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The lower reaches of the Nemunas River at the end of the Last (Weichselian) Glacial and beginning of the Holocene

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The Russian–Lithuanian cross-border area around the Nemunas and Šešupė rivers confluence is a key area for solving palaeogeographic issues important for this region: when the Nemunas Delta started to form, why the essential changes of hydrographic network occurred, and so on. The results of conventional radiocarbon (^{14}C) dating and pollen analysis in the present dry valley between the Šešupė River and the Įsrutis River as well as the results of former studies at the Riadino-5 archaeological site suggest that the essential changes in the Nemunas River hydrographic system occurred before 9.5 ka, most likely in Preboreal time, when the Nemunas River cut through the Vilkiškės Marginal Ridge and started to flow directly to the west from this ridge into one of the former basins of the Baltic Sea – to the Yoldia Sea, or to the Ancylus Lake. A new divide was formed between the Šešupė and Įsrutis rivers, and the basins of the Nemunas and Prieglius rivers (formerly a single hydrographic system) became two independent drainage basins of the Baltic Sea. The present Nemunas Delta formation started after the Litorina Sea transgression when the Nemunas River mouth moved from a Baltic Sea nearshore position to close to the western margin of the Vilkiškės Marginal Ridge. A set of palaeogeographic reconstructions of the Nemunas and Šešupė rivers confluence area for different periods of the very end of the Last (Weichselian) Glacial and the beginning of the Holocene have been constructed.

Key words: Baltic Sea, Nemunas Delta, Ancylus Lake, palaeogeography, hydrography, archaeology.

INTRODUCTION

One of the greatest tributaries into the southeastern Baltic Sea is the Nemunas (Neman, Memel) River, which flows into the freshwater Curonian Lagoon and the delta of which forms a large flat lowland on the eastern onshore of the lagoon (Fig. 1). From an administrative point of view, the largest part of the Nemunas Delta belongs to the Kaliningrad Oblast of the Russian Federation, and only about one tenth of the delta (northwestern part) is located in Lithuanian territory. This region has been an important focus for the research. Despite many scientific achievements, there remain a number of unsolved problems, for example: the definition of geographic limits of the delta (Basalykas, 1961; Gudelis and Klimavičienė 1990a, 1993; Žaromskis, 2000), interpretation of delta's geological structure (Basalykas, 1961; Dvareckas and Gaigalas, 1996; Kunskas, 1996), reconstruction of the geological evolution and changes in palaeogeographic conditions during different stages of the Baltic Sea development (Basalykas, 1961; Červinskas and Kunskas, 1982; Gudelis et al., 1989–1990; Gudelis and Klimavičienė, 1990b, 1993; Kunskas, 1996; Gudelis, 1998; Savukynienė and Ruplėnaitė, 1999), and others. A brief summary of these problems was presented in a special paper on the Nemunas Delta evolution during its final stage of development, i.e. during the last millennium (Bitinas et al., 2002), but this was related only to the Lithuanian part of the delta. The question of when the entire Nemunas Delta started to form has been discussed, but not solved until now. In the present paper we attempt to solve this problem using data from the Russian–Lithu-

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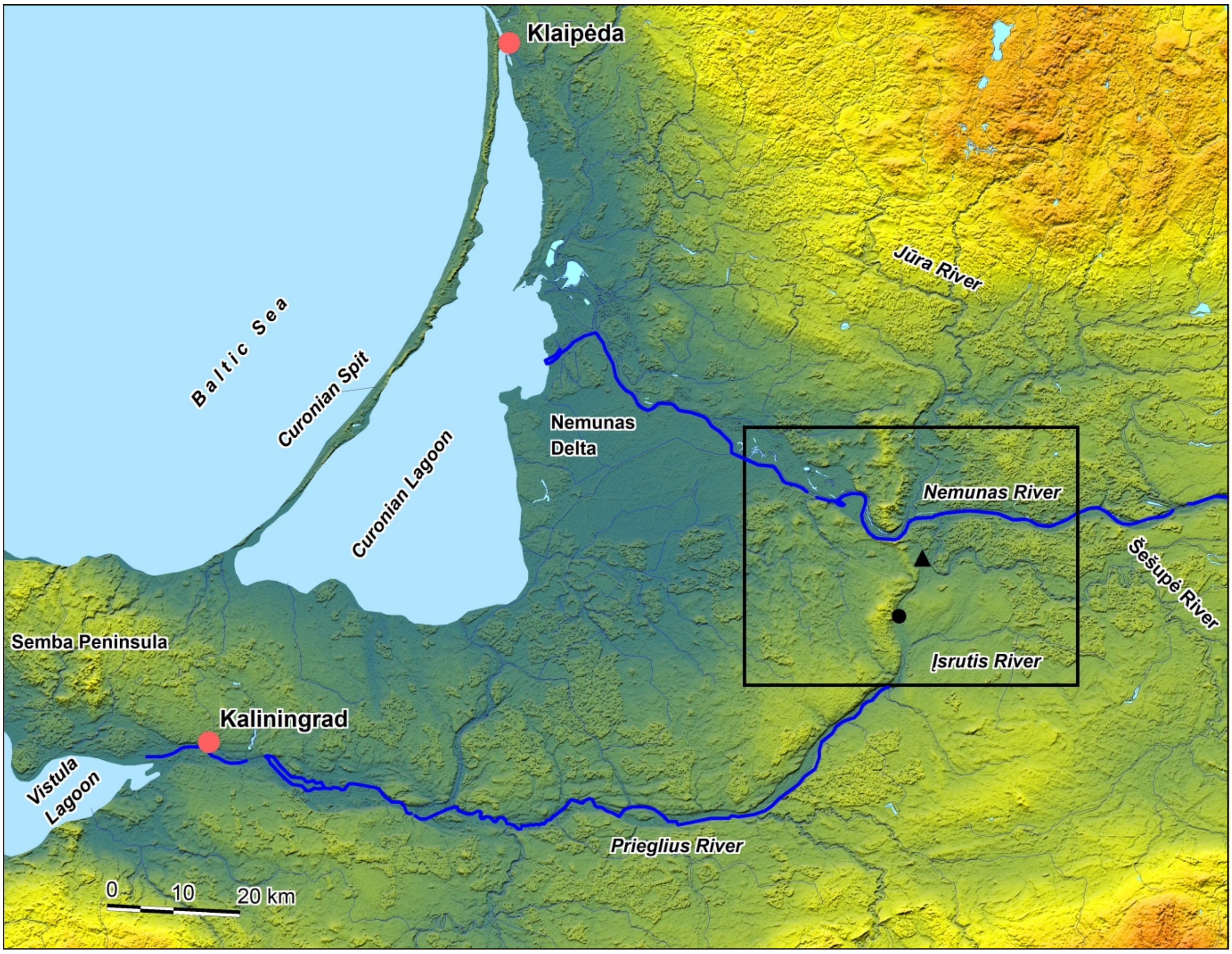

Fig. 1. Digital elevation model (DEM) of the Nemunas Delta and surrounding region of the Lithuanian Republic and Kaliningrad Oblast, Russian Federation

The area covered by palaeogeographical reconstructions (see Fig. 4) is defined by a rectangle: the geological section in the Riadino-5 archaeological site is shown by a triangle, and the drilling sites (including borehole no. 3) in the erosional Šešupė–Įsrutis valley by a circle

anian cross-border area around the confluence of the present Nemunas and Šešupė (Sheshupe) rivers, as well as from the Šešupė–Įsrutis (Instruch) divide. Researchers from two neighbouring countries were involved in the realization of this project.

GEOLOGICAL-PALAEOGEOGRAPHICAL SETTING

The dry valley located between the present Šešupė and Įsrutis rivers is a key area for resolving the problem of the Nemunas Delta formation. According to geological and geomorphological data (Figs. 1 and 2) this valley was the main channel for meltwater discharge from the north to south, and further – to the west, along the valley of the present Prieglius River, during the final stage of the Last (Weichselian) Glacial (Straume, 1982). This happened when large areas of Lithuania and the Kaliningrad Oblast were just semi-deglaciated, but the area of the present Nemunas Delta and northern part of Semba Peninsula was still occupied by a dead ice massif (Guobytė and Jusienė, 2007). The end-moraine ridge, named the Vilkiškės Marginal Ridge (VMR), was formed between these two areas by geological activity of the ice lobe that advanced via the present depression of the Curonian Lagoon and Nemunas Delta. Thus, meltwater runoff was directed along the margin of this end-moraine ridge and a large erosional valley, stretching from the lower reaches of the Jūra River to the present Baltic Sea (Vistula Lagoon), was developed (Fig. 2). Later, at the beginning of the Holocene, this valley became part of a hydrographic network. At that time the Nemunas River collected water from its tributaries – the Jūra and Šešupė rivers – and flowed into the Įsrutis River, then and farther to the Prieglius (Pregel) River. The runoff from the entire Nemunas hydrographic system was directed to the south from the Semba Peninsula (Straume, 1982). At that particular moment in the past the Nemunas River cut through the VMR and started to flow into the Baltic Sea basin to the north of the Semba Peninsula. Thus, this event became not only the starting point of the new Nemunas Delta formation, but also gave a beginning for two independent hydrographic drainage systems of the Baltic Sea basin. The present divide between the catchments of the Vistula Lagoon (Prieglius River system) and the Curonian Lagoon (Nemunas River system) is in the middle of a dry valley located between the lower reaches of the Šešupė River and the Įsrutis River (Chubarenko, 2008). A network of dry channels, the relicts of a few small rivu-

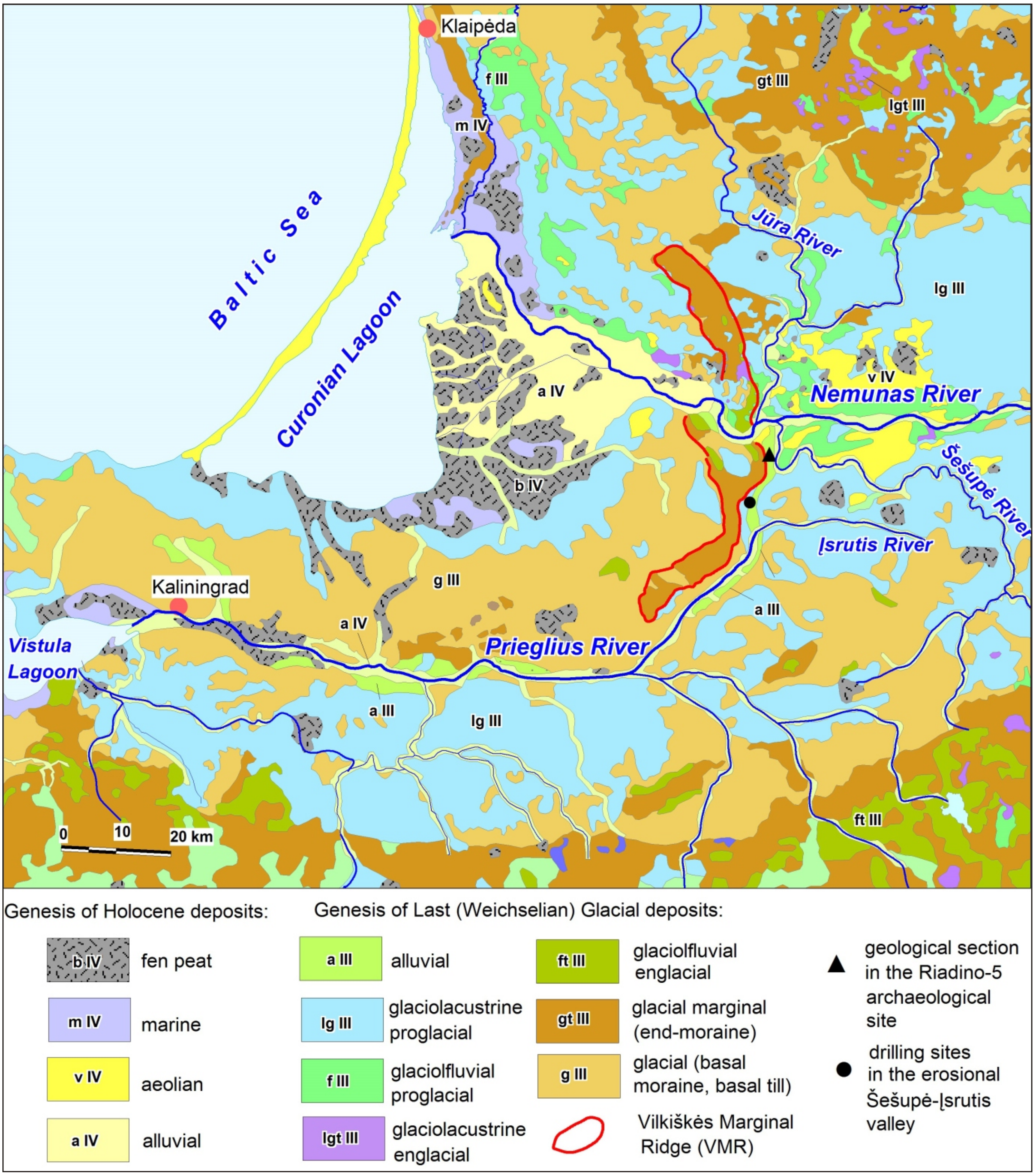

Fig. 2. Quaternary geological map of the Nemunas Delta and surrounding region of the Republic of Lithuania and Kaliningrad Oblast, Russian Federation (compiled by R. Guobytė)

lets and ponds in former peat exploitation sites, currently represents the hydrographic system in the erosional Šešupė–Įsrutis valley. Despite the general palaeogeographic situation of this region being evident, a few issues are still unresolved: (1) what exact geological-palaeogeographic situation existed at that time; (2) when did the Nemunas River cut through the VMR; and (3) what caused this event. For the more detailed reconstruction of the palaeogeographic situation, data from geological investigations at two key points in the former Nemunas River valley (our so-called erosional Šešupė–Įsrutis valley) were used: an excavated geological section at the Riadino-5 archaeological site; and a few specially drilled shallow boreholes in the middle part of this valley (Figs. 1 and 2).

METHODS

Geological field observations and drilling. The fieldwork, including the digging of a few tens of shallow excavations, geomorphological observations and photo documentation

Table 1

Geological section of borehole no. 3

No. of layer Depth [cm] Study methods	Lithological description
1 0.0–170 Pollen an.;^{14}C	Peat, black and dark brown, well-decomposed, compact, from the depth of 1.6 metres the peat has a brown tint, deposit contains an admixture of gyttja.
2 170–180 Pollen an.	Gyttja, greenish grey, compact, carbonated, with fragments of freshwater mollusc (*Valvata* sp.?) shells.
3 180–200 Pollen an.	Sandy-silty gyttja, greenish grey with brown tint, compact, with single fragments of freshwater mollusc (*Valvata* sp.?) shells.
4 200–220 Pollen an.	Sandy silt, greenish grey, compact, laminated (with thin interlayers of brown gyttja-sandy silt), with single fragments of freshwater mollusc (*Pisidium* sp.?) shells. At the depth of 2.0–2.15 m – thin interlayers of brown sandy silt with gyttja and remnants of freshwater molluscs (more frequent), at the depth of 2.5–2.2 m – very thin interlayers of grey clayey silt.
5 220–310 Pollen an.	Silty clay, greenish grey, compact, plastic, from the depth of 2.75 m with thin interlayers of very fine grey sand.
6 310–320	Till (clayey loam), yellowish brown, massive, compact, with individual gravel layers and pebbles.

around the confluence of the Nemunas and Šešupė rivers, was carried out in 2011. Three shallow boreholes (up to 2.9–3.4 m in depth) a few hundred metres apart were drilled by a hand auger in the central part of the dry erosional Šešupė–Įsrutis valley in 2012 (Figs. 1 and 2). A very similar sequence of geological strata was discovered in all borehole sections. One of the 3.2 m deep boreholes with the greatest thickness of organic deposits and the best quality of drill core (no. 3; Table 1; located 54°53'52"N, 22°08'12"E; about 14 m above mean sea level) was chosen as a key section and sampled for pollen analysis in detail, while a few samples for radiocarbon (^{14}C) analysis were also collected (Table 2). All samples were collected below 100 cm depth because the uppermost levels in the area investigated have been disturbed by peat exploitation and subsequent amelioration.

The geological section situated in the lower reaches of the Šešupė River and located on the highest (third) overbank terrace of the left riverside (55°01'40"N, 22°11'46"E) about 23 m above mean sea level was used as an additional point of investigations. This geological section was discovered and investigated in detail during archaeological excavations in 2009–2011 and is known as the Riadino-5 archaeological site (Druzhinina, 2012, 2013). The excavation was supplemented by the investigations of lithostratigraphy, geochemistry and chronostratigraphy, dating by radiocarbon (^{14}C) and infrared stimulated luminescence (IRSL) dating (Druzhinina, 2012; Druzhinina et al., 2016).

Pollen analysis. Palynological investigation was carried out for 32 samples taken from borehole no. 3. Pollen and spores for preparation were extracted by means of chemical treatment in several steps according to generally accepted principles (Faegri and Iversen, 1989). The preparations were examined microscopically under 400 magnification in order to identify pollen and spore taxa as well as other plant remnants. For this purpose a number of identification keys were used (Göttlich, 1990; Faegri and Iversen, 1993; Beug, 2004; Nelle, 2006). In pollen counting, the total sum of arboreal pollen was at least 500 grains. A pollen diagram was generated on the basis of the data obtained using the C2 data analysis programme (Juggins, 2014; Fig. 3). Pollen percentage values were calculated as a share of total sum of pollen grains from trees and shrubs (AP) and terrestrial herbaceous plants (NAP). The pollen of aquatic plants, spores and *Pediastrum* coenobia was excluded from the total pollen sum. Their percentage values were calculated as ratios to the sum of AP + NAP. Pollen concentration was calculated using *Lycopodium* tablets (Stockmar, 1971).

Table 2

Results of conventional ^{14}C dating of sediments in the borehole no. 3

No.	Lab. index	Depth [cm]	Analysed sediment	Investigated material after acid-alkali-acid (AAA) pre-treatment	^{14}C age [years BP] (±1)	Calibrated age (1 ranges)	Calibrated age (2 ranges)
1	Vs-2360	110–120	peat, bulk	total organic carbon (TOC)	3435 ± 75	3830–3785 BP (12.4%) 3775–3740 BP (9.8%) 3735–3605 BP (46.0%)*	3890–3550 BP (92.0%) 3535–3480 BP (3.4%)
2	Vs-2359	130–140	peat, bulk	TOC	3035 ± 70	3350–3155 BP (68.2%)*	3385–3005 BP (95.4%)
3	Vs-2361	160–170	peat with gyttja, bulk	TOC	8335 ± 140	9480–9230 BP (55.9%)* 9225–9195 BP (4.5%) 9180–9135 BP (7.7%)	9550–8998 BP (95.4%)

*main interval of 1 is considered in the text

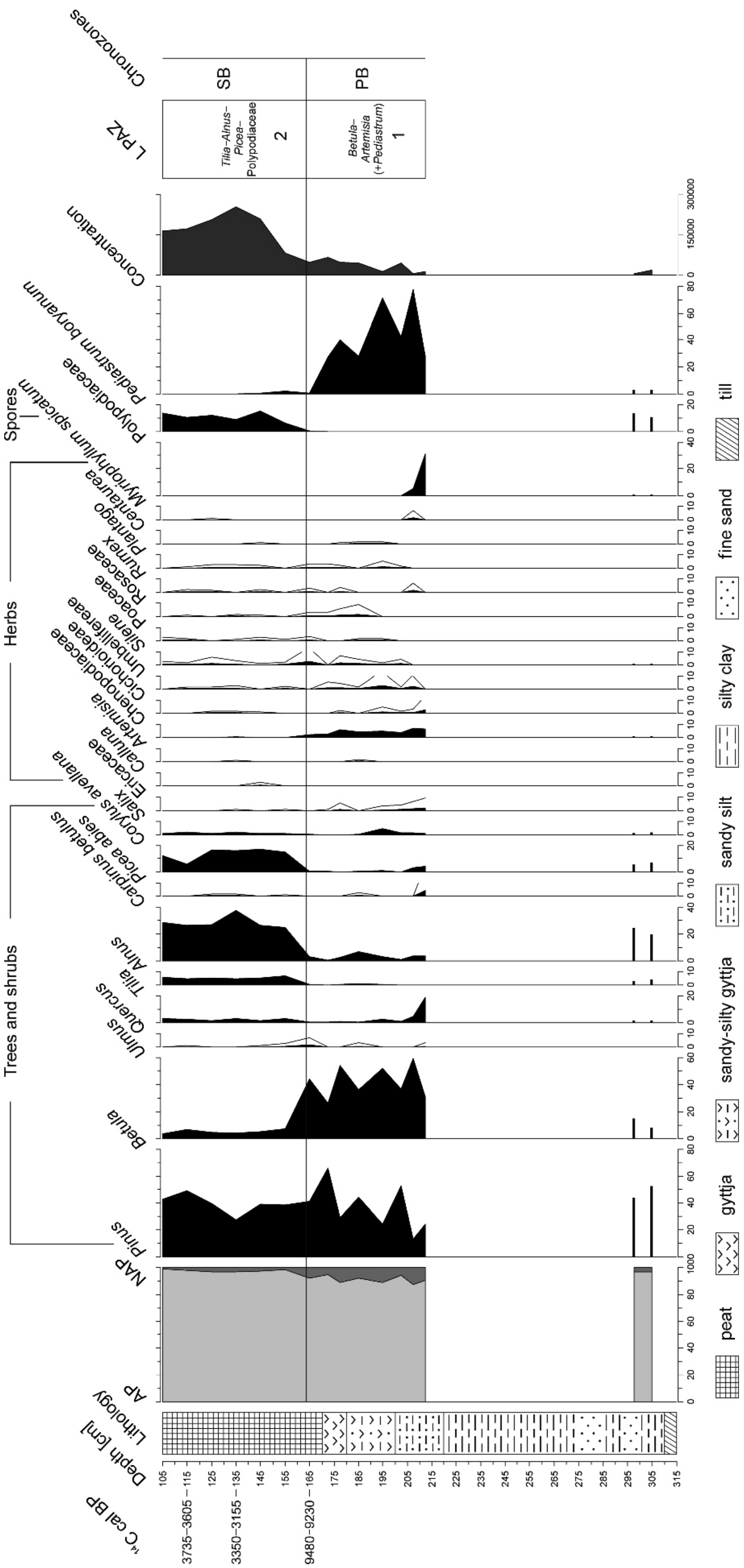

Fig. 3. Pollen diagram from borehole no. 3 (compiled by T. Napreenko-Dorokhova)

Radiocarbon (^{14}C) analysis. The analysis of three bulk samples of peat and gyttja peat collected in borehole no. 3 was performed by conventional (^{14}C) dating at the Laboratory of Nuclear Geophysics and Radioecology, State Research Institute Nature Research Centre, Vilnius, Lithuania (Table 2). The pre-treatment of the samples included crushing and acid-alkali-acid (AAA) washing to remove carbonate and humic acid contamination. The remaining bulk organic carbon was used for benzene production (Kovaliukh and Skripkin, 1994). The technological lines for benzene synthesis and purification used for analysis were produced at the Kiev Radiocarbon Laboratory, Ukraine. The specific ^{14}C activity in benzene was measured using the liquid scintillation counting (LSC) method described by Gupta and Polach (1985), Arslanov (1985), Kovaliukh and Skripkin (1994), and using the liquid scintillation analyser *Tri-Carb 3170TR/SL*. All radiocarbon dates were calibrated using the ^{14}C calibration program *OxCal v. 3.1* (Bronk Ramsey et al., 2010) and the calibration curve *IntCal13* (Reimer et al., 2013). The calibration of radiocarbon dates (calendar years BP) was performed using the calibration curve radiocarbon and calibration program *OxCal v. 4.1*.

Maps and palaeogeographic reconstructions. For geomorphological analysis of the area investigated a Digital Elevation Model (DEM) prepared from the Shuttle Radar Topography Mission (SRTM) data products (2003–2007) was used (Fig. 1). The geological map compiled by R. Guobytė (Fig. 2) was based on the geological information of the state geological maps at a scale of 1:200,000 (Grigelis, 1970) carried out in different years for the separate parts of the territories of Lithuania and Kaliningrad Oblast; the interpretation of aerial photo (scale 1:18,000–1:20,000) and cosmic-photo images (scale 1:50,000) was also used. The palaeoreconstructions of the Vilkiškės Marginal Ridge formation carried out for the Rambynas Regional Park, i.e. for the Lithuanian part of the VMR (Guobytė and Juodkazis, 2003; Guobytė and Jusienė, 2007) serve as a very important piece of information about the geological structure of the VMR. As a result of the compilation of all these investigations a number of palaeogeographic schemes with palaeogeological cross-sections were constructed for the region of the Nemunas and Šešupė rivers confluence – the area covered by the palaeogeographic reconstructions is shown in Figure 1.

RESULTS AND INTERPRETATION

DRY EROSIONAL VALLEY BETWEEN THE ŠEŠUPĖ AND ĮSRUTIS RIVERS

Geological setting. We have no detailed data concerning the geological structure of the Quaternary of the erosional Šešupė–Įsrutis valley, based on the results of detailed geological mapping (i.e. at larger scale than the state geological maps at 1:200,000 scale; Grigelis, 1970) or borehole sections of the full Quaternary made by drilling rig. Thus, the geological map at a small scale (Fig. 2) and three very shallow hand-made boreholes drilled in the bottom of the valley enabled an approximate interpretation of the geological setting of this region. The erosional Šešupė–Įsrutis valley is engraved into the glacial deposits of the Last (Weichselian) Glaciation that dominate the surroundings of the valley. The alluvial sediments of the Last Glaciation and of the beginning of Holocene were deposited at the bottom of this valley (Fig. 2). Holocene peat locally overlies these deposits. The geological description of the key section (borehole no. 3) sampled both for pollen and radiocarbon (^{14}C) analysis is shown in Table 1.

Pollen analysis: results. The core analysed is 310 cm long consisting in half of fen deposits (105–170 cm) with high pollen concentrations (Fig. 3). Downwards up to 215 cm depth these are replaced by lacustrine deposits of gyttja and silt where pollen concentrations decrease rapidly. The next 80 cm of the core consists of sandy silt and silty clay (215–295 cm) without pollen and spores. The lowest 15 cm contain a very small amount of pollen.

Based on the pollen diagram, two local pollen-assemblage zones (LPAZ) were identified for the profile (Fig. 3).

LPAZ 1: *Betula–Artemisia* (215–160 cm). The first zone is defined by low pollen concentrations (5725–65909 grains/cm^3), *Betula* pollen dominates (up to 60%). There is a considerable content of *Artemisia* (up to 10%) and *Pinus* (up to 66%) pollen. Pollen percentage of other species is negligible. *Pediastrum boryanum* spores prevail in this pollen-assemblage zone.

LPAZ 2: *Tilia–Alnus–Picea*–Polypodiaceae (160–100 cm). The second zone is defined by high concentrations of pollen and spores (82630–255021 grains/cm^3). The lower boundary of the LPAZ 2 is drawn along the increase in *Tilia*, *Picea*, *Alnus* pollen as well as in Polypodiaceae spores and simultaneous decrease in *Betula* and *Artemisia* pollen. Percentages of *Pinus, Corylus* and *Quercus* pollen are 25–45%, 1–2% and 1.6–3%, respectively.

Radiocarbon dating. The results of dating of three organic bulk samples from borehole no. 3 are shown in Table 2.

Interpretation. A high percentage of green freshwater algae *Pediastrum boryanum* is typical for this LPAZ and shows that sedimentation took place in water, though the gradual decrease and disappearance of *Pediastrum* remnants upwards in the profile indicates change of sedimentation conditions. Pollen have not been detected in the lowermost part of the borehole section (215–300 cm), or there are only single grains – this might be a result of rapid sedimentation. Two samples in the lowermost part of the silty clay layer, directly above the till (300–305 cm), contain a very similar pollen spectra to those determined in LPAZ 1. Thus, it is possible to assume that the lowermost part of borehole section was formed at the same time as the sediments of LPAZ 1, i.e. most likely during the Preboreal. The radiocarbon dating of peat with gyttja from the lowermost part of LPAZ 1 (9480–9230 cal yrs BP, 160–170 cm) gives ground for assuming that sedimentation in the basin continued until the first half of Boreal.

It is noteworthy that the lower part of the LPAZ 1 (205–215 cm) contains a large amount of *Myriophyllum spicatum* pollen while *Pediastrum* remnants occur rarely at this horizon. The first species grows in shallow basins; the second one inhabits deeper water bodies. The pollen concentration of *Myriophyllum spicatum* is present down to the 210 cm horizon and rapidly vanishes at 200–205 cm with the simultaneous increase of *Pediastrum* content. This shows that the increase of water level and change of sedimentation character in the lake started from the point of 200–205 cm, where gyttja accumulation starts. The arrangement of pollen spectra in LPAZ 2 reflects, apparently, a wide distribution of either broad-leaved forests with lime and oak dominance or present-day-like mixed broad-leaved-coniferous communities. Such a character of vegetation was rather typical for the Late Holocene in the adjacent area (Gams and Ruoff, 1929; Steffen, 1931; Neustadt, 1957). Peculiarities of pollen spectrum and the results of radiocarbon dating (3735–3605 cal yrs BP and 3350–3155 cal yrs BP) suggest that sediments attributed to the LPAZ 1 accumulated during the Subboreal. The sedimentation character at the core site is evidence of alder swamp formation at that stage which is additionally suggested by a considerable amount of *Alnus* pollen and spores of Polypodiaceae peculiar to alder swamp ecosystems.The results of both pollen and radiocarbon dating show that it was a relatively long (about 6 ka) period of peat accumulation at the site investigated: from the first half of the Boreal until the Subboreal (Fig. 3). The data allows us to form only a very general image of changes in palaeogeographic conditions during the formation of the post-glacial sedimentary succession in the Šešupė–Įsrutis dry valley investigated. This succession originated in two stages. The first stage began at a particular moment of the Preboreal with silty clay accumulation in the relict lake after the river drainage. During the existence of this basin the mineral components (clay, silt, and fine sand) were gradually replaced by organic sediments (gyttja), possibly due increase in water level. Finally – probably just in the first half of the Boreal – the lake was drained and peat accumulation began. Due to unknown reasons (most likely due to the lowering of the groundwater level) the peat accumulation was interrupted for a few millennia. This process was renewed at the second stage of sedimentation, during the Subboreal, and the uppermost part of the peat layer was formed.

LOWER REACHES OF THE ŠEŠUPĖ RIVER

Geological setting. The geological section of alluvial deposits investigated at the Riadino-5 archaeological site is located on the third overbank terrace of the Šešupė River. Individual aeolian dunes, complex dune systems and small sand ridges are developed on the flat top of this terrace. Alluvial sediments to 0.5 m depth are generally composed of light yellow fine- and medium-grained sand with individual pebbles and charcoal. The uppermost part of the alluvium (to ~0.25 m depth) has been changed by ploughing. The alluvial sand overlies a sedimentary unit (0.5–0.6 m) which consists of reddish-brown, ferruginous loamy sand, unsorted, with high gravel content. A layer of coarse and medium-grained light grey sand, with an admixture of gravel, comprises the lowest part of the section – from 0.6 m and deeper (Druzhinina et al., 2016). In some places, the sub-horizontal layering is destroyed by palaeo-seismodeformation structures (sand diapirs) that are characteristic for post-glacial deposits of the southeastern Baltic (Bitinas and Lazauskienė, 2011; Bitinas, 2012; Nikonov, 2013).

Chronology of the site deposits. The sample of charcoal (8800 ± 600 yrs BP calibrated at the 95.4% level to 11718–8446 cal yrs BP) is related to the lower part of the alluvial sand; the radiocarbon age obtained is roughly in accordance with the IRSL date for a sediment sample (8.1 ± 0.6 ka) taken from the same layer. The IRSL dates for the sediment units underlying the alluvial sand (deeper 0.6 m) show a 44.0 ± 3.4–62.1 ± 4.6 ka age that allow attributing them to the Mid Weichselian (Druzhinina et al., 2016).

GEOLOGICAL DEVELOPMENT OF THE REGION DURING THE END OF THE LAST GLACIAL AND BEGINNING OF THE HOLOCENE

The palaeogeographical reconstructions of the area of the Nemunas and Šešupė rivers confluence have been developed using the results of the geological data collected and published materials. A set of palaeoreconstructions has been subdivided into the 5 stages (Fig. 4A–E).

Stage A (Fig. 4A). Close to the end of deglaciation of the Last Glacial (about 15.0–14.5 ka BP) the dead ice massif that covered the entire territory was dissected into separate blocks. Meltwater basins started to form between the blocks. When reactivation of the Scandinavian Ice Sheet (SIS) occurred, a lobe of active ice surged into the dead ice massif from the west. Its margin stabilized approximately at the position occupied by the present VMR. A relatively deep (at least 80–100 metres) and large meltwater basin was formed between the massifs of active and dead ice in the place of the present Nemunas valley. About 80 m of glaciolacustrine kame deposits (generally composed of fine sand) accumulated in this basin (Guobytė and Juodkazis, 2003; Guobytė and Jusienė, 2007). Thrust-folding of the glacial deposits (deformational till) took place along the entire marginal zone of the active ice lobe.

Stage B (Fig. 4B). During the further deglaciation (about 14.0 ka BP), the active ice surge was transformed into a dead ice massif. The area covered with older dead ice massif (more completely melted and thinner) disappeared more quickly – only a few relicts of dead ice blocks were left in the eastern part of the area investigated. Meanwhile the western part of the area was still covered with dead ice. A large, shallow meltwater basin was formed in the eastern part of the area investigated: a few metre-thick sediment layers (fine sand, silty sand, silt) accumulated. At the end of this stage, when the meltwater basin became shallower, braided streams of meltwater dissected the glaciolacustrine sediments and left wide belts of glaciofluvial deposits, composed of sand or sand with gravel.

Stage C (Fig. 4C). The SIS in the southeastern Baltic Sea region completely melted at approximately 14–13 ka BP (Rinterknecht et al., 2008). Thus, at that time (about 13.5–13.0 ka BP) the VMR appeared as a landform elevated above the surrounding terrain. It was a typical end-moraine with thrust-fold structure (i.e. deformational till), except for the place where the marginal ridge is dissected by the present Nemunas valley – this part of the ridge is represented by a kame massif composed of fine sand. In the eastern part of the area investigated area a system of meltwater channels formed: the general direction of meltwater flow was to the south, along the eastern margin of the VMR. During this stage the present-day river system was born. The area to the west of the VMR became as a flat plain where a basal till or glaciolacustrine sediments were deposited.

Stage D (Fig. 4D). At the beginning of Holocene (about 11.0 ka BP), a network of rivers finally developed – they started to modify their valleys, and to meander. At that time, the Nemunas River flowed westwards, but the VMR, as an obstacle, determined its further flow to the south, to the valley of the present Prieglius River. A large meander on the eastern side of the VMR started to form – in this place the Nemunas River intensely eroded soft sand of the kame massif. A system of ravines on the steep slopes of the VMR and the valleys of rivers started to form – these processes developed most intensely on the slopes formed of soft sandy deposits.

Stage E (Fig. 4E). Due to the Nemunas River erosion from the east, and, most probably, simultaneously with the ravine erosion from the west, the VMR was cut through in the area where the sandy kame massif was developed. As a result, at some point before 9.5 ka, the Nemunas River radically changed its direction and started to flow westwards. The lower reaches of the Šešupė River occupied part of the former Nemunas River valley, and moved its mouth to the north. The Įsrutis River continued to flow to the Prieglius River. The large valley between the Šešupė and Įsrutis rivers became a dry valley with a few rivulets. A few relict lacustrine basins in the places of the former riverbed were later filled with peat. Linear erosion of the Nemunas River influenced the related erosion of its inlets (Šešupė and Jūra) what formed a few overbank terraces. At the same time aeolian processes, that were active in that part of the region approximately until 4.5 ka BP (Molodkov and Bitinas, 2006), started to change the flat sandy surfaces of glaciolacustrine and glaciofluvial plains and overbank terraces into a dune relief.

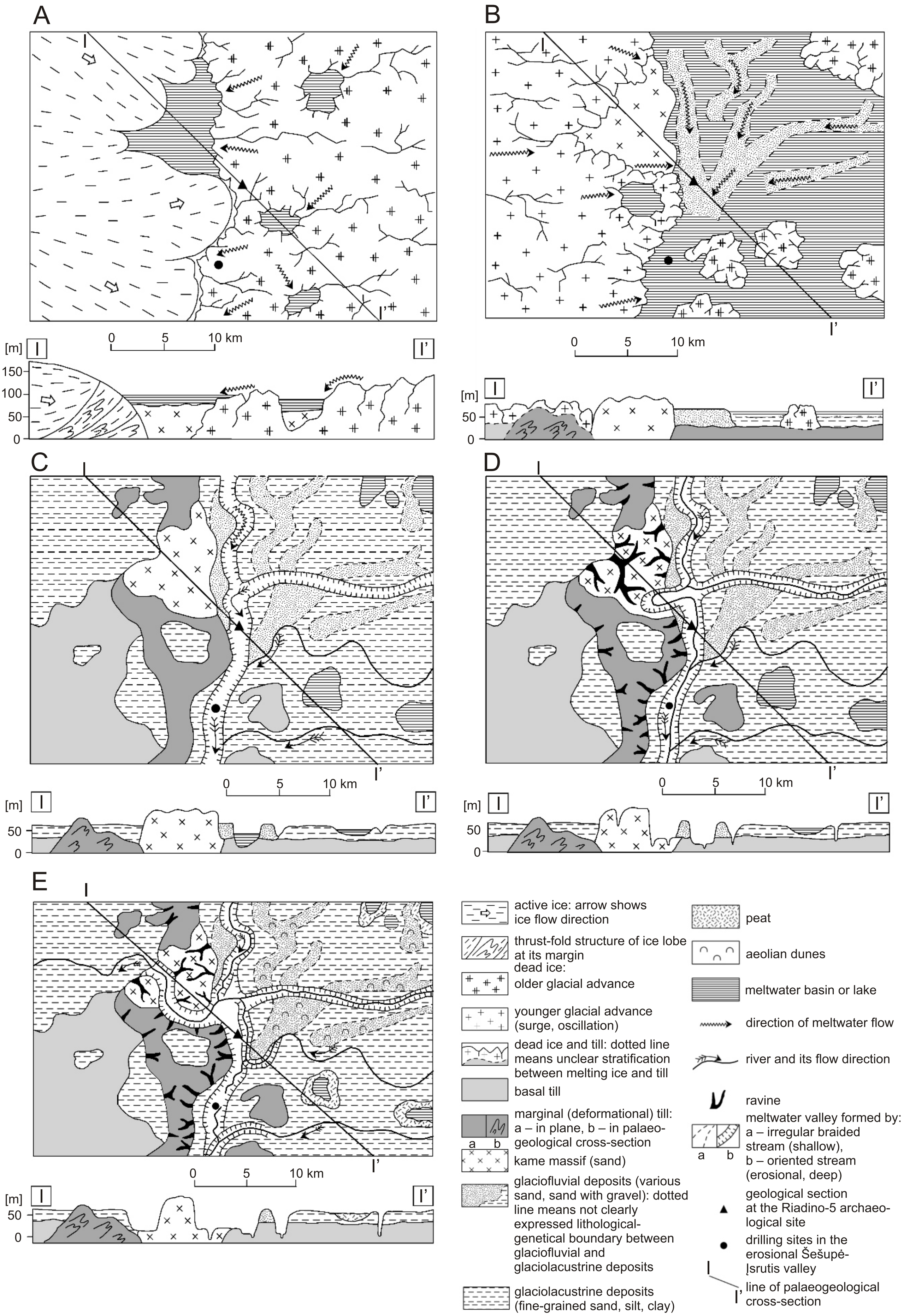

Fig. 4. A schematic model of the palaeogeographical changes in the Nemunas and Šešupė rivers confluence region at the very end of the Weichselian and beginning of the Holocene; below each scheme a palaeogeological cross-section is shown

The palaeogeographical schemes are approximately for the following periods:
A – 15.0–14.5 ka BP; B – ~14.0 ka BP; C – 13.5–13.0 ka BP; D – ~11.0 ka BP; E – >9.5 ka BP (compiled by A. Bitinas)

DISCUSSION AND CONCLUSSIONS

One of the main issues of investigations was to set a date when river activity in the present dry valley between the Šešupė and Įsrutis rivers terminated. The results of the radiocarbon dating of peat in borehole no. 3 show that the peat formation started 9480–9230 cal yrs BP, i.e. maximum about 9.5 ka BP, during the Boreal. Before that, a lacustrine environment existed in this valley, but it was impossible to date gyttja from the 170–180 cm depth due to technical issues of drilling and sampling (too little extracted core material). This means that the Nemunas River started to flow directly to the Baltic Sea basin across the VMR before 9.5 ka, most likely during the Preboreal. The Nemunas and Prieglius rivers basins were separated by a new divide formed between the Šešupė and Įsrutis rivers. A more precise age determination of this event could be possible by age determination of inorganic sediments between the till and the peat by other methods of geochronology: for example, by infrared stimulated luminescence (IRSL).

The base level of the Nemunas River until 8.3 ka BP had to be the Ancylus Lake, and before that, to 10.7 ka BP, the Yoldia Sea (Damušytė, 2011). At that time, the water level in both basins was lower than in the current Baltic Sea – from a few tens metres in the Yoldia Sea (Kabailienė, 1999) to several metres in the the Ancylus Lake (Damušytė, 2011). Thus, in both cases the Nemunas River and its tributaries – the Šešupė River and the Jūra River – saw significant linear erosion. The results of age determination of the alluvium of the third overbank terrace in the lower reaches of the Šešupė River varied in time from 11.7 to 7.5 ka (Druzhinina et al., 2016), i.e. a very wide age interpretation of sedimentation is possible. We tend to assume that this part of the terrace was formed after the changes to the hydrographic system. Most probably it continued (taking into account a very thin layer of alluvium) for a very limited time. It is supposed that the further erosion and formation of the second overbank terrace followed the formation of the third one after a very short time. As a result, the river valleys could be cut not only into the glacigenic deposits of the Last Glacial advance (i.e. Late Weichselian), but also into the Middle Weichselian deposits. This is evident from the IRSL dating results obtained at the Riadino-5 archaeological site (Druzhinina et al., 2016), but this situation has not been reflected in the palaeogeographic reconstructions (Fig. 4) due to very limited geological data, and also the small scale of the palaeogeological cross-sections.

The date mentioned – before 9.5 ka – could represent the starting point of the Nemunas Delta. But, at that time, the recent Curonian Lagoon did not exist, and the Nemunas Delta (i.e. pro-Delta), started to form somewhere in the present Baltic Sea nearshore region. Most probably this occurred in front of the southern part of the present-day Curonian Spit, because in the northern part of the recent Delta territory (at least in the Lithuanian Delta part) no erosional valley of pra-Nemunas River was found (Bitinas et al., 2002). Later, during the Litorina Sea transgression, the territory of the present Nemunas Delta became the Litorina Sea bay, and a new, present-day delta started to form not far to the west of the Vilkiškės Marginal Ridge. This is an issue of the further detailed investigations.

This brief overview of the palaeogeographic situation explains why the Late Palaeolithic and later settlements or single artefacts are not found in the present territory of the Nemunas Delta (Rimantienė, 1974, 1977; Jankuhn, 1977). The palaeogeographic reconstructions of the Nemunas and Šešupė rivers confluence region could be useful for the identification of the migration pathways of people during the Palaeolithic period as well as concerning the distribution of settlements during this archaeological interval.

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REFERENCES

Arslanov, Kh.A., 1985. Radiouglerod: geokhimiya i geokhronologiya (in Russian). Leningrad, Izdatel’stvo Leningradskogo Universiteta.

Basalykas, A., 1961. Nemuno deltos žemuma (in Lithuanian). Geografinis metraštis, **4**: 5–33.

Beug, H.-J., 2004. Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete. Verlag Dr. Friedrich Pfeil, München.

Bitinas, A., 2012. Implications of the paleoseismicity of the Eastern Baltic Sea Region. Quarternary International, **279–280**: 52.

Bitinas, A., Lazauskienė, J., 2011. Paleoseisminių įvykių prielaidos kvartero nuosėdų tekstūrų tyrimo duomenimis (in Lithuanian). Baltica, Special Issue, **24**: 127–130.

Bitinas, A., Damušytė, A., Stančikaitė, M., Aleksa, P., 2002. Geological development of the Nemunas River Delta and adjacent areas, West Lithuania. Geological Quarterly, **46** (4): 375–389.

Bronk Ramsey, C., Dee, M., Lee, S., Nakagawa, T, Staff, R., 2010. Developments in the calibration and modelling of radiocarbon dates. Radiocarbon, **52**: 953–961.

Chubarenko, B., ed., 2008. Transboundary waters and basins in the South-East Baltic. Terra Baltica, Kaliningrad.

Červinskas, E., Kunskas, R., 1982. Comparison of lagoon and avandelta sedimentation in the Kuršių Marios Lagoon (in Lithuanian with English summary). The Geographical Yearbook, **20**: 123–139.

Damušytė, A., 2011. Post-Glacial history of the Lithuanian coastal area. Summary of Ph.D thesis, Physical sciences, geology (05P), Vilnius.

Druzhinina, O.A., 2012. Rezultaty geokhimicheskikh issledovaniy kulturnogo sloya arkheologicheskogo pamyatnika Ryadino 5 (in Russian). Vestnik BFU im. Kanta, **1**: 29–33.

Druzhinina, O., 2013. Issledovaniye arkheologicheskogo pamyatnika Ryadino-5 (dolina r. Sheshupe, Kaliningradskaya oblast RF) (in Russian). In: Arkheologicheskiye Otkrytiya 2009 goda (ed. N.V. Lopatin): 23–25. Izdatelstvo Instituta Arkheologii RAN, Moskva.

Druzhinina, O., Molodkov, A., Bitinas, A. Bregman, E., 2016. The oldest evidence for human habitation in the Baltic Region: a preliminary report on the chronology and archeological context at the Riadino-5 archeological site. Geoarchaeology, **31**: 156–164.

Dvareckas, V., Gaigalas, A., 1996. Where Lithuanian river valleys rejuvenate in Late Glacial and Post-Glacial epoch? In: Geography in Lithuania (ed. R. Žaromskis): 20–27. Vilnius.

Faegri, K., Iversen, J., 1989. Textbook of Pollen Analysis. John Wiley and Sons, New York.

Faegri, K., Iversen, J., 1993. Bestimmungsschlüssel für die nordwesteuropäische Pollenflora. Gustav Fischer Verlag, Jena.

Gams, H., Ruoff S., 1929. Geschichte, Aufbau und Pflanzendecke des Zehlaubruches. Monographie eines wachsenden Hochmoores in Ostpreußen. Schriften der Physikalisch-Ökonomischen Gesellschaft zu Königsberg in Preußen, **66-1**: 1–193.

Göttlich, K., 1990. Moor- und Torfkunde. E. Schweizerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller), Stuttgart.

Grigelis, A., ed., 1970. Geologicheskaya karta SSSR (karta Chetvertichnykh otlozhenij), masshtab 1:200 000. Pribaltiyskaya seriya, N-35-X (in Russian). Aerogeologiya, Moskva.

Gudelis, V., 1998. Lietuvos įjūris ir pajūris (in Lithuanian). Lietuvos mokslas, Vilnius.

Gudelis, V., Klimavičienė, V., 1990a. Main development stages of the southern part of the Lithuanian coastal plain in Late Pleistocene and Holocene (in Lithuanian with English summary). Problems of Coastal Dynamics and Palaeogeography of the Baltic Sea, **1**: 81–94.

Gudelis, V., Klimavičienė, V., 1990b. Geomorphologic patterns of the southern part of the Lithuanian coastal plain (in Lithuanian with English summary). Problems of Coastal Dynamics and Palaeogeography of the Baltic Sea, **1** : 94–118.

Gudelis, V., Klimavičienė, V., 1993. Geomorphological and palaeogeographical features of the Nemunas River Delta (in Lithuanian with English summary). Geografija, **29**: 7–12.

Gudelis, V., Klimavičienė, V., Savukynienė, N., 1989–1990. Stratigraphy and paleogeography of the Kuršių Marios Lagoon shore exposures on the Ventės Ragas Cape (in Lithuanian with English summary). The Geographical Yearbook, **25–26**: 18–28.

Guobytė, R., Juodkazis, V., 2003. Rambyno regioninio parko vertybės (in Lithuanian with English summary). Geologijos akiračiai, **2**: 47–54.

Guobytė, R., Jusienė, A., 2007. Rambynas: the Vilkyškiai ice mariginal ridge. In: The Quaternary of Western Lithuania: from the Pleistocene Glaciations to the Evolution of the Baltic Sea: Excursion Guide: 77–81. The INQUA Peribaltic Group Field Symposium, May 27–June 02, 2007, Plateliai, Lithuania. Lithuanian Geological Survey, Institute of Geology and Geography, Vilnius.

Gupta, S.H., Polach, H.A., 1985. Radiocarbon Dating Practices at A.N.U. Radiocarbon Laboratory, Research School of Pacific Studies, ANU, Canberra.

Jankuhn, H., 1977. Einführung in die Siedlungsarchäologie. Archeology, Berlin, New-York.

Juggins, S., 2014. C2 Version 1.7.6. [Electronic resource]. Mode of access: https://www.staff.ncl.ac.uk/stephen.juggins/software/C2Home.htm

Kabailienė, M., 1999. Water level changes in SE Baltic based on diatom stratigraphy of Late Glacial and Holocene deposits. Geologija, **29**: 15–29.

Kovaliukh, N.N., Skripkin, V.V., 1994. An universal technology for oxidation of carbon-containing materials for radiocarbon dating. In: Abstracts and Papers of Conference on Geochronology and Dendrochronology of Old Town's and Radiocarbon Dating of Archaeological Findings, 31 October–4 November, Vilnius, Lithuania: 37–42. Vilnius University Press, Vilnius.

Kunskas, R., 1996. Development of Curonian Lagoon (Kuršių Marios) coast and Nemunas Delta. In: Geography in Lithuania (ed. R. Žaromskis): 28–54. Vilnius.

Molodkov, A., Bitinas, A., 2006. Sedimentary record and luminescence chronology of the Lateglacial and Holocene aeolian sediments in Lithuania. Boreas, **35**: 244–254.

Nelle, O., 2006. Übung Pollenanalyse. Anweisungen zum Laborpraktikum in der Pollenanalyse, Ökologiezentrum, Universität Kiel, Kiel.

Neustadt, M.I., 1957. Istoriya lesov i paleogeografiya SSSR v Golocene (in Russian). Akademiya Nauk SSSR, Moskva.

Nikonov, A.A., 2013. Novyy etap poznaniya seismichnosti Vostochno-Evropeyskoy platformy i eye obramleniya (in Russian). Doklady Akademii Nauk, **450**: 465–469.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P.G., Bronk Ramsey, C., Buck, C. E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatta, C., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., van der Plicht, J., 2013. IntCal13 and MARINE13 radiocarbon age calibration curves 0-50000 years calBP. Radiocarbon, **55**: 1869–1887.

Rimantienė, R., ed., 1974. Lietuvos TSR archeologijos atlasas, **1** (in Lithuanian). Mintis, Vilnius.

Rimantienė, R., ed., 1977. Lietuvos TSR archeologijos atlasas, **3** (in Lithuanian). Mintis, Vilnius.

Rinterknecht, V.R., Bitinas, A., Clark, P.U., Raisbeck, G.M., Yiou, F., Brook E.J., 2008. Timing of the last deglaciation in Lithuania. Boreas, **37**: 426–433.

Savukynienė, N., Ruplėnaitė, G., 1999. Biostratigraphic traits of the Nemunas submarine valley sediments. Baltica Special Publication, **12**: 103–107.

Steffen, H., 1931. Vegetationskunde von Ostpreußen. Jena.

Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. Pollen et Spores, **13**: 615–621.

Straume, J., ed., 1982. Geomorphological map of the Soviet Baltic Republics, scale 1:500 000. VSEGEI, Mingeo SSSR.

Žaromskis, R. 2000. Delta of Nemunas as object of geomorphologic investigations (in Lithuanian with English summary). Geografija, **35**: 5–13.