sibiricus*) and predominance of *Microtus gregalis kryogenicus*. Cranial morphology of rodents also implies the influence of severe climatic conditions. Notably, it demonstrates variability according to Bergmann's rule: most of subspecies and species described from Novgorod-Seversky (they are quite numerous, and reviewed in (Rekovets, 1985) excel their relatives in size.

But low temperature isn't the only characteristic feature of the periglacial environment. There was such an important condition as animals' diet, which also must have been changed during cool epochs. What impact does the diet change have on the rodents morphology? As for fossils, there is the closest relation between diet and teeth morphology. But on the other hand, teeth are established to be relatively slow variable[1], non-modified structures (tooth shape does not have ecophenotypic response). Did teeth have time to response on the diet changes during the Late Weichselian? There was one probable example from Novgorod-Seversky fauna. Gromov et al (1965) found out hypoconid increased on the lower forth premolar of *Spermophilus severskensis*, an extinct species of the ground squirrel, described by them.

Prolonged hypoconid increases tooth lophodonty and suggests enhancement of grass-feeding adaptation in *S. severskensis*. It was previously established, that *Spermophilus* occlusive surface can be characterized using sets of accessory cusps. Each of these sets corresponds to the certain direction of feeding specialization and their combinations create species-specific tooth morphology (Popova, 2007). If *S. severskensis* really was a grazing squirrel, it had to acquire the set of the most grass-feeding recent species (*S. odessanus* and *S. suslicus*). This hypothesis was tested using the sample of *S. severskensis* stored in National Museum of Natural History of the National Academy of Sciences of Ukraine.

S. severskensis appeared to have high frequency of additional cusps of paralophe and metalophe. This set is called Odessanus-set, i.e. characteristic for *S. odessanus*. Odessanus-structures are presented in some bunodont species also (*S. pygmaeus, S. xanthoprymnus*), but as real well-separated cusps; whereas in spotted ground squirrels (*S. odessanus* and *S. suslicus*) they form inclined surfaces, which project edges optimize tough vegetable food processing (Popova, 2007). In *S. severskensis* Odessanus-set is presented in the latter (advanced) form, so, the tentative assumption is proved convincingly.

But in other aspects, *S. severskensis* teeth morphology occurred to be quite surprising.

First of all, *S. severskensis* taxonomic status is suspicious by itself. It is too tachytelic, especially for the ground squirrel. Squirrels just don't belong to rapidly evolving groups. In addition, it was the time period, when even such a 'rapid' group as voles hadn't shown any speciation event. Most of other taxa described from Novgorod-Seversky locality are of subspecies level; moreover, their ecophenotipic nature can't be excluded. And, moreover, diagnostic characters of those taxa can easily be modified. Their rapid arising can be explained by the Baldwin effect, which accelerates evolution. But *S. severskensis'* specific

[1] Well-known fast evolution of voles during the Plio-Pleistocene, and high variability of their teeth is something else again. This variability is linked mostly with hypsodonty, i.e. ontogenetic by its initial nature.

characters belong to teeth system, which assumed to be unmodified.

The second surprising thing was the age structure of *S. severskensis* sample. It is shown on fig. 1, in comparison with age structure of any fossil sample close in geological time and morphologically. The comparison leads to shocking conclusion: it looks like the periglacial conditions significantly increased individual life span of the ground squirrels.

Then, although *S. severskensis* chose the way of grass-feeding specialization, like recent spotted ground squirrels *S. odessanus* and *S. suslicus*; as opposed to these species,

S. severskensis cheek teeth are not shortened. Shortened cheek teeth in ground squirrels are considered to be an adaptation to tough vegetable food (Gromov et al, 1965), and even tooth of the Middle Pleistocene *S. odessanus* representatives are more shortened then in *S. severskensis*. It is especially notable, taking into account that the shape of the occlusive surface is characterized by higher evolutional plasticity than cusps and lophes.

Teeth shorterning in the ground squirrels doesn't easy to measure, and better way is counting of accessory cusps frequencies on the lingual and buccal side of tooth, because the shorter tooth, the more rare are these cusps. *S. pygmaeus* teeth are unshorthened, and this species is characterised by relatively high frequensy of these cusps (Pygmaeus-set of characters). Spotted ground squirrels to a marked degree have lost these cusps, naturally enough, both inner and external ones. And *S. severskensis* looks quite an eccentric: it retains lingual cusps of the lower teeth, but buccal cusps in it are completely absent.

Discussion. There is a narrow range of choice in respect of *S. severskensis* ancestors. Two *Spermophilus* species only, *S. odessanus* and *S. pygmaeus* are known to exist before *S. severskensis* on the Dnieper area. And assuming that *S. severskensis* was a descendant of *S. pygmaeus*, i.e. could inherit both Pygmaeus and Odessanus sets and unshortened cheek teeth, we can reduce all mentioned *S. severskensis* teeth peculiarity to <u>the changes of wearing</u>. At this expense necessary morphological response can be given quickly enough.

Periglacial conditions by no means determined increase in percentage of ground squirrels reaching old age. *S. severskensis* remains shown as senex and subsenex on fig. 1 merely seems to be old; really they are worn. But such a hyperwearing didn't lower teeth fitness to vegetable food processing, as it was accompanied by teeth self-sharpening. Beside usual surface of wearing, there were additional surfaces occur, angular to the main one (fig. 1b).

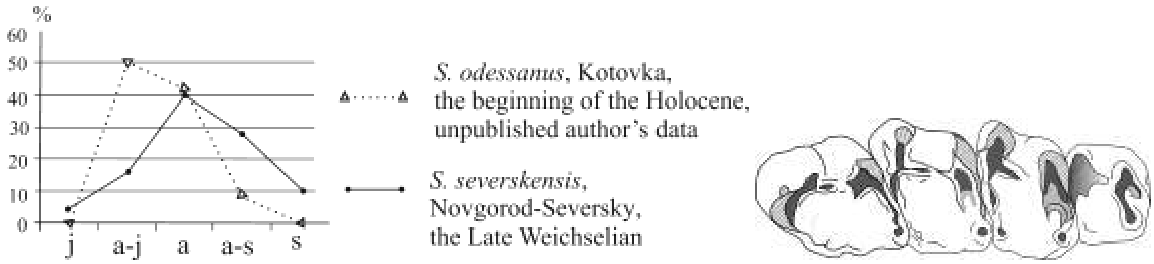

Fig. 1. "Age structure" of S. severskensis from the Novgorod-Seversky locality (j, a-j, a, a-s, s – wearing stages, from juveniles to senex) – ***a****; and typical wearing state of S. severskensis low teeth row –* ***b***

The situation can be described in terms of the niche dividing: in the second half of the Late Pleistocene a population of *S. pygmaeus* extended to the north, to areas watered better and rich in grass. The expansion can be causes just by the Weichselian glaciation coming and strongly aridizating landscapes of age-old southern natural habitat of *S. pygmaeus*; meanwhile new, northern part of the natural habitat provided food in excess supply.

It was a gain. But this gain, like any gain, must be repaid. That easily accessible food (grass) was a low calorie and high-abrasive. It increased workload to the ground squirrels teeth. Then, severe climatic conditions were increasing energy demands of individuals, meanwhile fattening season was shortening, which resulted in next portion of the load. So, chewing of the ground squirrel had to be long-running, quick, and maximally effective. A usual occlusive surface would be flattened under such conditions very soon. The self-sharpening of teeth provided *S. severskensis* the possibility to avoid it. But stability of the construction was sacrificed to its short-term high-effectiveness, because teeth self-sharpening could continue only until an edge of an additional wearing surface reach the gum. True, this latter distressing possibility stayed in the range of pure theory during the Late Pleistocene, on due to high nonselective mortality. But the situation was changed dramatically with beginning of the Holocene. It was then that mentioned palliative adaptations to grass-feeding turned on their reverse side and *S. severskensis* has been displaced by the *Spermophilus* species, which teeth don't bear such mechanism of self-sharpening/self-destruction (*S. pygmaeus* or *S. suslicus*).

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PALAEOGEOMORPHOLOGY OF INTERGLACIALS IN LOWER MERKYS AREA, SOUTH LITHUANIA

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The intensified fluvial erosion in the beginning of Pleistocene and glacial exaration in the Middle Pleistocene have modified the former relief by deepening of erosion-exaration system. The deposits of Dzūkija and Dainava glaciations have softened the former contrasting relief.

During Butėnai (Holsteinian) Interglacial, the morainic (at the altitude +50 - +60 m), glaciolacustrine (at the altitude +35 - +50) and glaciofluvial (at the altitude +50 - +60 m) plain, dissected by channelled water basin the width of which has ranged from 5 to 15 km, has predominated. On the grounds of investigation of lacustrine sediments, we have succeeded the reconstruction of deep and shallow parts of the basin. Only the northern part of basin, where sediments occur too high, raises doubt. It may be connected with later neotectonic rise or stratigraphical error.

After Žemaitija and Medininkai glaciations, the large deposits of glacial, glaciofluvial and glaciolacustrine has remained. On its surface during Merkinė (Eemian) Interglacial the relief of another character has been formed. There are distinct three erosional palaeovalleys near the recent Merkys, northwards from Daugai and near Barčiai. If alluvial and lacustrine sediments, remained at the altitude +40 - +45 m, testify availability of palaeovalley near Merkys, then northwards from Daugai and near Barčiai the palaeovalleys are deepened and filled up by glaciolacustrine sediments of dammed of later glacier. In intervale localities the glacial and glaciolacustrine plain, here and there terraced, with little lakes, has been formed (Fig.).

The available poor and debatable geological material has not allowed to reconstruct relief of Middle Nemunas (Middle Weichselian) period reliably. However, it has been done to the Late Nemunas (Late Weichselian) period, occurring between Grūda and Baltija stadial glaciations. The prevailing glaciolacustrine plain, in some localities transiting to glacial and glaciofluvial, one has been dissected by narrow valleys near Merkys and Lower Varėnė. In the south-eastern its margin the hilly peripheral deposits are rised above the plain by 35-40 m. The palaeogeomorphological reconstructions of Lower Merkys area well correlate with the reconstructed relief of interglacials in the Middle Nemunas area below Merkinė.

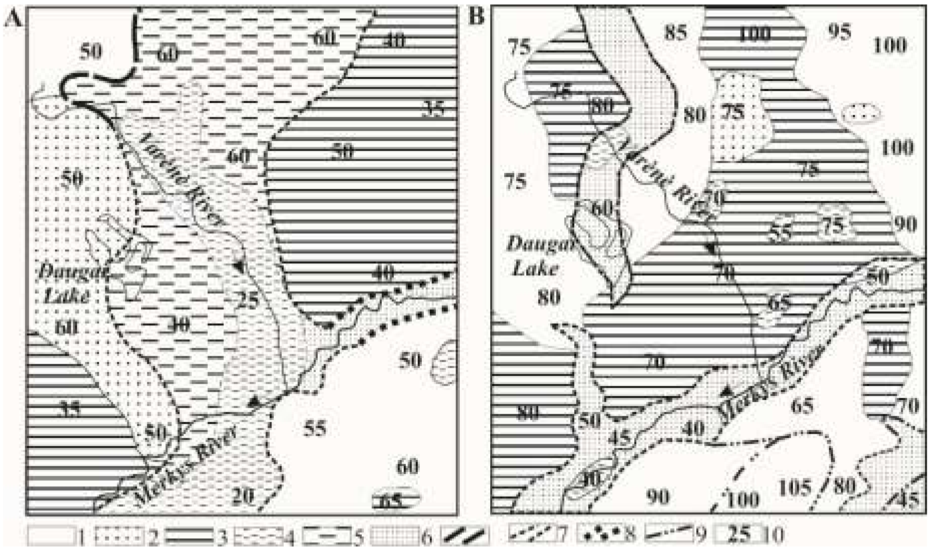

Fig. Palaeogeomorphological schemes of Interglacials of the Lower Merkys: A – Butėnai, B – Merkinė. 1 – accumulative till plain, 2 - accumulative glaciofluvial plain, 3 - accumulative glaciolacustrin plain, 4 – water basin - deep parts, 5 – water basin - shallow parts, 6 – slopes of water basin, 7 – erosional valleys and their slopes, 8 – supposed valleys and their slopes, 9 - erosion-exaration-denudation slopes of terraces, 10 – prevailing absolute height of palaeosurface.

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ESTABLISHMENT OF GIS-BASED DATABASE OF THE BALTIC ICE LAKE SHORELINES FOR THE LATVIAN COAST OF THE GULF OF RĪGA

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In the course of the lobate deglaciation of the Late Weichselian ice sheet vast glaciated lowland areas of Latvia were occupied with large local ice-dammed lakes. After the Valdemārpils (North Latvian) deglaciation phase these proglacial bodies flowed together creating Baltic Ice Lake (BIL). The ancient shorelines of the BIL transgressive stage Bgl II and regressive stage phase Bgl IIIb are well traceable in all coastal area of Latvia. Bgl I and Bgl IIIa, Bgl IIIc may be observed with interruptions. Due to a stretch NNW-SSE direction which coincides with regional ice flow direction and ice thickness gradient the depression and adjoining glaciated plains S of the Gulf of the Rīga are very attractive location for studies on BIL shoreline-displacement to estimate crustal movements and glacio-isostatic rebound in the central part of South-eastern Baltic region.

Study area includes long but relatively narrow zone from the North of the Kurzeme Peninsula where ancient shorelines of the BIL appear as an erosional escarpment of the Slītere Zilie kalni ("Blue Hills") to Estonian-Latvian border. Different coastal accumulation forms can be recognized in the coast of the Kurzeme and Vidzeme. Northern parts of the study area can be characterised with maximal intensity of the uplifting. The elevation of the BglI stage shoreline near the Slītere village is 52.0 m a.s.l. but near Estonian-Latvian border is located at 42.3 m a.s.l. The glacio-isostatic uplift has been minimal in the glaciated plains located S of the Gulf of Rīga. According to previous studies, shorelines of the BIL have been identified S of the Jelgava Town at 8.5 m a.s.l. (Grīnbergs 1957).

The aim of this study is to re-investigate the BIL shorelines with modern land surveying methods and evaluate their deformation affected by glacio-isostatic rebound in the term from the beginning of BIL until nowadays. Research is based upon established GIS-based database of the BIL shorelines for the Latvian Coast of the Gulf of Rīga and improved quality of the palaeogeographical modelling for case studies of the ancient shorelines and coastal accumulation landforms. In the course of this study modern geomorphological, geodetic and geospatial analysing methods were used. As a result regionally important and high quality data are collected. These data enable to calculate maximal shoreline tilting gradient for each BIL stage. The obtained results allow to evaluate glacio-isostatic uplift for the inner zone of peripheral cover of the Fennoscandian ice sheet for the last ~13 000 years in the sector of the Gulf of Rīga.

As a result of this research a database of BIL shorelines was created to compose diagram of the BIL shorelines of the west coast of the Gulf of Rīga. In addition data about shorelines applied to earlier or later time are included in the database if they are identified in the study area. In overall, database contains 265 points for different age shorelines and 212 of them are concerned to BIL for the coast of the Gulf of Riga. For this study 188 shoreline levels were used for composing of shoreline displacement diagramme composing. BIL shorelines are divided in 3 stages – Bgl I, Bgl II and lower located phases of the Blg III stage – Blg IIIa, Blg IIIb and Blg IIIc (Grīnbergs 1957, Veinbergs, 1979). The information on spatial location of the shorelines from previous studies done by Grīnbergs (1957) and Veinbergs (1964) is also stored in this database. Unfortunately these data are not high spatial accuracy. More useful data are obtained from cross-sections of the previous studies. Modern digital terrain model was used and method was developed to reconstruct spatial location of these cross-sections. Available cartographic materials in scales of 1:50 000 and 1:200 000 from the Latvian Geological Fond were analysed and included in the database. The most recent data sources are form 8 cross-sections done by Nartišs et al. (2008) in total length of 20.3 km along the eastern coast of the Gulf of Rīga and 20 cross-sections in total length of ~ 24 km along the western coast measured within the framework of this research. Surveying was done using real time kinematics GNSS systems or combination of the post-processing GPS and total stations measurement techniques.

Interpolated gradient of the maximal land uplift of Bgl II stage water level using Surfer software package Polynomial Regression gridding method was applied for constructing of shorelines displacement diagramme. Acquired value of the gradient of the maximal land uplift is 335° in the central part of the Gulf of Rīga. Maximal shoreline tilting gradient for BlgI is 37.9 cm/km. However, as the territory of Latvia in that time was in periglacial location, glacio-isostatic uplifting can be described as a semi-exponent function. On the peak of the Gulf of Rīga gradient is only 24.6 cm/km, but in Northern Kurzeme amounts 55 cm/km. Maximal shoreline tilting gradient for Bgl II stage is 32.6 cm/km, for Bgl IIIa phase – 29.0 cm/km, for Bgl IIIb phase 24.2 cm/km and for Bgl IIIc phase – 21.1 cm/km.

Polynomial Regression bi-linear saddle surface gridding method was used for first time obtaining of water level surface of the BIL stages. Points with elevation difference more than 1.5 m were filtered and the gridding was revised. For second time 22 points were used for Bgl I stage water level interpolation, 35 points – for Bgl II stage, 30 points – for Bgl IIIa phase, 39 points – for Bgl IIIb phase and 34 points – for Bgl IIIc phase. 75 % of points included in the data base were validated for water levels interpolation of different BIL stages. As a result the gradient of the maximal land uplift for each stage is constructed. The value of this gradient for Bgl II is 335° whereas the value for Bgl IIIb phase slightly changes to 330°. Probably this difference might be indicate the migration of the location of the maximal isostatic uplifting centre during the period between Bgl II and Bgl IIIb stages. Reconstructed water level surfaces and the gradients of the maximal land uplift makes possible to apply data for successful palaeogeographical modelling using different accuracy of DTM's to reconstruct spatial location of the shorelines and formation of coastal accumulation forms.

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LITHO- AND KINETOSTRATIGRAPHY OF GLACIAL DEPOSITS WITHIN THE PŁOCK ICE LOBE, CENTRAL POLAND, AND THEIR PALAEOGEOGRAPHICAL SIGNIFICANCE

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The Płock lobe constituted a characteristic element in the last Scandinavian ice sheet margin contour. It is being referred to the glacier that invaded the territory of Poland flowing southward along the depression of the Vistula (Weichsel) palaeovalley, reached the Płock Basin and the surrounding morainic plateaus, and, finally delineated the Last Glacial Maximum (LGM) in central Poland. The number, extent and age of glacial events in the Płock lobe advances during the last glacial period have been largely debated (i.a. Skompski 1969, Baraniecka 1989, Marks 1988, 2010, Roman 2003, 2010,Wysota et al. 2009).

Lithostratigraphical investigations have revealed that the last ice sheet reached its maximum during the Late Weichselian (MIS 2) and left a separate basal till of individual pethrographic characteristics (*Lisica* lithotype). The stratigraphic position of the till was determined referring to the sites of subfossil plants at Kaliska (Domosławska-Baraniecka 1965, Janczyk-Kopikowa 1965), Łanięta (Balwierz, Roman 2000) and also Kubłowo (Roman, Balwierz 2010) where an undisturbed interglacial-glacial sequence was documented, comprising in a palynologic record the Eemian Interglacial, the Early Weichselian and a significant part of the Middle Weichselian. Fito-climatic relations determined as against vegetation development of that profile, show that at the Płock Basin area, there was no ice sheet either at the Early (MIS 5a-d) or the Middle Weichselian (MIS 4, 3).

The age for the Late Weichselian ice sheet advance is given by optical stimulated luminescence (OSL) dates of the glaciofluvial sand from beneath and above the till, and is believed to fall between 22,9 and 18,7 ka BP (Roman 2010).

Another argument, speaking for one only advance of the last ice sheet onto the area investigated appears from kinetostratigraphy whereby we can infer that the assumption is true in the light of the investigations carried out by the author. Documented in a number of exposures glaciotectonic mezostructures, such as folds and thrust faults, and also small-scale shear deformings, were studied in disturbed sediment sequences. From this, the direction of ice movement which caused the deformations can be deduced and used as a stratigraphic indicator. Another evidence such as till clast fabric, striations and lee ends orientation of clasts in boulder pavement has also been used to establish the directions of ice flow.

Two kinetostratigraphic units were distinguished i.e. the older, the Odra (Saalian) glaciation and younger, the Weichselian manifesting itself by a progressive sequence. Such sequence combined from proglacial and subglacial structural domains as seen at the Otmianowo, Paruszewice, Izbica Kujawska-1, Korzeń Królewski, Zawada Nowa sites proves a singular ice advance. Important for palaeogeography and assessment of the Płock lobe dynamics is, that the progressive sequence pertains as well the glaciomarginal zones allocated in the LGM hinterland.

Proved was, that the transverse ranges in the LGM hinterland are overridden end moraines. Ranges determined as preLGM-1 and preLGM-2 were being formed during short standstills of transgression along transverse terrain obstacles. Deposited at that time glaciomarginal sediments underwent distortion resulting from proglacial compression, a subsequent truncation beneath the moving ice, recognized in the zones examined, and belong to two kinetostratigraphic units, the Odranian and the Weichselian. Older structures constitute the king-pin of the preLGM-1) morainic ridge, and hence is to be accepted as a relict form transformed in the younger, Weichselian, morphogenetic stage. Weichselian glaciotectonic structures constitute together with their covering till a coherent kinetostratigraphic unit consisting in a progressive sequence of deforming structures which in fact, is a record of a singular deformative transgression cycle (c.f. Berthelsen 1978, Hart, Boulton 1991, Van der Wateren 1995, Pedersen 1996). The results obtained allow to abrogate earlier findings, mainly based on morphostratigraphic criteria, treating of an oscillative–recessive nature of the LGM hinterland zones examined (i.a. Galon, Roszkówna 1967, Niewiarowski 1983, Pasierbski 1984, Mojski 2005).

The preLGM-1 zone, because of its morphological rhythm and inner structure, can be thus ascribed in the Bennett category of narrow multi-crested push moraines regarded as the effect of a consequent ice advance and propagation of compressive structures towards the foreland (Bennett 2001). That character of marginal zones is ascribed to surging glaciers or is referred to palaeo-ice streams (i.a. Croot 1987, Evans, Rea 1999, Andrzejewski 2002, Van der Wateren 1981, Zandstra 1981). The statement is substantial for the assessment of the transgression dynamics that has exceeded the push moraine belt (preLGM-1) and again, curtly, its front halted at the transversely oriented terrain obstacles in the preLGM-2 zone. Moraine forming in that margin was short-lived which is testified by a low glaciomarginal deposits thickness, usually thin with only locally occurring proglacial sediments and an absence of subglacial channels clearly bound with the ridges.

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CARBONATES IN THE HETEROCHRONOUS TILLS OF SOUTH-EASTERN LITHUANIA AS A CRITERION OF THEIR STRATIGRAPHIC CORRELATION

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It is very important to use the same criteria for geological unit subdivisions and comparisons (Bitinas, 2011). The biostratigraphical principle as the main criterion in stratigraphical subdivision of the Pleistocene sediments is not sufficient for the simple reason: the great deal of Pleistocene sediments lack paleontological remains (Baltrūnas, 2002). Different lithological criteria are applied for the Pleistocene sediments correlation. The most often such a correlation is applied for till horizons. The great deal of Pleistocene tills from Lithuania contains elevated content of carbonate material. The different lithological composition of the tills reflects different directions of glaciers advance as well as different lithology of the Prequaternary sediments they were advancing over. The tills of different age are different in distribution of carbonate material quantities, mineralogical composition and dolomite and calcite ratio (Rudnitskaite, 1983). Thus, total carbonate material content, dolomite and calcite ratio could be used for the sediments of Pleistocene subdivision and correlation in Lithuania (Rudnickaitė, 1980; Rudnitskaite, 1983 Rudnickaitė, 2008).

Methods

Studies of thin sections are used for of structure, texture as well as for the general evaluation of tills peculiarities. The origin and lithostratigraphy of tills could be pinpointed examining thin sections of tills as well. The thin sections of till‘s fine fraction from Jurkonys, Žalioji and Neciūnai drill sites were examined (Fig.1, Gaigalas & Rudnickaitė, 1981 (in Russian)). This „reconnaissance“examination enabled us to single out minerals like calcite and dolomite, which could be used as a potential „correlatives“. The bulk content of carbonate material in the tills of the different Pleistocene age from the southern Lithuania was determined. The sediments fraction less than 1 mm was used for the carbonate content analysis. More on the methodology could be found in literature (Sanko et al., 2008; Kabailienė et al., 2009). The dolomite and calcite ratio was calculated from dolomite and calcite data. For further lithological units correlation Van der Warden criterion was applied. Non-parametric Van der Warden criterion (X criterion) could be applied for a small number of samples as well in a case when distribution is non-normal or unknown. The criterion is also useful when data is semi quantitative.

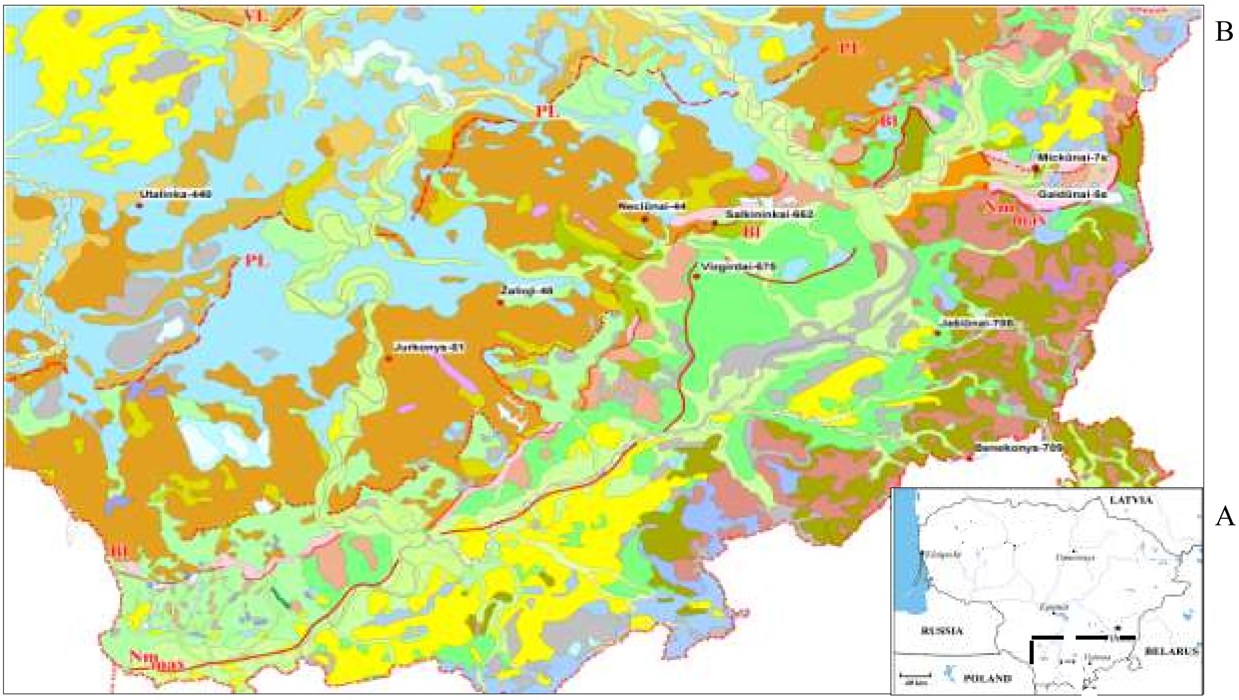

Fig. 1: A - A map showing the location of the studied area and ***B*** *– the locations of studied boreholes on the Lithuania Quaternary geological map (Guobytė, 2002) cutout background.*

Material and results

Thin sections from the south-eastern Lithuania (Benekonių, Gaidūnų, Jašiūnų, Mickūnų, Paleckiškės, Salkininkų, Vizgirdų, Utalinkos) drill sites sediments were examined. It was found that among carbonate group minerals calcite and dolomite dominate. The percentage and ratio of the latter minerals is different in tills of different age. The vertical and lateral composition and content variation will be presented in the article. Our results show that total carbonate content, calcite and dolomite quantities and their ratio, at some extent, could be utilised for tills correlation. The till of Medininkai age could be used as a marker. The ratio of dolomite and calcite in mentioned till is more than 1.

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THE LATE WEICHSELIAN INTERSTADIAL IN SE LITHUANIA: MULTI-PROXY APPROACH

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In order to reconstruct the Late Weichselian Interstadial environmental dynamics (vegetation pattern, climatic changes, sedimentation history) in the marginal area of the Last Glaciation, the terrestrial record from the outcrop of Ūla River, Zervynos 1 (54°06´30,6´´N; 24°29´08,4´´E), was investigated.

Detailed multi-proxy analyses i.e. pollen, diatom, plant macrofossil survey, $\delta^{18}O$, $\delta^{13}C$, ^{14}C (AMS), loss-on-ignition (LOI) and grain-size measurements alongside with the magnetic susceptibility investigations, were applied with high temporal resolution.

The lowermost part of investigated sequence (155-180cm) consists of well-sorted sand with negligible amount of silt and clay particles. Values of $CaCO_3$ and organic particles are negligible in this interval suggesting initial lake sedimentation.

The results of AMS dating show that the formation of the bottom-most part of the investigated gyttja (83-155cm) took place at about 13950-14650 cal BP (Poz-51807) that could roughly be correlated with the earliest stages of Interstadial, Bölling warming or GI-1e event according to Lowe et al. (2008). High representation of AP pollen as well as presence of tree's stomata indicates development of forest cover during the GI-1e event in area. Simultaneous drop in the $\delta^{18}O$ values to more negative ones (from -9 to -11‰) may indicate a rise in the evaporation rate likely caused by increasing mean temperature. Simultaneously, amount of organic constituent and $CaCO_3$ started to increase that was coincided with increasing amount of clay and silt in sediments suggesting stabilization of sedimentary environment in the basin. However short-lasting deterioration of environmental situation was recorded at the depth of 145-149 cm. Changing palaeobotanical, $\delta^{18}O$ and grain-size records suggests instability of environmental regime that could be attributed to GI-1d event or Older Dryas cooling.

Starting at the depth of 143 cm, considerable changes recorded in the $\delta^{18}O$ and $\delta^{13}C$ curves, as well as those seen in pollen, LOI and grain-size curves, indicate climatic, hydrological and vegetation shifts had taken place in the region. Drop in sand input and increasing number of organic constituent suggests stabilization of the surface and consolidation of vegetation cover considering pollen record. Subsequently, supply of allochthonous material from the catchment decreased and as a result, the increasing value of recorded $CaCO_3$ must have originated from the lake itself mainly. In turn described shifts point to the climatic amelioration that could be correlated with Alleröd warming or GI-1c event (Lowe et al., 2008). In the territory of Lithuania this shift was dated back to 13700 cal BP.

Approaching the upper part of the gyttja bed, at the depth of 100 cm, changing pollen curves indicate some thinning of the vegetation cover followed by the opening of the landscape subsequently. Shortly after (93-95 cm), changing $\delta^{18}O$ and $\delta^{13}C$ records indicate some aridification and deterioration of the climatic regime. Increasing input of terrigenous matter and drop in $CaCO_3$ representation could be related with erosional processes and destruction of the soil cover. Culmination of the above mentioned environmental fluctuations could be related with the formation of sand interlayer (71-84cm) on the top of the gyttja bed. Deposition of the gyttja was interrupted at about 13350-13710 cal BP (Poz-51806). Contemporaneous changes in biota structure and oxygen isotope composition have been correlated with the Gerzensee oscillation or GI-1b event in Europe (Lotter et al. 1992; Björck et al., 1998).

Collected multi-proxy data obtained from the outcrop Zervynos 1 enabled us to make a detailed environmental reconstruction of the first part of the Late Weichselian Interstadial in SE Lithuania. Formation of the investigated gyttja bed started during the earliest stages of the Interstadial (GI-1e event) whereas the first instability of the environmental regime could be correlated with the Older Dryas cooling (GI-1d event). Climatic and environmental fluctuations provoked by the Gerzensee oscillation or GI-1b event coursed the first infilling of the basin. It is evident that the latter process started earlier in comparison with the former estimations.

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THE LATEGLACIAL VEGETATION PATTERN: FROM BELARUS TO THE EASTERN BALTIC

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Resent detailed multi-proxy investigations conducted in the peri-glacial and glacial-influenced zones of the Late Weichselian Glaciation have provided scientific community with new information describing the late-glacial vegetation history.

Being covered by the ice sheet during the maximum stage of the Late Weichselian Glaciation area of the present Baltic States was occupied by vegetation, including various tree species, during the different intervals of the Lateglacial. Immigration pathways followed from the peri-glacial zone where particular trees survived in so-called "refuge areas". Pollen data suggest the presence of *Pinus* sec. Strobus, *Pinus sylvestris* L., *Larix*, *Betula* and *Betula* sec. Fruticosa, *Ephadra*, *Hippophaë*, *Salix* in the area of Belarus between 15,000-16,500 cal BP.

The pollen records indicate forestation of the Baltic region with open *Betula-Pinus* forest during the initial stages of the vegetation formation, approximately correlated to the GI-1d-a events in SE Lithuania and NE Poland and even earlier – in Belarus. Presence of *Pinus* pollen suggest establishment of these trees in the central part of this country before 16,000 cal BP. Shortly before 13,700 cal BP the *Pinus sylvestris* L. established in the north-eastern Poland and south-eastern Lithuania according to pollen and plant macrofossil data. Obviously, these trees followed SE-NW migration pathway. Existing pollen data suggest representation of spruce in the central and northern Belarus during the final stages of Allerød and further flourishing of this tree until about 11,000 cal BP. The spruce cone is dated by 12,500 cal BP in NE section of Belarus. In SE Lithuania, *Picea* sp. seeds were found in deposits of Allerød age (G-Ia-c event), and became established in western Lithuania in the late Younger Dryas (GS-1 event). The pollen and plant macrofossils show an early Holocene, ca. 11,507–10,790 cal yr BP, immigration of this tree into northern and north-eastern and shortly before 11,500 cal BP – into the eastern Lithuania. Collected information suggest NE-SW or E-W migration pathway of this tree in the territory.

DEVELOPMENT OF THE MORAINE REEFS IN THE SOUTH-EASTERN BALTIC SEA DURING HOLOCENE APPLYING GEOLOGICAL MODELLING

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This study was aimed to investigate underwater moraine ridges known as one sub-type of underwater reefs in the Lithuanian coastal waters of the Baltic Sea. Since moraine ridges have been described for the first time in the Lithuanian coastal waters in 2006, data and knowledge on this underwater habitat were very scarce. Our project was focused on biology, geomorphology and geological properties of moraine ridges, which would enable description of origin and geological succession of these underwater structures.

According to the results of acoustic seabed mapping, two distinct types of moraine ridges were distinguished:

1. relatively large up to 1.5 km long and 50-100 m width elongated ridges (elevation of 5-10 m) mainly covered by large boulders and distributed parallel to the coastline (S-N direction) (further referred as Type I ridges);

2. relatively small up to 4.5 m high, 8-150 m long and 1-20 m wide elongated (length – width ratio of 3:1) hard till ridges (further referred as Type II ridges.

Various analysis demonstrated, the Type I moraine ridges most likely being formed during the Middle Pleistocene (Medininkai (Saalian) Glaciation) and (or) the Upper Pleistcene (Middle Nemunas Glaciation). Morphologicaly these ridges are very similar to De Geer moraines, which typically are formed at the glacial margins. This theory is supported by analysis of geomorphological features and measurements of the long axis orientation of pebbles and cobbles sampled from the ridge. The origin of type II moraine ridges is highly uncertain, however geomorphology and orientation support hypothesis on the dominant role of erosion in their evolution. It is likely, that the till loam of Medininkai Glaciation contained lenses and intersections of sandy type, which are less stable in respect to erosion effects in comparison to the base material (till loam). Effects of underwater currents and nearshore waves could be the major factors for erosion of unstable sandy intersections and leaving more stable till loam material in a form of 3-5 m high ridges.

Modelling results of paleorelief development in Holocene showed that the study area was overflowed in Late Glacial during the Baltic Ice Lake stage. Later, during the Yoldia Sea regression it was a part of the coastal zone and later dry land. In the late Ancylus Lake-begining of Litorina Sea stages (8600-8000 BP) the area was overflowing again and became completly submerged 7300 BP (Šečkus 2009, Gelumbauskaitė 2009, Damušytė 2011).

Reconstruction of the relief development in the study area had the aim to check all the possible processes which could have the influence on Type II moraine ridges formation. Detail analyses of paleorelief in Holocene allowed visually recognise the changes of the coastline and bathymetrical (topographical) variations of relief position. The study area during Holocene most of time was under the water (7300-0 BP) and the last 6000 years the bottom was in the depth of more than -10 m. According to Shuisky (1982) the underwater erosion in the inner seas (Baltic Sea, Barents Sea, Black Sea etc.) is active only till the depth of -10 m.

The main idea was that Type II ridges could be formed as erosional forms during different Baltic Sea development stages, especially when terrain was the dry land or coastal area. The main hypothesis which could explain the erosion of the 5 m high, very steep (almost 90°) walls was fluvial or waves erosion.

During the Yoldia Sea (11600-10700 BP) the study area was dry land. The median height of the terrain was about 35 m. The median gradient of Z value is equal to 0,0055 m. In the study area were not found any signs of valleys or fluvial relief formations. If we take into account theoretically that the fluvial water was flowing from east to west (relief lowering) we would see that there are no direct ways - as the river bed would be stopped by barriers of moraine ridges which are stretching from north to south. If we take into account that the lows would be filled by water (lake like) – the Type II ridges would occur in the middle of the lakes. There the stream of flowing water would be the weakest. Most probably these lows were swampy areas (raised bogs). According to all mentioned facts we can assume that Type II ridges as geomorphological forms could not be formed by fluvial water.

The first overflow of the area was in the Late Glacial, during the Baltic Ice Lake stage. During the Yoldia Sea regression the area became coastal zone. Taking into account the fact that during that time the deposits of Last Glaciation (Weichselian) could still exist we can predict that relief configuration was different from the recent as well. Most probably the lows were filled by Late Glacial deposits (as well as the whole area could be covered by these deposits). During the following transgressions of different stages in Holocene the coastal processes washed out (eroded) the “mellow” deposits of Last Glaciation (Weicheslian) and harder moraine (Saalian) remain. The overflowing again started at the end of Ancylus Lake (according to Damušytė 2011) or beginning of Litorina Sea stage (according to Gelumbauskaitė 2009). The complete overflow of the area (according to both models) occurred 7300 BP. During that time the area had very changeable coastline position with numerous islands and inlets. Detail analysis of relief let us ascertain that the waves could not affect the Type II ridges that they would get the recent form (canyons like). At first, the long axis of ridges is stretching from west to east and they have the right angle to the former coastline position. The second, ridges were shielded from the open waves by barriers (Type I ridges) as they are in the middle of the lows between these barriers.

After the detail study of relief development we can conclude that Type II ridges were not formed as erosional forms during Holocene. Most probably the geomorphological genesis of theses forms is connected with primary formation during the Saalian glaciation (as the glacial marginal formations) and later during the Baltic Ice Lake stage they got their recent form when deposits of last Glaciation were eroded.

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QUANTITATIVE RECONSTRUCTION OF EEMIAN (MERKINĖ) AND WEICHSELIAN (NEMUNAS) CLIMATE IN LITHUANIA

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Quantitative reconstruction of mean January (T_{Jan}) and July (T_{Jul}) temperature for the Medininkai site in Lithuania was performed. The method applied is an indicator taxa approach which estimates plant climate relationships and, in a subsequent step, combines the relationships of the different taxa in order to stabilise the reconstruction and to narrow its uncertainty (Kühl *et al*., 2002). Reconstruction was based on pollen and plant macrofossils from Medininkai site, which reveal the vegetational development characteristic to much of northern Europe sites during the Eemian and Weichselian. Rather gradual evolution of vegetation suggests a relatively stable climate conditions have existed during the Eemian, hence based on the vegetation development. During the last decade this traditional view was supplemented by the new opinion on the presence of short and low amplitude cooling phases during this period.

Our reconstruction results demonstrated quite uniform climate with slight temperature fluctuations. The thermal optimum was registered during the first part of the interglacial at *Quercus, Ulmus* and *Corylus* zone were T_{Jul} reached 18.5□C and T_{Jan} -4.5□C. Only a slight decrease of 1□C in both T_{Jul} and T_{Jan} during the time of immigration of *Tilia* at the mid-Eemian is observable. This decline is even less than detected by Klotz *et al*. (2003) during the *Carpinus-Picea* phase and reaching average winter temperatures of ca. 5.2□C and differs remarkably from an abrupt Mid-Eemian decrease in T_{Jan} of about 6-10□C as reconstructed by Cheddadi *et al*. (1998). However it is in agreement with the generally stable conditions for this period were reconstructed from the data of 106 sites across north-western Europe by Aalbersberg, Litt (1998) and reconstructions made by Kühl, Litt (2003), Kühl *et al*. (2007) from the sites in France and Germany. Reconstructed mean T_{Jul} of climatic optimum appear as being about 2□C higher than today and the same could be concluded about the January temperatures. This is consistent with the studies of Aalbersberg, Litt (1998), Kühl, Litt (2003) and Kühl *et al*. (2007). During the last two phases July and January temperatures have dropped by several degrees. Drop in temperature at the end of interglacial is more pronounced in T_{Jan} (about 4□C) than in T_{Jul} (about 1□C). However, the decrease of temperature was much lesser degree than recorded in central Germany and France (Kühl, Litt 2003; Kühl *et al*. 2007) where it reaches about -8-10□C for January and 5□C for July temperature.

Rather high T_{Jul} ranging from 16□C up to 17.5□C was registered for Early Weichselian. Meanwhile, T_{Jan} gradually decrease from -7□C during Herning stadial reaching -11□C during the Rederstall stadial. Rederstall stadial was the coolest period during the Early Weichselian. Similarly, the investigations in Voka section at the Gulf of Finland suggest interglacial climatic conditions may have persisted until the end of MIS 5a (Molodkov & Bolikhovskaya, 2010). This is also consistent with recent data from Netiesos section in south Lithuania (Baltrunas *et. al*. 2013) pointing out the warm character of the stage 5 d. Some evidence of warmer than present climate during the Brorup interstadial obtained by plant macrofossils studies from the Sokli sediment sequence at Finnish Lapland (Väliranta *et. al*., 2009) showing the T_{Jul} at least 3□C higher than at the present day as well as from northern Russia (Henriksen *et al*. 2008) were Odderade interstadial seems to be as warm as interglacial. Our study confirms this view of relatively warm interstadials in the

Baltic. Hence, the new climate reconstructions from Lithuania also contribute to our knowledge and understanding of climate variability in the wider region.

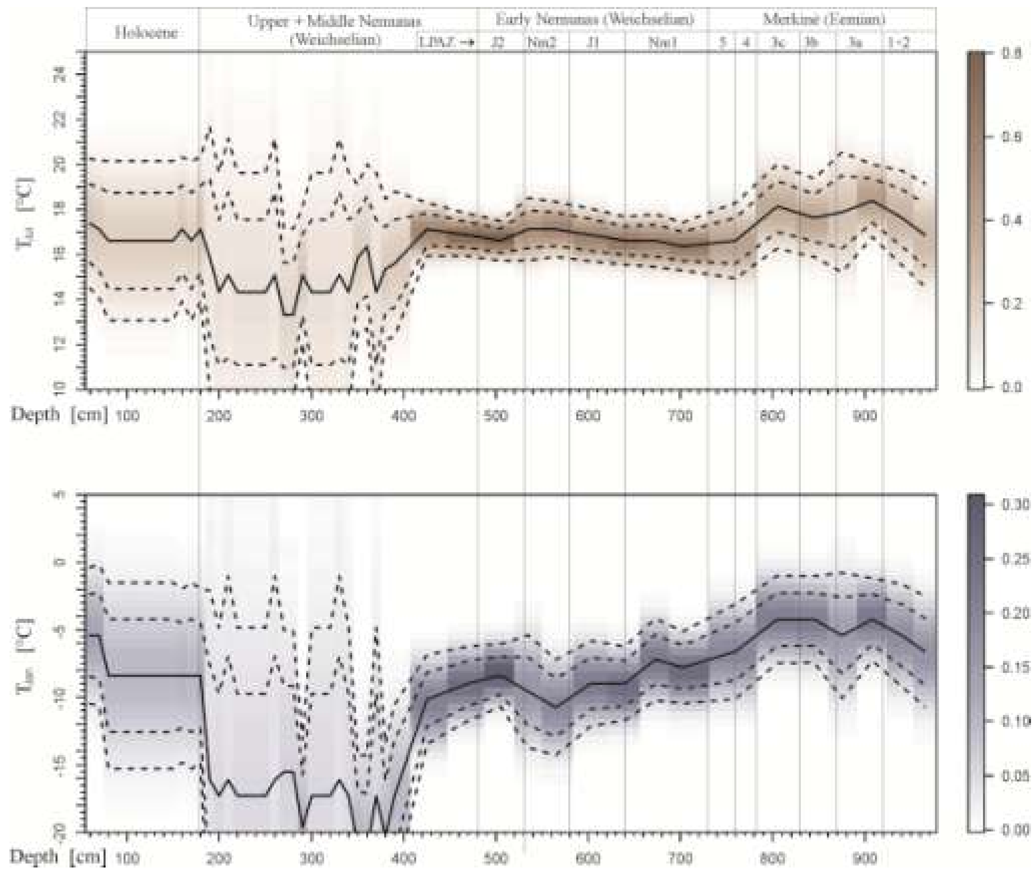

Fig. 1. Reconstruction of T $_{Jul}$ and T $_{Jan}$ during the Eemian and Weichselian at Medininkai section.

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GLACIODELTAIC FAN TERRACE AT THE MIDDLE LITHUANIAN ICE MARGINAL ZONE

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The limits of glacial lobes of so-called Middle Lithuanian phase of the final Fennoscandian ice sheet retreat from Lithuanian territory are clearly marked by the zone of ice marginal formations. The distal slopes of these recessional marginal morainic ridges in many places are reshaped by glacial melt water erosion and proglacial sedimentation. Some of such forms accumulated represent terrace shape landforms of different height and with adjoining the distal slopes of marginal ridges. Such terrace like landform of 1-1.5 km width and 3.5-4 km length stretching along the distal slopes of the ridge was studied south-east from Vilkija Township. The sediments in sand and gravel pits were described, sampled and analyzed in means of grain-size distribution and sediment structures, the well logs to analyse the deposit body architecture were used as well.

Lithofacies of subhorizontally laminated and ripple bedded fine grained well sorted sand usually characteristic of deltaic bottomsets were described in a distal (with respect to the glacier lobe) lower part of the terrace composing deposit sequence. The largest middle part of the terrace forming deposit sequence is comprised of large scale planar cross-beds of NW dip direction towards the proglacial lake perpendicular to the marginal ridge. These delta foreset lithofacies are composed of poorly sorted gravel and gravelly sand, the upper surface of which should more or less correspond to the former proglacial lake-level. Trough cross-bedded sediment sequence created by the subaerial lakeward migration of glaciofluvial sediments on the delta plain in braided streams comprises the delataic topsets. So the features of deposits and sedimentation processes characteristic of topset, foreset and bottomset units of glaciofluvial delta were interpreted as the result of complex sedimetological study.

The terrace of glaciodeltaic origin is being created by supraglacial rather than subglacial melt water drainage along the ice lobe margin and its related sedimentation at the merged marginal outwas fans. The character of marginal fan transition to the glaciodeltaic facies depended on proglacial lake level.

RELICT SAND WEDGES IN GLACIAL TILL SEQUENCES: INDICATORS OF LATE PLEISTOCENE PERIGLACIAL ENVIRONMENT IN NORTH-CENTRAL POLAND

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Relict sand wedges are valuable indicators of periglacial paleoenvironment, typically characterized by extremely cold and dry climatic conditions. Some field exposures in the Polish Lowland reveal Pleistocene glacial till sequences consisting of distinctive horizons of fossil primary sand wedges. In the current work, we present the results of the comprehensive studies conducted at four sites located in north-central Poland, some distance to the north of the maximum limit of the last Scandinavian Ice Sheet. Our aim is to present the relict sand wedges horizons in glacial till sequences and discuss their potential in paleogeographic reconstructions.

Three of the investigated sites (Barcin, Dulsk and Nieszawa) are located at the edges of the moraine plateaux and one (Rozental) is situated within the morainic hill covered by a glacial till. All exposures reveal basal till layers dissected by fossil sand wedges of different dimensions (up to 1.3 m deep and 50 cm wide) and shape. The wedges usually occur as one criostratigraphic level within the till sequence, except Rozental when two periglacial horizons are exposed in superposition. Fossil frost cracks are typically filled with vertically laminated fine sand containing significant amount of quartz grains with eaolian features on its surface. Most of the analyzed structures have been deformed, either as a consequence of density instability within the permafrost active layer or as a result of subglacial shearing during subsequent ice sheet overriding. The shape of the deformed structures often deviates significantly from the typical wedge-shaped geometry. Vertical lamination of the sand within deformed structures is usually disturbed to a different degree.

OSL dating of sand deposits from wedges suggests that infilling of the frost cracks took place between 43.8 ± 1.9 ka to 21.0 ± 1.4 ka (MIS 3-2) and between 17.3 ± 0.8 ka and 15.4 ± 0.7 ka (MIS 2). The obtained results show various distribution of paleodoses characteristic for individual aliquots within measured samples. Some of them reveal high degree of the replicability whereas multimodal distribution is characteristic for others. OSL dating of a few wedges gave clear underestimation of their age (13.8 ± 0.7 ka – 9.8 ± 0.4 ka) which could have been caused to some degree by relatively high water content in the sediments within the permafrost active layer or occurrence of ice lenses. This could have led to absorption of part of the radiation by the water or ice and therefore to an overestimation of the annual dose. Moreover subglacial shearing of the wedge structures during subsequent ice advances could have an impact on OSL signal resetting as well. However, such significant underestimation of the OSL ages (up to 50%) is still a matter of debate.

Investigated horizons of fossil wedges and their remnants, clearly indicate subaerial conditions with periglacial climates prevailing in northern Poland in the late Pleistocene. They are good paleogeographic markers indicating ice-free periods occurring between particular ice sheet advances. Having the relict sand wedges coexisting with other fossil periglacial features (involutions, frost segregation structures, ventifacts, etc.) it is feasible to trace the superposition of diverse paleoclimatic conditions: from extremely cold, dry and windy to relatively warmer and seasonally humid circumstances or vice-versa. Despite some uncertainties of the luminescence dating of periglacial wedges, we argue that testing of the OSL method with application of high-resolution techniques (e.g. “single grain” dating) seem to be

valuable for reliable paleo-periglacial reconstructions

LATE-GLACIAL AND HOLOCENE ENVIRONMENTAL HISTORY OF SAMOGITIAN UPLAND, NW LITHUANIA

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Three sediment cores were investigated in the geographical region, called the Samogitian Upland, NW Lithuania. Two cores were drilled in a small hollow Lopaičiai and one in the Lake Pakastuva (near the Lake Plateliai).

Pollen, ^{14}C dating, plant macrofossil, lithological and carbonate analysis were applied for the cores investigation in new sites. The data obtained and results of previous studies in the region enabled to reconstruct history of palaeoenvironmental conditions in the area during the Late Glacial and Holocene. Characteristic vegetation was described according to local pollen assemblage zones, which were compared with chronozones distinguished in Lithuania and correlated with NW Europe (Mangerud et. al., 1974; Kabailienė, 2006).

Late Glacial. The earliest, Oldest Dryas, deposits were found only in the Lopaičiai site. Abundant herb pollen (mainly *Artemisia*, Poaceae and Cyperaceae) was found. Tundra typical dwarf species of *Betula* were growing. Possibly, ice sheet had just retreated from territory and conditions were far from favourable for trees, soil formation was very weak. Open landscape with herbal vegetation predominated around the area.

Bølling characterized by slightly warmer climate, the arboreal birch (*Betula*) species spread in the area. Cyperaceae was widespread and local distribution of pine (*Pinus*) and Poaceae took place also. Open landscape prevailed and soil formation was still weak.

Older Dryas pollen of characteristic vegetation was found in a few places in the NW Lithuania. Number of herbs (mainly Poaceae, Cyperaceae, *Artemisia*) increases in pollen diagrams. Macrofossils suggest that birch and pine were common in forest (Stančikaitė et al., 2008). Climate of the Older Dryas became cooler and drier comparing with the previous time period.

The deposit charactersitic of Allerød were found in many places (also in the Pakastuva Lake) in the NW Lithuania. ^{14}C dating results (12925±145 cal. yr BP) confirm Allerød chronozone in the Lopaičiai site. For sediments characteristic higher content of organic matter, significant drop in herb pollen quantity and increase in abundance of arboreal pollen, especially *Pinus*. Pine and birch were dominant trees in the forest (Balakauskas, 2012). The climate was warmer and more humid, favourable for accumulation of higher content of carbonates in the sediments.

At the beginning of Younger Dryas an increase in amount of herb pollen and decrease in tree pollen was observed in sediments of all investigated boreholes. Vast growth in amount of herb Cyperaceae and Poaceae, as well as dwarf birch (mainly *Betula nana*) was observed. *Artemisia* and Chenopodiaceae also were abundantly growing. It shows that the climate during Younger Dryas was not only cool but also dry.

Holocene. Preboreal was characterized by birch forests with admixture of pine and significant amount of juniper (*Juniperus*), alder (*Alnus*) and willow (*Salix*). However, the forest was not dense at the beginning of Holocene. The content of herb pollen decreases in all diagrams of investigated sites.

For Boreal the significant increase in *Pinus and Corylus* and decrease in *Betula* pollen content is characteristic for many sites. Herbs, common to dry and sunny habitats, had declined during Early Boreal when forest became denser. Alder was common in the western part of Lithuania where the soil moisture was higher. Alder appeared in the Samogitian Uppland at the middle of Boreal because of its western–eastern spreading direction (Stančikaitė et al., 2006; Balakauskas, 2012). During Late Boreal climate became warmer with increased precipitation. Pine was still dominant in the north-western areas of Lithuania, but hazel (*Corylus*) and elm (*Ulmus*) began to spread also.

The onset of Early Atlantic can be traced by significant increase in *Alnus* pollen content and more abundant *Corylus* and *Ulmus*. Lime–tree (*Tilia*) became widespread during the first half of Atlantic (Stančikaitė et al., 2006). Previously prevailed pine and birch gradually decreased. Late Atlantic was characterized by the peak of termophilous trees pollen (*Quarcetum mixtum*). Deciduous trees lime–tree and hazel were common in the forest, rather frequent – elm, but rare oak (*Quercus*). Spruce (*Picea*) began to spread in the NW Lithuania and became significant in the forest.

During Subboreal climate became slightly cooler, precipitation was lower (Seppä, Birks, 2002) and amount of termophilous trees decreased. A peat formation started in many lakes of the investigated area. Mixed coniferous (spruce and pine) and deciduous (alder and birch) forest became common in the area during Early Subboreal. Especially spruce was widespread in the NW Lithuania. According to ^{14}C data spruce was widely spread in the area of the Lopaičiai approximately at 4350±100 cal. yr. BP. During Late Subboreal prevalence of *Pinus* pollen in diagrams became higher but *Picea* slightly decreased. Significant increase in herb pollen curves is notices and it is related to the increase of human economic activity. Sporadic occurrence of cultivated plant pollen is also detected.

Early Subatlantic coincides with the second *Picea* peak in pollen diagrams. Increase in *Pinus* and herb pollen content should be mentioned. Freshwater diatom *Gomphonema angustatum* (characteristic for running water) was found in the sediments of the Lake Pakastuva. It confirms that water level rose at the beginning of Subatlantic. Possibly, Early Subatlantic was warmer and more humid than at present. During Late Subatlantic amount of spruce decreased in the forest. Pine, birch, alder and oak were spreading in the territory of the NW Lithuania. Characteristic forest cover loss, because of human economic activity, is observed.

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PALEOGRAPHY OF NW BLACK SEA AND E BALTIC SEA ACCORDING TO LOWER MIDDLE HOLOCENE DIATOM ASSEMBLAGES

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Diatom composition studies of sediments from the Eastern Baltic Sea (Lithuanian coastal area) and north–western shelf of the Black Sea (Karkinitsky Bay, Ukraine) revealed similarities of palaeogeographical situation during Lower and Middle Holocene. Diatoms were studied in two boreholes situated in the northern coast of Lithuania (E Baltic Sea) and three boreholes from the NW Black Sea shelf area (Bitinas et al., 2000; Tymchenko, 2012).

Bugazian horizon in the Black Sea coincides with Ancylus Lake and Yoldia Sea stages in the Baltic Sea according to stratigraphy of Holocene (Tab. 1). Diatoms (predominates brackish and freshwater complex) of the Bugazian horizon indicate shallow near–shore environment of the north–western part of the Black Sea with significant input of fresh water. Sediments of Yoldia Sea stage were not found in the eastern part of the Baltic Sea because of low water level during Preboreal. The next, Ancylus Lake stage, sediments were found in the southern part of Lithuanian coastal area (Kabailienė, 1999) but sediments of this stage were not discovered in the investigated northern part.

At the beginning of Middle Holocene water level and salinity of the Baltic Sea began to rise. Litorina Sea transgression in the Baltic Sea was identified according to increased number of brackish diatoms. Prevailing brackish and planktonic diatoms (Tab. 1) show that Lithuanian coastal area was open, shallow littoral zone of the Litorina Sea. Increase of Litorina Sea salinity coincides with Vityazevian horizon in the Black Sea. Vityazevian diatom complex is composed of benthic freshwater and brackish diatoms (Tab. 1), which is characteristic for shallow brackish bay of the sea. It was detected a few benthic brackish diatom species (*Campylodiscus clypeus*, *C. echeneis*, *Terpsinoë americana*) which were characteristic for marine sediments of Middle Holocene in the E Baltic and in the NW Black Sea also. Mentioned species are an indication of water salinity increase in the Baltic Sea during Atlantic climatic optimum (Risberg, 1986; Saarse et al., 2009). We suppose that according to specific diatoms it is possible to trace Middle Holocene climatic optimum not only in the Baltic Sea but in the Black Sea also.

Water level and salinity slightly decreased in the Baltic Sea with the beginning of Postlitorina Sea (at the end of Middle Holocene). According to diatoms Postiltorina Sea bay was shallow and relatively freshwater in the eastern part of the Baltic Sea. Prevailing freshwater benthic *Pinnularia* sp. diatoms indicate that bay was not closed and had an input of brackish water. However, numerous *Fragilaria* sp. diatoms show that bay was very shallow with a large inflow of fresh water from the coast. Different environment existed in the NW part of Black Sea at the end of Middle Holocene which is represented by Kalamitian horizon. Prevailing marine–brackish benthic diatoms (Tab. 1) indicates, that sediments were deposited in shallow, relatively closed bay of the sea. Marine and brackish diatoms became dominating (comparing with the previous horizon) and it means that water salinity increased at that time.

Comparing diatom analysis data of E Baltic and NW Black Sea Holocene sediments (littoral zone) can be made a few generalized conclusions about palaeogeographys: a) maximum transgression and the highest salinity in the Baltic Sea was during Middle Holocene; b) maximum transgression and the highest salinity the Black Sea reached at the end of Middle Holocene and the beginning of Upper Holocene; c) specific brackish diatoms can be used as an evidence of Middle Holocene climatic optimum in the Baltic Sea as well as in the Black Sea.

Table 1. Characteristic diatom species of Lower-Middle Holocene sediments in E Baltic Sea and NW Black Sea coastal areas (stratigraphical subdivision of Holocene according to Andren, 1999 and Gozhik, 1984)

Baltic Sea				Black Sea		
Age, thous. yr BP	Stage	Baltic Sea stage	Prevailing (>10%) diatoms in the Lithuanian coastal zone (E Baltic Sea)	Prevailing diatoms in the NW Black Sea shelf	Horizon	Age, thous. yr BP
1 2	HOLOCENE	Postlitorina Sea	Brackish: *Campylodiscus clypeus, C. echeneis, Diploneis smithii* var. *rhombica, Tryblionella acuminata, Terpsinoe americana* (4%), Freshwater: *Pinnularia viridis, P. gibba, Fragilaria brevistriata, Staurosira construens* var. *venter, F. pinnata, Planothidium hauckianum, Martyana martyi, Aulacoseira ambigua*		Nimphaean Fanagorian (Dzemetinian)	1 2
3 4 5		Litorina Sea	Brackish: *Hyalodiscus scoticus, Actinocyclus octonarius, Diploneis didyma, D. smithii* f. *rhombica, Campylodiscus clypeus, C. echeneis, Tryblionella acuminata, Cocconeis scutellum, Grammatophora oceanica, Terpsinoe americana* (4%) Freshwater: *Epithemia turgida, E. adnata, Pinnularia viridis, Aulacoseira ambigua, A. granulata, Martyana martyi*	Marine-brackish: *Paralia sulcata, Tryblionella punctata, Diploneis chersonensis,Campylodiscus clypeus, Anomoeoneis spraerophora, Terpsinoe americana* (4%) Freshw.: *Epithemia turgida, E. adnata*	Kalamitian	3 4 5
6 7				Freshw.: *Epithemia turgida, E. adnata, Navicula oblonga* Brackish: *Campylodiscus clypeus, C. daemelianus, Grammatophora marina, Diploneis smithii,Ulnaria ulna, Anomoeoneis sphaerophora,Terpsinoe americana* (10%)	Vityazevian	6 7
8 9		Ancylus Lake		Brackish: *Anomoeoneis sphaerophora, Campylodiscus clypeus, Tryblionella gracilis , T. punctata, Diploneis bombus* Freshwater: *Pinnularia viridis, Epithemia turgida, E. adnata, Navicula oblonga, Aulacoseira ambigua, A. distans*	Bugazian	8 9
10		Yoldia Sea				10

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ASPECTS AND WAYS OF VILNIUS RELIEF RECONSTRUCTION

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The article deals with the geomorphological diversity (confluence of Neris and Vilnia rivers, interface of two ice ages, erosion hill terrains, terrace levels, etc.) of Vilnius city which played an important role in choosing the place for the city to be established and in formation of its defence structure.

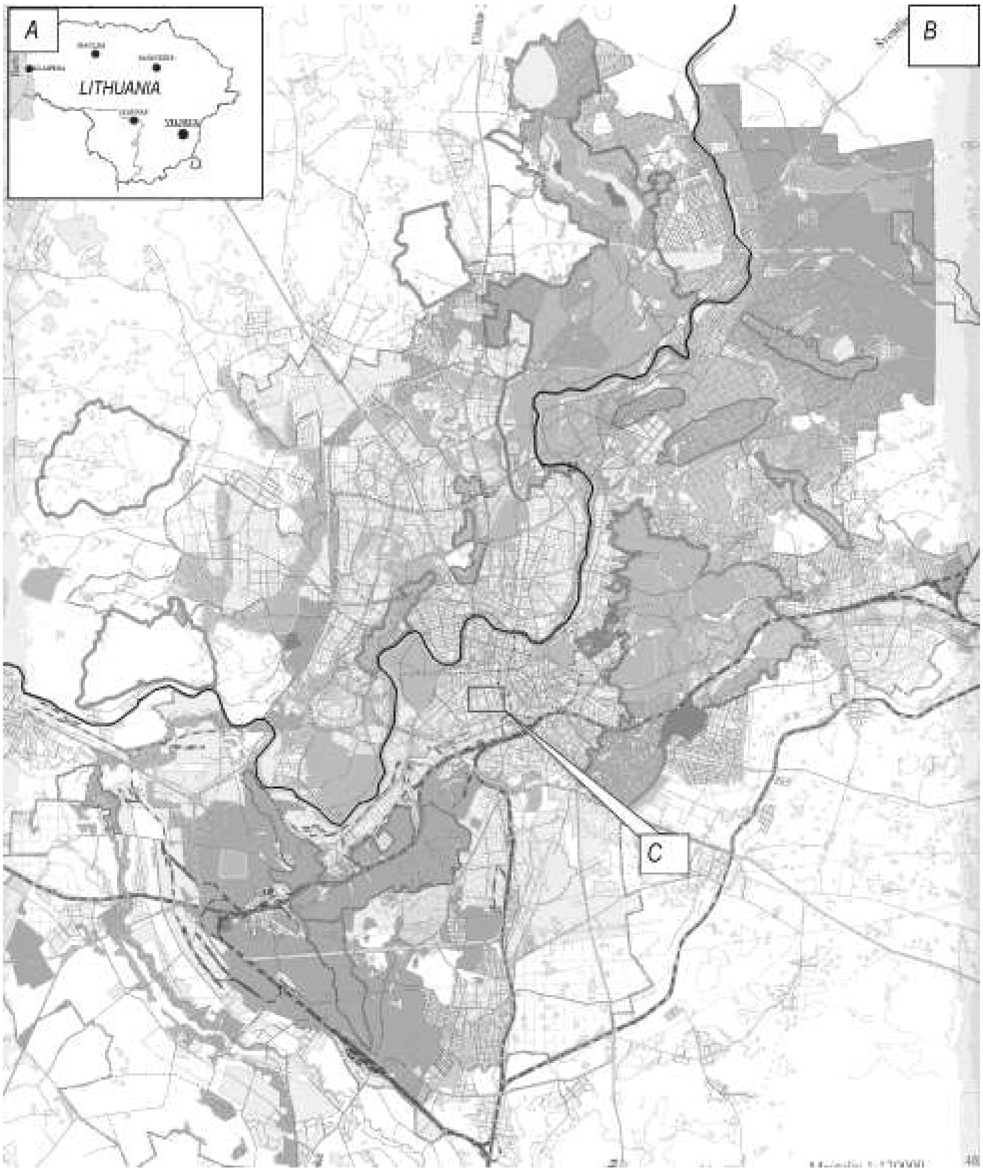

Fig.1. A- Investigated area –Lithuania; B-Investigated area-Vilnius city; C-Investigated area-location of Vingrė stream segment.

The diversity of relief of Vilnius and its environs is demonstrated by the distinguished morphogenetic zones: 20 morphogenetic units including 5 zones within the area of medieval city. From the point of view of the history of environment, the historical relief of Vilnius city has five types of relief: 1 – Altarija and Castle Mount represent fragments of erosion hill terrain; 2 – Užupis slope stands for terraces; 3 – moraines with terraces IV–V left by glaciers (part of Kuprijoniškės–Salininkai morainic slope); 4 – the larger part of the Old City and the south-eastern part of the Middle city with the surfaces of river terraces III–II; 5 – floodplain terrace on the left Neris River bank and part of the terrace above the floodplain.

The research was carried out in one of the five types of city relief: moraines left by glaciers (part of Kuprijoniškės–Salininkai morainic slope). The shallow tills acted as impermeable barrier and created conditions for accumulation of groundwater. Springs took source at the slope bottom turning into streams. The largest among them is the Vingrė River which marks the boundary between the two types of relief.

The studied territory occupies 2.6 ha and it is important for its primordial relief. Through the reconstruction of the primordial relief it could be possible to trace back the direction of Vingrė stream and the location of the defensive wall.

The LIDAR relief and borehole data, topographic maps of 1842 and 1994, and archaeological atlas were used. Geophysical and digital methods were applied. The research contributes to reconstruction of the primordial, without anthropogenic layer, relief, possibilities of its optimization and living conditions.

SAALIAN PALAEOGEOGRAPHY OF CENTRAL POLAND – MĄKOLICE CASE

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Key words: polygenesis, interlobal node, Wartanian (Saalian) ice-sheet, structural, petrography, magnetic analyses, Quaternary, Łódź Region, Central Poland

The hill at Mąkolice is a large, isolated convex form lying on the watershed between the Vistula and the Odra rivers, on the axis of the so-called Lodz hump in central Poland. Morphometric analysis of the hill relief, structural and textural studies of sediments, e.g. petrographic and magnetic ones carried out at the I-V sites in active gravel pits at Mąkolice (Piekary) on the Bełchatów Plateau were discussed. The complex internal structure of the form was highlighted. Within it, 10 series of different age sediments assigned to 6 lithocomplexes were distinguished (Wachecka-Kotkowska *et al.,* 2012).

Sediments of the older Pleistocene glaciations (MIS 30-10, Southern Polish Complex, Southern Polish Complex, Sanian II) built the northern slope of the form (lithocomplex 1). Detailed research, especially petrographic, allowed to determine the age of the oldest till, considered hitherto to have come from Wartanian, as San II (MIS 10). The dominant morphogenetic factor was the Wartanian ice-sheet (MIS 6, Late Saalian, Middle Polish Complex, after Marks, 2011), which arrived from NW (Widawka lobe) and NE/E (Rawka, Pilica and Luciąża lobes) creating an interlobal node zone. A Mesozoic surface elevation influenced the direction and rate of the glacier mass flow. The hill is built mainly of glaciofluvial and glacial series originating from the Wartanian stadial of the Odranian glaciation (MIS 6, Late Saalian, Middle Polish Complex).

The ice-sheet and meltwater formed in two stages the core of a sand and a gravel moraine hill with glacitectonic disturbances and a decay level (lithocomplexes 2 and 3). Radially outflowing water destroyed the lower part of the slopes of glacial origin which, in turn, have become an erosive remnant hill and on its outskirts the Bogdanów valley was established (lithocomplex 4) as a marginal valley.

The next stage of the relief development was associated with the Vistulian (MIS 5d-2, Northern Polish Complex) when the studied area got under the influence of a periglacial climate. It was stressed that at that stage the morphogenetic factors were glacial processes – fluvial, denudational and aeolian, modelling the original glacial relief, as the form slopes have been wrapped by denudational sand covers. Gray mud occurs between vertices (lithocomplex 5) and aeolian sands in the southern part at the base of the hill (lithocomplex 6).

The internal structure of the hill classifies it as a moraine or a kame with a stamped core which became an erosive remnant in the end of the Odranian glaciation (Late Saalian). Retouch of the original glacial relief has taken place during the Vistulian, then in Holocene and has been continuing up to now thanks to the industrial and agriculture activity of the human being. The hill presented is a next example confirming the hypothetical polygenic character of the Central Poland relief.

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DEVELOPMENT OF THE EEMIAN PALAEOLAKE IN THE KLESZCZOW GRABEN, SZCZERCOW FIELD, BELCHATOW OUTCROP, CENTRAL POLAND

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Keywords: Eemian, Aleksandrow Formation/Lawki Formation, lacustrine sedimentation, Kleszczow Graben, Central Poland

Rhythmic sediment layers investigations were carried out in April 2012 in the eastern part of the first level of a new open cast mine in the Szczerców field of the Bełchatów outcrop (PARCHLINY D site; 51°14’30,84” N; 19°08’47,08” E). The deposits occur in the tectonic valley, in the axis of the Krasowka valley. Geologically they are located in the centre of the upper floor of the tectonically active Kleszczow Graben (Allen & Krzyszkowski, 2008). They are lying at an altitude of 165 - 153 m a.s.l., for a distance of over 350 m, at a depth of 15-19 m from ground. The thickness of the series was estimated at 8-10 m and are mainly represented by massive clays and silts *Vc* structures. Deposits discussed lie erosionally on ripple-sandy and muddy sediments *Sr* (Czyzow Formation). At the top the deposits are cut and inserted into a fluvial series of sand-mud of the Piaski Formation

(Weischelian MIS 3-2). A mud sediment series is discontinuous and limited from south by the Chabielice fault and to the west it is dissected by sand and mud deposits (Weischelian Pleniglacial, MIS 3).

In the central part of the series, from a depth of 158.67-157.75 m pm (ca 17-17.9 m below the surface), over a distance of a 92 cm profile, 31 samples were collected and from which 23 were tested palynologically and geochemically ($\delta\ ^{13}C$ – $\delta\ ^{18}O$ isotopes analysed). Palynological analyses (Kuszell & Iwanus, 2012) carried out show the sequence of quaternary vegetation and interglacial succession. The palynological picture allowed for a diagram of individual spectra divided into five sections that represent local sets of pollen levels (levels E1-5). The pollen diagram of Parchliny D, although of an incomplete succession, has distinct Eemian features. It is characterized by a well-elaborated and generous amount of hazel from the optimum level, a minimum share of coniferous trees and plants with a higher incidence of plants with better thermal requirements. Also marked were similarities of the thickness of the E3 level with the protracted period of the reign of oak forests.

Geochemical studies indicated the existence of at least two stages of the basin. The first stage describes a closed, fairly deep lake present in relatively warm conditions. Later the reservoir shallows, becoming a better oxygenated, an open and flow basin. This may be due to shallowing and evaporation of the climate optimum.

Initially it was assumed that glaciacustrine deposits could be derived from the Saalian (Lawki Formation), but the results of our studies suggest that the investigated deposit may represent the Aleksandrów Formation, formed during the last interglacial (Eemian). The results complement the study of the neighbouring Bełchatów field (Krzyszkowski, 1996, Gozdzik & Balwierz, 1994), where recently was documented the so called Eemian lakeland (Gozdzik & Skorzak, 2011). These geochemical and palynological studies shed a new light on the palaeogeographic conditions of intense sedimentation during the Eemian climate optimum in the distal part of the assumed lake close to the Chabielice fault of the Kleszczow graben, within the tectonic depression of the Krasowka valley.

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DYNAMICS OF THE SUBGLACIAL ENVIRONMENT: A COMPARATIVE STUDY OF LITHUANIAN AND ICELANDIC DRUMLINOIDS

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The streamlining, elongation and "drumlinization" of materials is a characteristic geomorphic process associated with subglacial environments, capable of generating a broad range of landforms including flutes, drumlins and drumlinised ridges though to larger features such as mega-drumlins and mega-scale glacial lineations, Whilst Lithuanian landforms composed of glacigenic deposits have in general been thoroughly investigated, few studies have focused specifically on the development of drumlinoid relief. One of the reasons for this paucity of research has been the limited observation of drumlins and related lineations currently forming within active glacial environments and the lack of an associated methodology for their investigation.

This research compares the dynamics of the subglacial environment as determined from an analysis of the structure of old and recent glacial deposits. More specifically, this involved a comparison of Pleistocene drumlins located near the Ruopiškiai village (Biržai Distric) in Lithuania and modern drumlins exposed in the foreland of Skeiðarárjökull, SE Iceland. The drumlins near the margin of Skeiðarárjökull were chosen because of their documented association with a surge event in 1991. This research involved an examination of their geomorphological characteristics and the sedimentology of the associated deposits, including grain size composition, till macrofabrics analysis and microfabrics using the anisotropy of magnetic susceptibility (AMS) of micro clasts.

Comparative analysis of Ruopiškiai and Skeiðarárjökull drumlinoids demonstrates differences in both their formation and subsequent modification. In both cases, the crucial role in their initial stage of formation was associated with ice advance in the subglacial environment. However, the processes of drumlinization were different. The westward shift of the degrading glacier lobe played an important role in the formation of Ruopiškiai drumlinoids whereas deformation of the proximal part of Skeiðarárjökull drumlinoid occurred due to retreat of the degrading glacier.

INTENSITY OF FROST WEATHERING IN PLEISTOCENE PERIGLACIAL ENVIRONMENT IN THE PODLASKA LOWLAND ON THE EXAMPLE OF DROHICZYN PLATEAU (E POLAND)

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Periglacial conditions create the possibility of intensive development of a whole range of processes including frost weathering, slope processes or aeolian ones (French 2007). They are responsible, e.g. for relief transformations (Dylik 1953) and changes in the structure and texture of the sediments. In Pleistocenie the Podlaska Lowland (E Poland) was at least twice in the permafrost zone after the regression of the last glacial in this part of Poland Ithe Wartanian Stadial of the Odranian Glaciation) and during the Vistulian Glaciation (Gilewska 1991; Twardy, Klimek 2008). The intensity of periglacial processes and their influence on the relief transformations is so far poorly recognized in this part of Poland.

Presented research aims to answer the question of how intensive frost weathering was in the E Poland, are focuses on three issues: (1) the impact of this process on the silt fraction formation, (2) frost weathering recorded on the surface micromorphology of quartz sand grains, and (3) its effect on the chemical elements migration under the influence of permafrost. Hall (1990) emphasises that the silt fraction content in sediments testifies to frost weathering and its intensity. Similar importance in assessing the intensity of frost weathering is assigned to the frequency of the occurrence of microstructures such as breakage blocks (> 10 mm and <10 mm) on quartz grains surface, which origin is believed to be the impact of process accompanying the freeze-thaw (Woronko, Hoch 2011; Woronko 2012). At the same time permafrost plays an important role as a geochemical factor (Ostroumov et al. 1998). To reconstruct the intensity of the frost weathering studies included investigations on sample sites located in the former permafrost zone, ie Koczery and Wierzchuca in the Drohiczyn Plateau They were located within the continuous permafrost zone during the Vistulian Glaciation, on the slightly inclined slopes built of the glacial boulder clay, overbuilt by slope and aeolian deposits. Deposits from palaeo-active layer were investigated in detail. The deposits were examined using analysis of granulometric composition, frosting and rounding of quartz grains, micromorphology of quartz grains in a scanning electron microscope (SEM) and concentrations of major and trace elements in bulk samples. A frost action index (FAI) was developed on the basis of the frequency of the occurrence of microstructures forming by frost weathering. The FAI value varies between 0 and 3, and the higher the value, the more intensive the frost weathering (Woronko, Hoch 2011; Woronko 2012).

The thickness of the paleo-active layer in the Vistulian Glaciation was found to range from 0.50 to 0.80 m on the Drochiczyn Plateau. Structural analysis of sediments, and development of the syngenetic sand wedges in particular, suggest that the freezing was two-sided and the plug-like flow occurred.

The results of particle size analysis show that the sediments are frost susceptible. Furthermore in Koczery and Wierzchuca sites there is a clear increase in the share of the fraction <0.1 mm in the upper surface of an active layer. The results of analysis following Cailleux (1942), indicate that the most frequent grains are those which represent the aquatic environment (including fluvial and highly energetic, beach environments) and grains which surface was shaped by intensive chemical weathering (mainly amorphous precipitation) and mechanical (frost) weathering, occurring *in situ*. The presence of grains with the surface affected by aeolian abrasion was recorded only in aeolian sediments.

SEM analyzes of quartz grain microstructures show that they usually have low relief and high edge rounding. In both sample sites, the most typical microstructures associated with frost weathering and observed on the surface of the quartz grains are breakage blocks with fraction >10 mm and <10 mm and conchoidal fractures also >10 mm and <10 mm. The frost action index (FAI) calculated on the basis of the presence of the microstructures on Wierzchuca site sediments varies from 0.8 in the roof of the active layer to more than 1.1 in its floor. In Koczery site it ranges from 1.45 in the roof of active layer to about 2 in its floor. Similar values of the FAI index were obtained for sediments from the central part of Poland and in Mongolia on the area which was not glaciated in the Quaternary (Woronko, Hoch 2011). At the same time, on the Ellesmere Island (Eureka area, northern Canada), where freeze-thaw processes have been active since the mid-Holocene (Bell 1996), the effects of frost weathering are emphatically less clear. Furthermore, in the active layer, there was the migration of chemical elements to the roof of permafrost layer, including Ca, Na, K, Mg and Fe. Complete leaching of $CaCO_3$ and a clear depletion of the elements listed above proceed to a depth of 0.85 m. The maximum level of calcium and $CaCO_3$ is found directly under the permafrost table.

Obtained results allow to conclude the weathering process under periglacial conditions in the active layer of the Drohiczyn Plateau, was long-lasting and probably intensive, leading to development of microstructures on the surface of quartz grains, as well as selective cryogenic concentration of chemical elements and chemical sedimentation. Frost weathering also led to an increase in silt fraction in the active layer.

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THE WEICHSELIAN GLACIAL RECORD IN NORTHERN POLAND – TOWARDS A WIDER PERSPECTIVE

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Detailed studies of the Late Weichselian glacial tills in northern Poland and reconstruction of the processes that led to their creation allowed the authors to draw a number of general conclusions. They relate to paleogeographical issues of regional and trans-regional scope, petrographic research methodology as well as interpretation of variation of glacial tills profiles. The study was conducted in northern Poland in the area covered by the Vistula ice stream during the last glaciation. The study area remained covered with ice during the interphase recessions. As a result, the entire Late Weichselian is usually represented by one glacial till layer. In most cases this layer shows a complex vertical profile. Separate glacial till layers, representing successive phases of the Late Weichselian, are found further to the south (Leszno Phase = Brandenburg Phase, Poznań Phase = Frankfurt Phase, see Wysota *et al*. 2009).

That situation, which is the area remaining covered with ice regardless of the changes in the ice sheet reach due to subsequent advances and recessions, took place in the Late Weichselian in large parts of northern and central Europe. Thus, during older glaciations there must have been areas covered with ice during smaller ice sheet recessions. This led to the formation of a single layer of glacial till, representing several phases of ice sheet accumulation. This means that the conclusions drawn in relation to the glacial tills of the Late Weichselian in the Vistula Lobe may be extended to all glaciated areas and all glacial periods.

Although the macroscopic characteristics of glacial till, which may indicate signs of reactivation of the ice sheet and the formation of one glacial till during the successive phases, are observed in the study area quite often, they are not a rule. In addition, it is sometimes difficult to determine whether they result from changes in the ice sheet dynamics during one advance or are related to long term changes. This is because there is no record, however brief, of the ice-free period. Changes in the characteristics of glacial till in a vertical profile, resulting from temporary differences in the ice dynamics, are quite often not visible macroscopically in the outcrop. They only become apparent during laboratory analyses of the petrographic composition and interpretation of the measurements of till fabric.

Such differences in the Weichselian glacial tills have also been observed in Lithuania (Gaigalas 1996). In order to properly investigate this diversity, it is necessary to carry out high resolution vertical sampling as well as study changes in the petrographic composition and characteristics in a vertical sequence (Woźniak and Czubla 2011), instead of using the average value for the entire till layer. As it turned out, even so detailed sampling does not always ensure the reproducibility of the results for the same glacial till layer occurring in various positions. There are significant regional differences, not only between the areas covered with the paleo-ice stream and lying on its periphery, but also along its axis (in the meridional system). There is no doubt that the responsible factors include spatial variations and temporal modifications of the thermal features of the glacier's sole, resulting in a change of efficiency as well as intake of the debris followed by the till deposition.

The results shed new light on functioning of the Baltic Ice Stream, highlighted by Punkari (1993, 1997), whose proposal was later implemented and developed by, *inter alia*, Boulton *et al*. (2001). Interpretation of the results of petrographic studies of the medium-and coarse-gravel fraction (> 20mm) contained in the Late Weichselian glacial tills indicates the need to revise the model. The petrographic composition of the studied tills cannot be properly explained if northern Poland was supplied with the moraine material by only one dominant ice stream, running along the main meridional axis of the Baltic Sea and next latitudinal axis of its southern part. The tills contain a very large proportion of the rocks from the eastern Småland and the western part of the Baltic depression (west of Öland and Gotland), whereas there is no or there is very low share of rocks from the outcrops lying along the axis of the proposed stream (e.g. Old Red sandstones, red Baltic quartz porphyry). This is confirmed by the results obtained by the authors in the research sites located along the central coast of the Baltic Sea as well as those published by Górska (2008) for the Odra Lobe. A separate comment is required by a fairly large share of erratics from Skåne and Bornholm, observed in many samples. The presence of these rocks in glacial tills in the research sites in the vicinity of the Vistula river valley is particularly at odds with the concept of the Baltic Ice Stream. The authors admit there is a possibility very similar rocks are found in other parts of Fennoscandia and that they were erroneously attributed to the extreme south of Sweden and Bornholm. However, even after exclusion of these rocks from consideration, other petrographic data indicate the need for a significant shift of the Baltic Ice Stream towards the east coasts of Sweden and/or delimitation of a more developed system of routes along which the Scandinavian ice sheet was supplied with rock material.

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HISTORY AND DYNAMICS OF THE VISTULA ICE LOBE DURING THE LGM, NORTH-CENTRAL POLAND

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The LGM glaciation and dynamics of the last Scandinavian ice sheet in northern Poland was influenced by a few second-rank paleo-ice streams fed by the Baltic ice stream. One of the major streams was the Vistula ice stream, which controlled the spatial and temporal variability of the ice in north-central Poland (fig. 1). This land-based ice stream moved along the Vistula (Weichsel) River valley towards its broad lobate termination (the Vistula ice lobe) in central Poland.

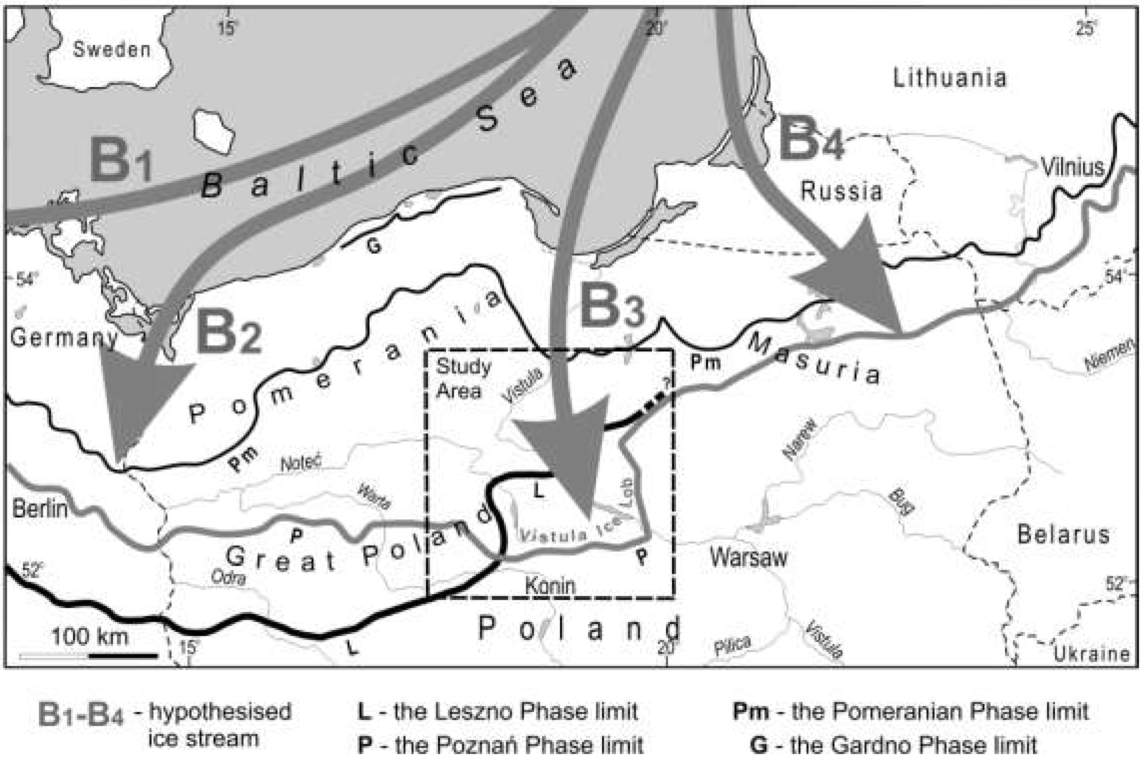

Fig. 1. The study area against the last ice sheet limits in northern Poland and neighbouring regions (ice streams according to Punkari, 1993).

The paper summarises geological, sedimentological and geochronological data for 112 research sites within the north-central Poland area. It is proved that during the LGM this area experienced two ice advances of varied extent: the older one as the Leszno (Brandeburg) Phase and the younger one as the Poznań (Frankfurt) Phase (fig. 1). During the Leszno Phase the ice sheet limit in the study area was much smaller than it had been accepted previously. A significant ice sheet retreat was followed by the ice re-advance in the Poznań Phase, overriding the extent of the Leszno advance. The Poznań re-advance reached the maximum limit in the Vistula ice lobe area.

Convincing geological and sedimentto-logical records of fast ice movement during the Poznań re-advance have been found in the study area (i.e. unconformities under subglacial till layers, uniform thickness and composition of till sheets, deformation till facies, striated boulder pavements, macro-ploughing marks, bedded till facies with evidences of ice bed decoupling). Geomorphological signature supporting rapid ice movement have also been documented (e.g. the trough-shaped exaration depression, low relief till plains and streamlined landforms).

Finally, the spatial-timing model of the Vistula ice lobe formation in north-central Poland has been created. The reconstruction includes: i.e. paleo-ice flow directions, estimation of ice velocities as well as scenarios of the ice lobe spreading.

LATE GLACIAL IN THE EUROPEAN NORTH-EAST: GEOCHRONOLOGY, SEDIMENTARY RECORD AND PALAEOGEOGRAPHY

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The Late Glacial and Late Pleniglacial (LGM) are characterized by high-amplitude climatic fluctuations. On the other hand, in the European North-East, natural history of this time was to a high extent governed by residual glacial phenomena, such as emptying of proglacial lakes, Earth crust postglacial rebound etc. Deciphering of climatic signal in the landscape development is therefore complicated due to multiple factor responsibility. One more difficulty is deficit of available information because in most cases the Late Glacial deposits are buried by younger sediments or represent very short or reduced records. Thus if we can find continuous transition records, particularly with organic layers which can be radiocarbon dated and studied with spore-pollen and plant macrofossil analysis, we have a greate chance to obtain a detailed and high-resolution Late Glacial archive and then correlate it with other natural archives such as Greenland isotopic records, etc.

Such a chance has been provided by a series of outcrops of the 1-st terrace of the Vychegda River (North Dvina and White Sea basin, North-Eastern European Russia) in its upper and middle course. This terrace occupies the wide (6-7 km) Vychegda valley bottom; its modern surface is mostly flat due to accretion of peat in bogs that totally cover its surface, with sandy massifs rising above bogs covered by pine forests. In many cases sand massifs bear aeolian dunes. Traces of palaeochannels (550 m wide against the modern channel width of 300-350 m) can be seen on its surface on satellite images. The terrace mean height above the water level is 7-8 m, maximum is 12-13 m.

The terrace outcrops in their bottom parts contain loamy laminated horizons with organic-bearing layers (peat, loamy peat, detrital matter), which has been radiocarbon dated, and studied by spore-pollen and plant macrofossil analysis. Lithology and sedimentary pattern (layers of sand and loamy peat) show the alteration of flowing and stagnant water conditions. The studied sections are as follows (in downstream order): Ust'-Timsher, Myjoldino (the upper course), Lökvozh'jol, Biostation (the middle course), and Sol'-Vychegodsk (near the river mouth). Also, the broadening valley section at the Severnaya Kel'tma River confluence was studied: low terrace covered by peat bogs with a number of remnant lakes (Kadam, Donty) with preliminary dated to the Late Glacial.

Ust'-Timsher (N 61.84103°, E 54.89095°, 114 m a.s.l.) is a 7-m outcrop located at the left bank of Vychegda. The terrace is composed of horizontally and cross-bedded sands and sandy silts, and underlain by peat and peaty loam; 14C samples had been taken from the top and bottom of 80-cm lens and two dates 12910±60 (GIN-14562) and 12900±60 (GIN-14565) respectively had been obtained.

Myjoldino (N 61.80744°, E 54.88687°, 114 m a.s.l.) is a 7-m outcrop located at the right bank of Vychegda. The terrace is composed of horizontally and cross-bedded sands and sometimes gravel sometimes underlain by peaty loam, dated back at 12980±40 (GIN-14568). Given that the age of these two terraces is the same; we synchronize the organic horizon formation with Bølling warm stage, and the terrace with Older Dryas.

Lökvozh'jol (N 61.86022°, E 52.13371°, 91 m a.s.l.) is a 4-m section located in the right bank of a left tributary of Vychegda which is crossing the terrace. Here the 3 m of horizontally bedded sands are underlain by 23-cm laminated peat-and-loam horizon dated back as 10850±60 (GIN-14580, upper layer) and 11300±50 (GIN-14582, bottom layer). The organic horizon is underlain by a horizontally bedded sandy-loamy layer. Thus, the organic horizon had been forming during the Allerød warm stage, and the sandy terrace – during the Younger Dryas.

Biozones NW Germany		Eifelmaar region Meerfelder Maar	Lower Saxony Hämelsee	Poland Lake Gosziaz	Poland Lake Perespilno	Dendro-chronology	GRIP (INTIMATE)	Warm intervals in the European NE
HOLOCENE							HOLOCENE	Holocene
		11.590	11.560	11.480-11.550	→	11.570	11.550	
LATE-GLACIAL	Younger Dryas	4	III (no varves)				Greenland Stadial GS-1	Younger Dr. >12.800
		12.680		12.650	12.630		12.650	
	Allerød	3c 3 (200a above LST)	IIc (200a above LST)				Greenland Interstadial GI-1a	Allerød 12.800 - 13.400
		LST: 12.880	LST				12.900	
		3c 2 (Gerzensee)	IIb				GI-1b	
		entire duration: 670a	entire duration: 625a				13.150	
		3c 1	IIa				GI-1c1	
		13.350						
	Older Dryas	3b	Ic (no varves)				GI-1c2	? Colder interval
		13.540						
	Bølling	3a	Ib (ca. 200 varves)				G-1c3	
		13.670					13.900	
	Oldest Dryas	2	Ia (no varves)				GI-1d	
		13.800					14.050	
	Meiendorf	1	Mei (no varves)				GI-1e	
		ca. 14.450					14.700	Warmer Interval 14.600 - 15.700
PLENIGLACIAL							Greenland Stadial GS-2	? Colder interval
								Raunis 16.500 - 17.100
								LGM

Table 1. Correlation of the European North-East data with earlier published European Late Glacial varvochronology and GRIP data (Litt et al., 2001)

Biostation (N 61.79837°, E 51.82697°, 89 m a.s.l.) is the longest (~ 2 km), the highest (12-13 m) and the best studied section located at the right bank of Vychegda. The upper part of the section is composed of fine-bedded aeolian sands underlain by well-sorted horizontally and cross-bedded alluvial sands. In the middle and lower parts of the section, two organic-mineral horizons come out, which in turn are underlain by channel alluvium. Radiocarbon dating (14 dates in total) showed that the organic horizons had been forming discontinuously during the Late Glacial: the upper layer was forming since 12900±60 (GIN-14339) till 11430±40 (GIN-14023), and for the lower there is a series of dates: 13890±50 (GIN-14192), 12560±80 (GIN-14190), and 10530±80 (GIN-14189). Probably this alluvial sequence was formed as a result of lateral accretion in a braided channel without any significant vertical deformation – incision or accumulation.

The last and lowest section is Sol'Vychegodsk (N 61.33431°, E 46.96924°, 52 m a.s.l.), located at the right bank of Vychegda 15 km upstream from its outflow to the North Dvina River. This is a 7-m outcrop exposing the lower part of the 12-m terrace: horizontally-bedded (in the upper part) and cross-bedded (in the lower part) sands; near the water line, there was a lens of detrital matter, dated at 18390±40

(GIN-14869, 22174-21770 cal BP). This date coincides to the LGM in this area, and therefore the 12-m terrace was formed around LGM, which questions the stretch of the proglacial lake into the Vychegda valley.

Pollen studies of two sections of the Biostation outcrop showed the climatic rhythmicity of the Late Glacial in the European Northeast (Table 1): organic horizons were forming during the warm stages Raunis (17.1-16.5 cal kyr BP), unnamed warm interval (15.7-14.6 cal kyr BP) and Allerød (13.4-12.8 cal kyr BP); the interbedded alluvial (river bed) sands accumulated during some cold intervals between 16.5-15.7 and 14.6-13.4 cal kyr BP. During the Yonger Dryas (12.8-11.5 cal kyr BP), the 1-st terrace of Vychegda was forming. Its formation corresponds to major channel rearrangement in the upper course of the river at the confluence with the Severnaya Kel'tma River – abandonment of a long section of the channel and its jump to its modern position.

The correlation of the European North-East Late Glacial chronology with those of Central and Western Europe and GRIP (Table 1) shows the divergence of archives downwards the lower Allerød boundary, and this is a subject for discussion.

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THE DEPOSITION CONDITIONS OF THE FLUVIAL-AEOLIAN SUCCESSION DURING THE LAST CLIMATE PESSIMUM BASED ON THE EXAMPLES FROM POLAND AND NW UKRAINE

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Fluvial-aeolian sedimentary succession is characteristic of sites located in the periglacial zone of the last glaciation, within the European Sand Belt. It documents the change from a fluvial to an aeolian sedimentary environment. The literature on the subject indicates that when the last ice sheet had its maximum extent, braided rivers occurred out in the glacier forefield in conditions of continuous permafrost. Pleniglacial/Late Glacial changes in climate (temperature and humidity) determined the deposition of fluvial sediments in the Pleniglacial, fluvial-aeolian sediments towards the end of the Pleniglacial, and aeolian sediments in the Late Glacial. In addition, the analysed succession contains a record of warm periods in the Bölling-Alleröd interstadial, in the form of fossil soil horizons. Most of the studies indicate global or regional determinants shaping the fluvial-aeolian succession. Much less attention is paid to local factors, e.g. land relief.

The goal of the present study is to characterise regional and local factors determining the variability of sedimentary environments recorded in the fluvial-aeolian sedimentary succession in Poland and Western Ukraine. The studies were conducted based on 14 sites located in the central part of the European Sand Belt, within the raised terraces of river valleys, in denudation valleys or alluvial fans (as part of the Ministry of Science and Higher Education grant N N 306 197639). Investigations carried out in these sites were concerned with the lithological characteristics of sediments (their texture, structure—including structural linear elements, grain size, morphoscopic features of quartz grains, analysis of heavy metals), characteristics of periglacial structures, pedogenic horizons and their chronostratigraphic position (TL, OSL, 14C dating).

Fluvial-aeolian succession is comprised of three lithofacial complexes. It was fully documented in 7 sites, while in each of the 7 remaining sites, only 2 complexes were found. The succession consists of the following units:

1) Fluvial complex. It is made up of sands of varying grain size, with a normal fractional grain-size distribution, with trough cross-bedding (St), tabular horizontal bedding (Sp) and ripple mark cross-bedding (Sr), to a lower extent sand-silt rhythmites with flaser (SFf), wavy (SFw) and horizontal lamination (SFh). This complex is a record of a braided river formed in two typical sub-environments: deep channel, represented by the succession of St→Sr lithofacies, and mid-channel shallows (Sp→Sh or Sh) as well as the proximal (Sh→Sr→SFw/SFf) and distal (SFh, Fh/Fm rhythmite) floodplain. Within this unit, periglacial structures were documented in the form of syngenetic pseudomorphs developed from ice wedges, complex wedges, thermal contraction fissures and mostly large-scale cryoturbations. At the Berezno site, on the other hand, poorly developed Gleysol was found at the top of the fluvial complex.

2) Fluvial-aeolian complex. It mainly consists of sands with horizontal stratification (Sh), ripple mark cross-bedding (Sr), translatent stratification and/or sand and silt rhythmite with wavy (Sfw), horizontal (SFh) stratification. In addition, single troughs occur, filled with cross-bedded sands (Se). This complex is a record of alternating fluvial and aeolian processes, usually within the floodplain or in the bottom of denudation valleys. It is a sequence of sediments deposited as a result of: a) sheet flooding (Sh) followed by aeolian accumulation on a wet surface (SFw); b) aeolian deposition on a dry surface as a result of ripple mark migration (Src or sands with translational bedding), followed by the redeposition of sediments due to short-lasting, mostly subcritical flows (St, Sr). Small cryogenic structures commonly occur within this complex. These are primarily thermal contraction fissures, vertical platy structures, small-scale cryoturbations and, accessorily, syngenetic pseudomorphs developed from ice wedges. In 2 sites, horizons of synsedimentary poorly developed Gleysols were identified at the top of the complex.

3) Aeolian complex. It is composed of sands of varying grain size with high-angle cross-bedding (Si), translatent and horizontal bedding or tabular cross-bedding (Sp) and, to a smaller extent, in the bottom parts of the unit, of silty sands with wavy (SFw) or horizontal (SFh) bedding. The sediments were deposed on the leeward side of shifting parabolic dunes (Si), windward of stationary dunes or sandy aeolian covers (sands with translatent stratification, Src, Sp, Sh) the sides of elongated dunes (Sp, Src). In 6 sites, fossil soils occur within the aeolian series and are usually represented by poorly developed podzolic soils (Albic/Arenosols/Podzols)or Arenosols. On the slopes and the foot of the dunes, colluvial soils occur quite frequently, which indicates sporadic but repeated re-modelling of dune forms by aeolian and slope processes when they were already covered by vegetation.

Based on the lithostratigraphic position of the investigated sediments, the layers of periglacial structures and absolute dating of sediments and soil horizons, the formation of the sediments can be dated back to the Pleniglacial and Late Glacial. The lithological features of sediments and the documented periglacial structures give grounds to conclude about the variability of sedimentary environments in the bottoms of river valleys and denudation valleys. The three complexes distinguished here prove the progressively increasing dryness of the climate. In consequence, the role of aeolian activity was successively increasing at the expense of fluvial processes. The fluvial complex provides evidence of fluvial outflow in rivers with a braided character and continuous flow in the harsh pleniglacial conditions. The high variability of the channel position resulted in the encroachment of permafrost on the abandoned parts of the valley bottom and the development of frost structures. The fluvial-aeolian complex is a record showing the existence of rivers following a nival streamflow regime, accompanied by intensive enrichment of alluvial sediments with wind-borne material. The aeolian complex, on the other hand, indicates the development of aeolian processes and limited role of fluvial processes. The development cycle of aeolian processes is also a period of gradual improvement of climate conditions, which is indicated by two warmer periods in the development of: a) Gleysols, developed mainly at the top of the middle complex, indicative of tundra conditions, and b) poorly developed Podzols in the aeolian complex, documenting the emergence of boreal forests; the degradation of permafrost also occurred at this time.

All the sites clearly demonstrate a change in environment conditions caused by regional/global climate fluctuations, recorded in the general succession tendency of lithofacial complexes of the sedimentary succession under study. However, the investigated sites exhibited distinct temporal differences with regard to the changes in sedimentary environments, differences in the depositional efficiency in the particular environments and very poorly marked tendency of latitudinal changes of temperature and humidity changes, manifested in the development of cryogenic structures. This situation suggests a significant influence of local conditions on the character and changes in sedimentary environments.

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