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Palaeo–Nemunas delta history during the Holocene time

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Abstract A study is focused on the Palaeo–Nemunas delta morphogenesis and development during Late Glacial and Holocene time span. Geomorphometry and morphological features of the submerged delta were recognized for the first time on the submarine Curonian (Kuršių) Plateau in 1986–1992. This paper presents a pilot study applied in 2006–2008 and is based on multi–beam echo sounder and side–scan sonar images data. Two geological sections across the Palaeo–Nemunas delta are compiled from the data of core studies. Geomorphologic, sedimentological, biostratigraphical and radiocarbon AMS ^{14}C and IR–OSL analyses suggest that Palaeo–Nemunas delta begun to develop in the palaeotopography of this area during Preboreal time and ended at the second half of Boreal. The basal residual level of the Ancylus (A_2) regression phase was identified in the delta trunks at a depth of 41.3-39.9 m and dated 9.31-8.87 ka BP (8300–8000 ^{14}C kyr BP). This residual layer is overlapped by marine depositional Litorina ($L_{1\text{-}2\text{-}3}$)—Post–Litorina complexes up 2 m thick and supported by 7.40±0.5 ka BP; 6.80±0.5 ka BP (IR–OSL, RLQG 1881-118, 1882-118); 6.87±45 ka BP (6030±25^{14}C kyr BP); 4.66±110 ka BP (4100±25 ^{14}C kyr BP, UGAMS #03138, 03139).[1]

Keywords *Palaeogeomorphology, deposition, erosion, ancient shorelines displacement, Holocene, south–eastern Baltic Sea.*

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INTRODUCTION

Although permanent depth measurements in the Baltic Sea began in the 19th century, detailed bathymetric maps with 5-2 m depth contour intervals that could reveal micro–features of the offshore morphology, were not compiled until the 1980's. These circumstances have delayed investigations of the subaerial relict relief merged on the Baltic Sea and also studies of the diversity of marine shallow morphology. Because of that only macro–form characteristics and recent ongoing marine processes were reflected on the geomorphologic maps of the Central Baltic Sea compiled in 1970–1980 (Gudelis, Litvin 1976; Gudelis *et al.* 1977; Pieczka 1980).

Comprehensive geomorphologic investigations of the south–eastern (SE) Baltic Sea floor started in 1982, which resulted in compiled bathymetric map at a scale of 1:25 000–1:50 000 with depth contour intervals of 2-5 m (Gelumbauskaitė 1986; unpublished). The detailed morphology of the sea floor, and the Palaeo–Nemunas delta relief, was disclosed and depicted on the geomorphologic map of the SE Baltic Sea in 1991 (Gelumbauskaitė *et al.* 1992).

At the same time marine national geological programmes for mapping at scales of 1:200 000–1: 50 000 were launched on the eastern Baltic Sea. These programmes led to the compilation of detailed bathymetric–morphologic and geomorphologic maps not only for navigation or fishing purposes, but also for

[1] ***Abbreviations:*** ka BP – calibrated years before present (BP), cal. yr BP; ^{14}C kyr BP – radiocarbon ^{14}C years BP; IR–OSL – Optically stimulated luminescence dating; RLQG 1881–118 – index and sample number, OSL Laboratory, Institute of Geology, Tallinn, Estonia; UGAMS 03138 – index and sample number, Radiocarbon Laboratory, the University of Georgia, USA; Vs-1657 – index and sample number, Radiocarbon Laboratory, Nature Research Centre, Institute of Geology and Geography, Vilnius, Lithuania.

the assessment of environmental conditions of the sea (Mojski 1995; Juškevičs, Talpas 1997; Gelumbauskaitė 1999).

Recently, the marine geological–geophysical researchers started to use innovatory multi–beam echo sounder and side scan sonar methods. They obtained high resolution and precision measurements that can reflect small topographic level changes, namely morphology changes ranging from 1-3 m to some decimal centimetres. These allow the creation of 3– and 4D imagery models (Gajewski *et al.* 2004; Gulbinskas *et al.* 2009; Dorschel *et al.* 2010).

MATERIAL AND METHODS

The pilot study of this area was performed in 2006–2008 with the German vessel *HELMSAND* using a multi–beam system and single beam 200kHz echo sounder, side–scan sonar (a Klein digital system 2000) with a 3.5 kHz sub–bottom profiler, video controlled small box corer, and vibro corer (VK 200).

During stormy weather conditions, the multi–beam and side–scan sonar survey was carried out only in the western part of the Palaeo–Nemunas delta. Seven samples were taken by small box corer with a maximum thickness of 9 cm. Three vibro cores with a maximum length of 2.30 m were taken aboard the Polish R/V IMOR in 2008. Taking cores longer than 2.5 m at the scarp, among fisherman named *Brezhnev's Wall*, and in the delta trunks did not succeed and led to difficulties in using fresh material to reconstruct the lower part of the Holocene sequence in its entirety, so data from previous studies were used (Blazhchishin *et al.* 1981; Gudelis *et al.* 1977).

Grain size compositions of bottom sediments were determined by a sieving method. Five fractions from long and short cores were measured ranging from 1.0-0.05 mm to <0.04 mm. The remnants of shells were tested from long cores by radiocarbon AMS ^{14}C analysis at the University of Georgia in the USA, and analyses of samples by optically stimulated luminescence (IR –OSL) dating were performed in the Institute of Geology in Tallinn, Estonia.

GEOMORPHOLOGIC AND GEOLOGICAL SETTING

Recent detailed bottom topography shows that the predominant delta area is located on the steep north–western (NW) slope of the Curonian (Kuršių) Plateau at depths of 30-40 m, between the latitudes of the settlements Juodkrantė and Preila (Fig. 1). The submerged Palaeo–Nemunas delta is a semicircular body that is well–exposed in the recent topography. It separates the Curonian Plateau from the submarine Litorina Sea plain, which is oriented in a northeast direction. Originally, the Curonian Plateau is a homogenous subsurface characterised by large scale elements and fragments of the subaerial glacigenic and marine shallow morphology (Gelumbauskaitė 1986).

Our investigation found that the submerged Palaeo –Nemunas delta, 16.6 km long and 11.2 km wide, is gently inclined from SE to NW and its mouth is flanked at the end by a scarp, the front form of the delta, of two steps with a maximum height of 17 m (Fig. 2). This scarp separates the Palaeo –Nemunas delta body from a depression floor, with fragment of the incised channel of the river (see Fig. 1).

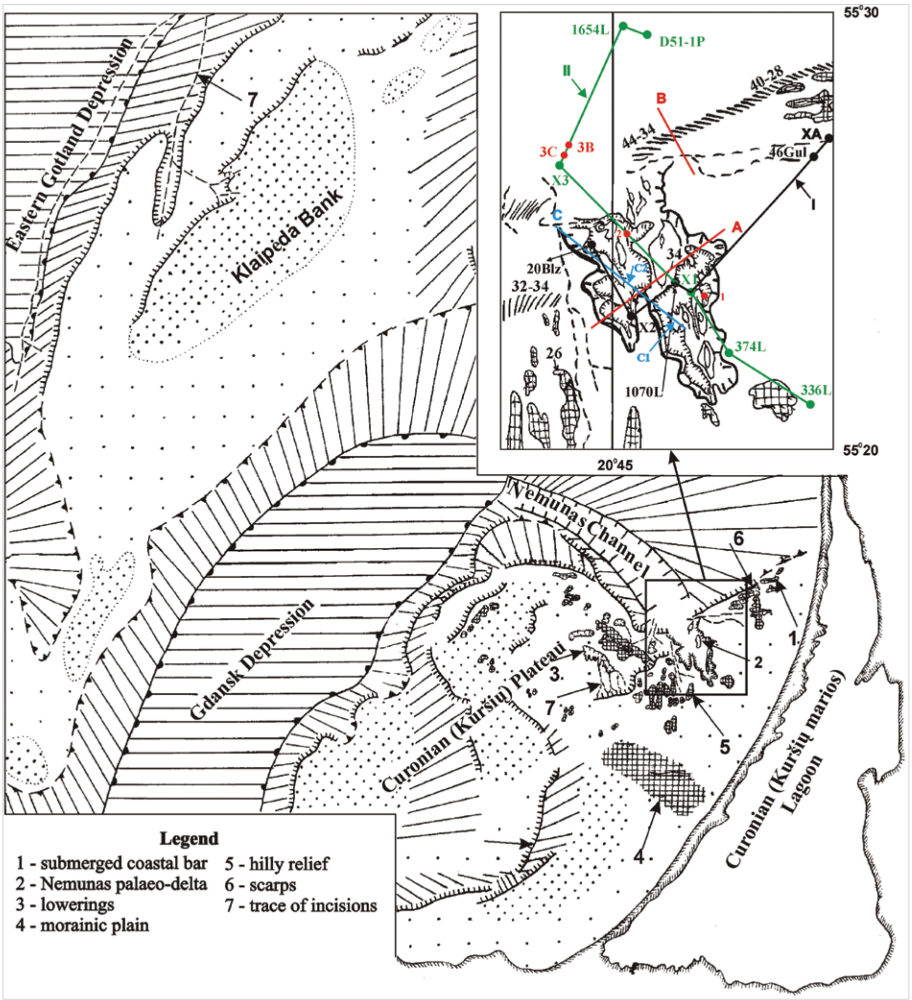

Fig. 1. Morphogenetic sketch map of the south–eastern Baltic Sea. Profile lines on the inset: A, B, C (Fig. 2); I (Fig. 3); II (Fig. 4).

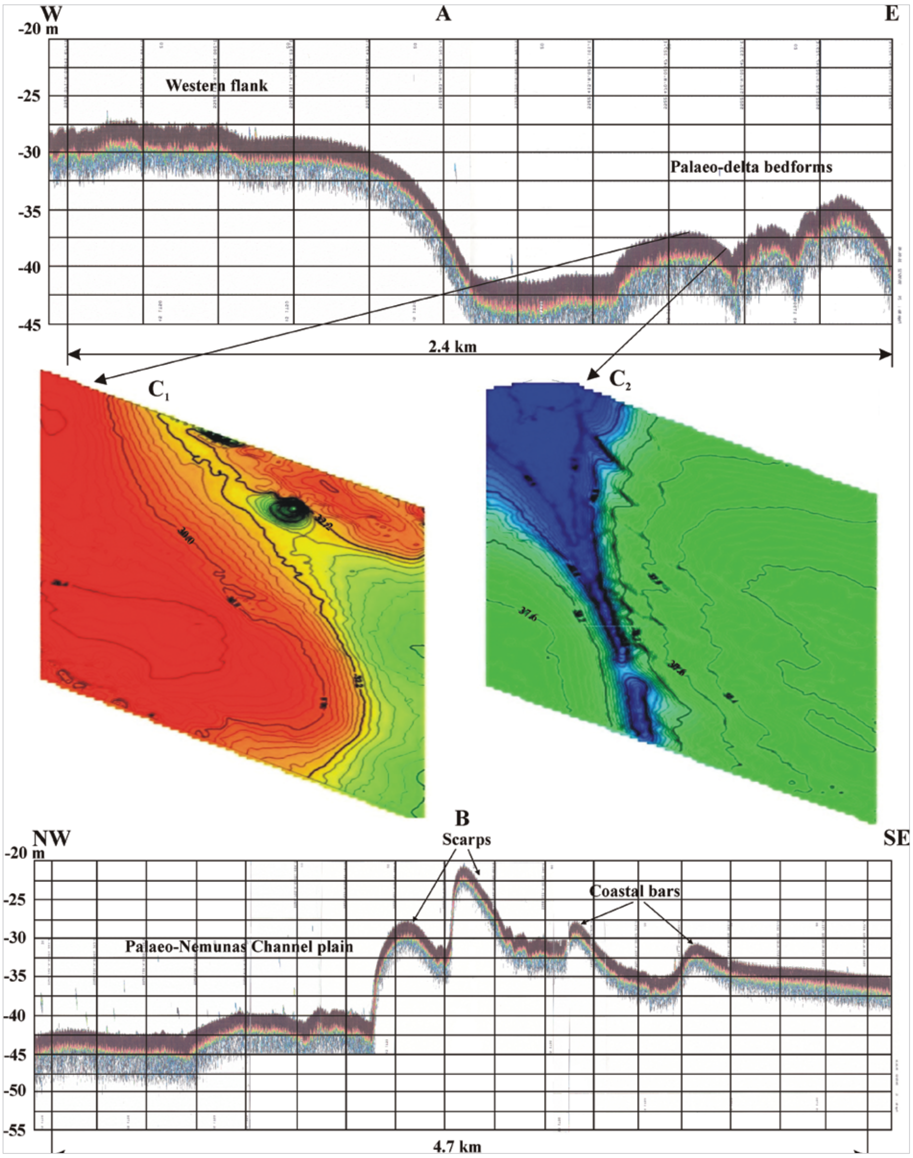

Fig. 2. Topography profiles A, B, C across the Palaeo–Nemunas delta. C_1 and C_2 show the palaeo–delta bed forms.

The western bank of the delta is steeper, and the relative height of its flank achieves 10 m. The eastern bank is not clearly visible in the modern topography and gradually passes into the submarine plain of the Litorina Sea. The Palaeo –Nemunas delta is shaped by four trunks mutually separated by levees, morphologic features disclosed by a multi–beam topographic model (Fig. 2A, B, and C).

Previous studies of the SE Baltic Sea sub–Quaternary surface have identified two denudation levels at 95-70 m and 65-50 m b.s.l., separated by a step, marking the peneplenization of Jurassic and Cretaceous sedimentary rocks (Grigelis 1999). According to seismo–acoustic interpretation, the cover of Quaternary deposits varies from 25 m deep at the delta floor to 40 m in the direction of the depression bottom (Gelumbauskaitė, Grigelis 1997). The Quaternary sequence in the borehole D51-1P, taken at a sea depth of 52.7 m and located at the bottom of depression, is 24.5 m thick and consists of 1.5 m of sand, 9.9 m of clay and 13.0 m of till, from top to bottom (Fig. 3). The western bank of the delta is associated with an internal structure of the Curonian Plateau headland. In the boreholes D6-3/84 (taken on the western slope at a depth of 55.2 m) and D6-2/1P (at the central part of the plateau, at a depth of 33.0 m) only till loam and till clay lithofacies of the Pleistocene are recognized. Glacial deposits overlie a thin, 0.25 m, residual layer of mixed composition. The average thickness of this depositional complex is 25.0 m (Gelumbauskaitė 2009).

Segments of the palaeo–channels distinguished in Triassic / Jurassic / Cretaceous sedimentary substrata from deep to shallow parts (75-30 m of relative depth) identified in this area, can be interpreted as the roots of the Pra–Nemunas valley system. The inter–calibration of seismo–acoustic data with existing boreholes data shows that the palaeo–channels have been filled by Lower and Middle Pleistocene till and Middle/Upper Pleistocene interglacial sediments. The Late Weichselian sediments entirely overlie the channels. Incisions as erosion forms appeared again during the Late Glacial (Gelumbauskaitė 2000).

DELTA DEVELOPMENT

In this study, the internal structures and morphogenetic features of the Palaeo–Nemunas delta were evaluated from the geological sections I–II across the delta body (Figs 3, 4). By analysing the geological correlation of the 20Blz, X2, 1070L, XI, and 46Gul cores of the profile I, crossing the delta from west to east, it could be constituted that changeable lagoon, deltaic and coastal conditions prevailed during Late Glacial–Early Holocene time.

The 3.8-4.0 m long cores (20Blz, 1070L) taken from the western part of the delta during previous studies, and their stratigraphic subdivision by A. I. Blazhchishin, L. Lukoshevichius, and E. M. Kleimionova (Gudelis *et al.* 1977; Blazhchishin *et al.* 1981; Blazhchishin 1998) were used for evaluating the delta development.

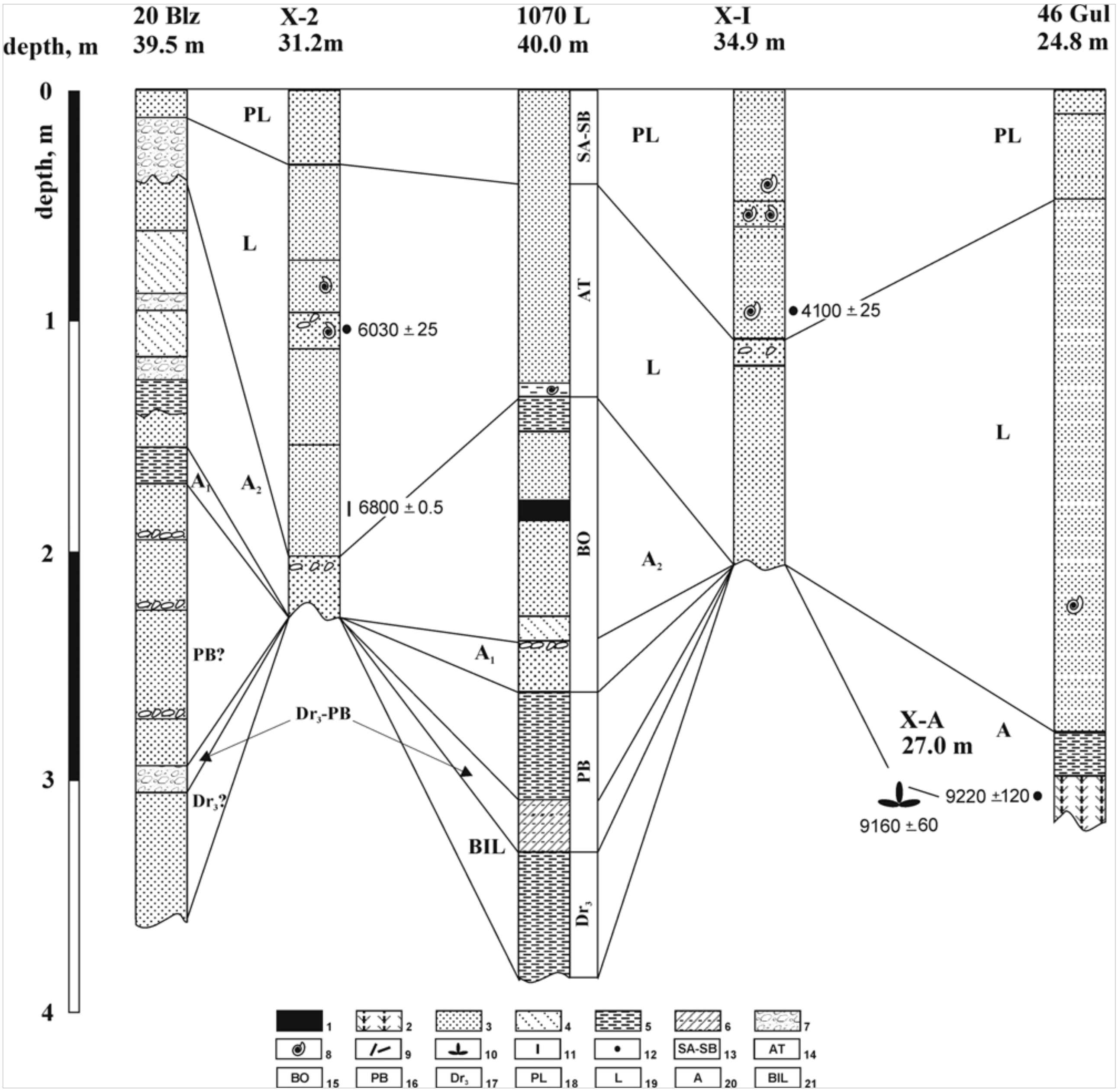

Fig. 3. Core logs correlation, geological section I. Legend: 1 – peat; 2 – gyttja; 3 – sand; 4 – cross-bedded sand; 5 – silt; 6 – cross-bedded silt; 7 – gravel; 8 – shells; 9 – remnants of organic matter; 10 – dating of stumps remnants; 11 – IR–OSL date; 12 – radiocarbon date. Chronozones: 13 – Subatlantic; 14 –Atlantic; 15 – Boreal; 16 – Preboreal; 17 – Younger Dryas. Sediments of the Baltic Sea stages: 18 – Post–Litorina Sea; 19 – Litorina$_{1\text{-}2\text{-}3}$ Sea; 20 – Ancylus$_{1\text{-}2}$ Lake; 21 – Baltic Ice Lake.

Seven lithological complexes were interpreted by the litho– and biostratigraphy from the base to the top of the cores. An accumulation of the fresh basin was fixed at intervals of 296-388 cm on core 20Blz and 326-362 cm on core 1070L at the their bases. Going up, cross bedded silt from core 1070L (at 303-329 cm) and gravel layers from core 20Blz (at 296-299 cm) indicate a break in the basin deposition and that is identified as the Younger Dryas (D_3) / Preboreal (PB) boundary. A subsequent lithozone of 170-298 cm, evident in core 20Blz, is composed by fine sand with little thin coarse sand and gravel inter–layers overlays a silt–sandy lithological complex of D_3. This lithozone was recognized as eolian facies (Blazhchishin 1998). Studies in latter years show that *'eolian facies'* can be suspected to be of the coastal bars origin (Gelumbauskaitė 2009; Gulbinskas *et al.* 2009). Development of the submerged beach likely prevailed when the limit of the Yoldia Sea was at an altitude of about 50 m b.s.l., behind the *Brezhnev's Wall* scarp. This lithological unit is correlative with the silt texture layer, 260-303 cm deep, in core 1070L. It could be recognized as lagoon sediments of the Preboreal time.

The Ancylus Lake level rise in the geological sequence is reflected by a mud layer, 53 cm thick (from core 1654L, profile II) on the depression and by a thin

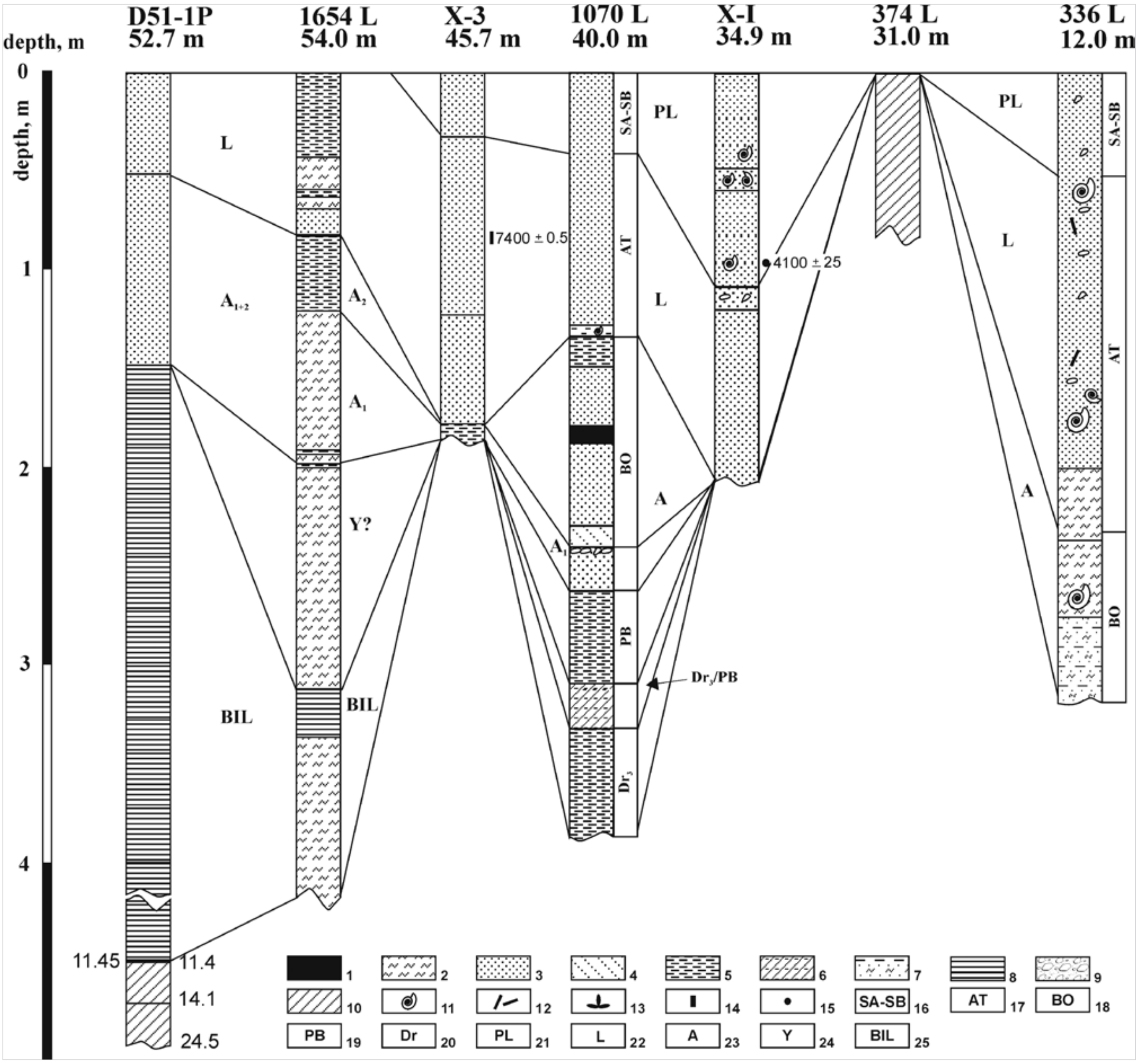

Fig. 4. Core logs correlation, geological section II. Legend: 1 – peat; 2 – mud; 3 – sand; 4 – cross-bedded sand; 5 – silt; 6 – cross-bedded silt; 7 – sand–silt–mud lamination; 8 – clay; 9 – gravel; 10 – till; 11 – shells; 12 – remnants of organic matter; 13 – dating of stumps remnants; 14 – IR–OSL date; 15 – radiocarbon date. Chronozones: 16 – Subatlantic; 17 – Atlantic; 18 – Boreal; 19 – Preboreal; 20 – Younger Dryas. Sediments of the Baltic Sea stages: 21 – Post–Litorina Sea; 22 – Litorina$_{1\text{-}2\text{-}3}$ Sea; 23 – Ancylus$_{1\text{-}2}$ Lake; 24 – Yoldia Sea; 25 – Baltic Ice Lake.

layer, 13-15 cm thick, of sand and silt on the plain subsurface. Development of the *Brezhnev's Wall* scarp is closely connected to this event. Recent topographic expression and the internal structure of core logs show that Ancylus Lake could have begun when the sea water level in this area was at the altitudes of –48.0–45.0 m. The scarp forming on the delta flanks (step I at –40.0–32.5 m and step II at –32.5–22.5 m) took place during the A_1 transgression. A. I. Blazhchishin (Blazhchishin 1998) correlates the A_1 lithological complex with Vistula delta advances (after B. Rosa) which developed during the Ancylus Lake transgression phase.

The well being of the Palaeo–Nemunas development indicates a lithological complex composed during the Ancylus Lake regression phase (Gelumbauskaitė 2009). The lithozone of the 97-115 cm thick silt and sand with cross bedded silt and gravel inter–layers of 115-119, 115-94, 94-90, 90-90 cm (from core 20Blz) and 227-247 cm (from core 1070L) reveals some repeated lagoon–deltaic accumulation cycles. More quiet conditions prevail in the outskirt of the delta mouth. A peat layer of an interval of 173-185 cm from core 1070L evidences this fact.

With regard to the eastern bank of the Pra–Nemunas delta (profile I, core 46Gul, at 275-322 cm), the silt layer containing sapropel of 10.40±140 ka BP (9220±120 ^{14}C kyr BP, Vs-1657) is located at 27.5 m below the sea

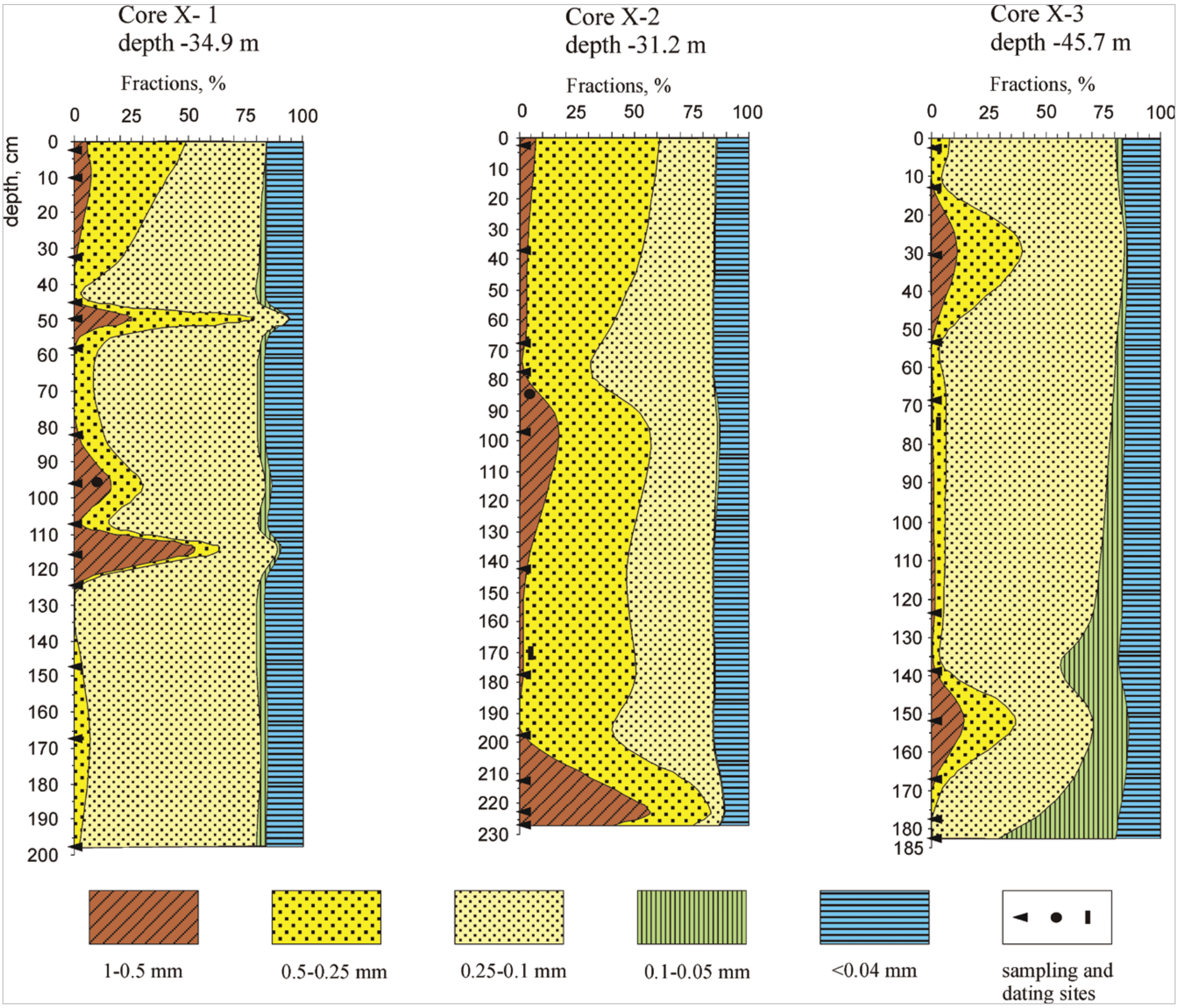

Fig. 5. Grain size composition, cores X-1, X-2, X-3.

level (Gulbinskas *et al.* 2009). The ^{14}C age of coarse silt layer correlates well with wood remains dating at the same depth 10.34±76 ka BP (9160±60 ^{14}C kyr BP, Vs-1372; profile I, site XA, at a depth of 27.0 m) to the north (Bitinas *et al*. 2003). Dating allows the identification of the PB/B boundary and evidence of the outset of Ancylus Lake in this area at the depth of 40.0–30.0 m b.s.l. The basal level of the Ancylus$_2$ regression phase peak in the delta trunks according to the litho–biostratigraphy was identified at the depth of 41.3-39.9 m; this layer dated from 9.31±20–8.87±40 ka BP (8300–8000 ^{14}C kyr BP).

Following geological sequences, the upper basal layer of pebbles and gravel of 10-40 cm deep (core 20Blz), coarse silt with a detritus layer of shells, 125-130 cm deep (core 1070L) and sand gravel layer, 206-227 cm deep (core X2) is recognized as the beginning of the first Litorina Sea transgression phase. The marine depositional complex of the Litorina$_{1\text{-}2\text{-}3}$–Post–Litorina stages is composed mostly of sand. The grain size composition of cores XI, X2, and X3 shows that sediment differentiation is in direct hydrodynamic relationship with the fluctuation of the sea level (Fig. 5). Marine accumulation in the Atlantic–Subatlantic time is well dated by ^{14}C AMS and IR–OSL. Changes in lithology correlates with AMS ^{14}C–IR–OSL ages and allow the recognition of L$_1$ transgression infilling on the depression area (core X3, 7.40±0.5 ka BP; IR–OSL, RLQG 1881-118), L$_2$ depositional complex (6.80±0.5 ka BP; IR–OSL, RLQG 1882-118, 6.87±45 ka BP (6030±^{14}C kyr BP, UGAMS#03139, core X2) and trace L/PL boundary 4.46±110 ka BP(4100±25 ^{14}C kyr BP, UGAMS#03138, core X1) on the delta area (Figs 3, 4, 5).

The grain size composition of the deposits on the subsurface top shows no recent marine accumulation at the delta region (Fig. 6). Multi–beam images display a hydrodynamic activity at the delta trunks.

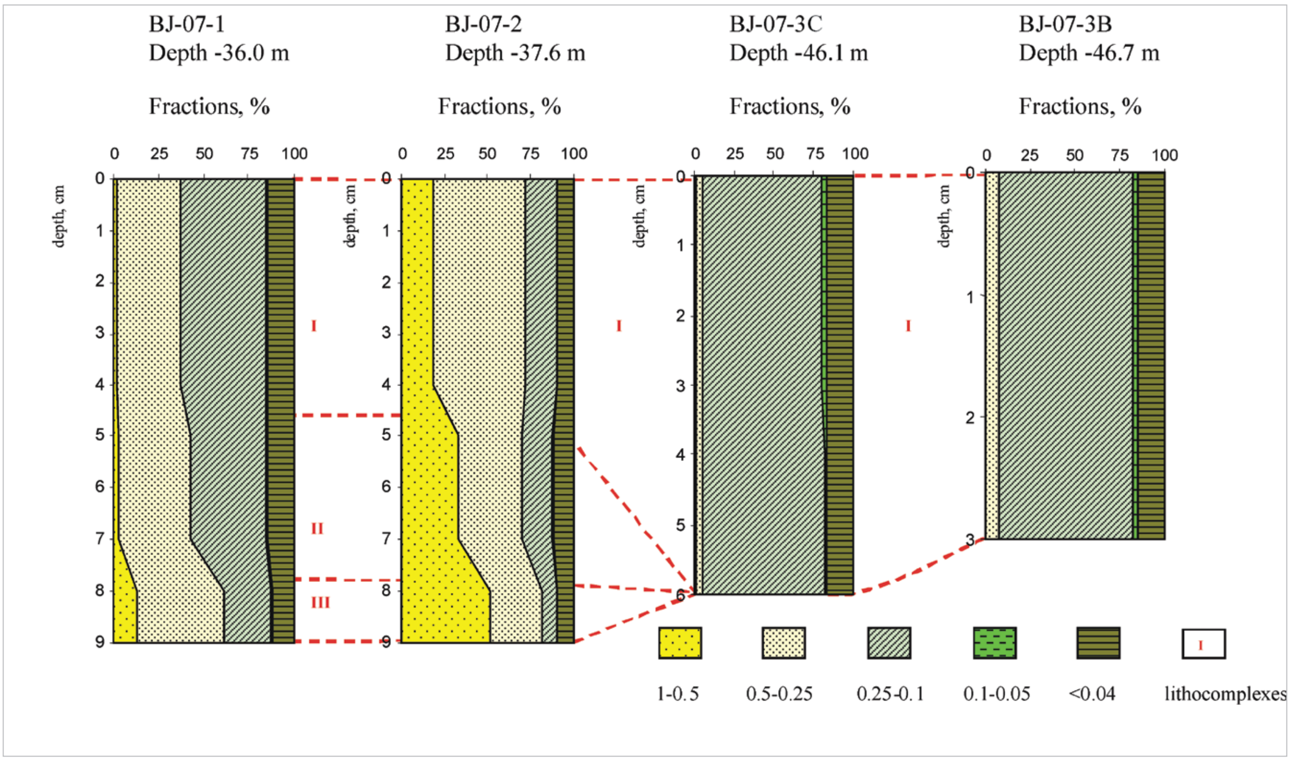

Fig. 6. Grain size composition, sampling sites BJ-07-1; BJ-07-2; BJ-07-3C; BJ-07-3B (numbered 1, 2, 3C, 3B on Fig. 1).

CONCLUSIONS

Analyses show that the Palaeo–Nemunas delta as a morphogenetic form began to develop in the palaeotopography of this area during the Preboreal time and finished during the Boreal. Reconstruction of the Palaeo–Nemunas delta development confirms previous findings that the low stand peak of the Ancylus regression phase on the Nida–Preila traverse could be set at the present depth of 42.5-41.2 m b.s.l.

The internal structure of the geological sequences demonstrates that marine accumulation continued well into the Atlantic–Subatlantic time, during Litorina–Post–Litorina sea stages. Recent deposition on the Palaeo–Nemunas delta is rather weak because of hydrodynamic activity.

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