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Character of sea level changes in the subsiding south–eastern Baltic Sea during Late Quaternary

Leonora Živilė Gelumbauskaitė

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Abstract A study of palaeogeomorphologic and geodynamic conditions during Late–Glacial and Holocene is focused on the reconstruction palaeomorphology, sediments structure and ancient shoreline displacement. The study is based on the analysis of ancient shore formations of the sea level changes attempting to separate eustatic and isostatic factors and evaluate crustal movements. Three seismogeological profiles stretching from W-E offshore to onshore, northern at the latitude Šventoji, middle at the latitude Klaipėda offshore–northern part of Curonian Lagoon onshore, and southern at the latitude Nida offshore–Nemunas deltaic plain onshore have been constructed. According to the traced geo–seismic profiles, the palaeomorphology and internal structure of the Baltic basins transgressions–regressions was examined, and the curves of the relative sea level fluctuations have been compiled and interpreted. The eustatic–isostatic changes stretching from south to north have been evaluated.

Keywords *Late Quaternary, SE Baltic Sea, ancient shore-level, relative sea level fluctuations, eustatic and isostatic changes.*

Leonora Živilė Gelumbauskaitė [leonora@geo.lt], Institute of Geology and Geography, Vilnius, Lithuania. *Manuscript submitted 10 January 2009; accepted 21 May 2009.*

INTRODUCTION

South–eastern part of the Baltic Sea is a key basin for investigation of development and geodynamics of the shelves and coastal zone units, as the Curonian and Klaipėda plateaus, with inter–Klaipėda gentle slope of the Gdansk depression offshore, and the Maritime plain, with Curonian Lagoon, barrier island Curonian Spit and Delta Plain area of the Nemunas river onshore.

According to previous data (Gelumbauskaitė, Grigelis, 1995; Gelumbauskaitė, 1999, 2000) the palaeosurface of the sedimentary bedrock contains some denudation levels inserted in the Devonian / Triassic / Jurassic / Cretaceous basement at 95–70, 65–50, 45–35 m b.s.l., slightly tilted south–westwards and reshaped by ridges. The thickness of Quaternary deposits varies from 40 m at the depression flat to 15–5 m on the peneplain ridges and slopes. Following the coastal zone, thickness of the Quaternary cover increases and reaches on average 50–60 m.

Average thickness of the Holocene sediments offshore is only 3 m. On the other side, the thickness of the binominal Ice Lakes–Baltic Ice Lake[1] sedimentary complex at the depression flat exceeds 17 m. Very uneven Late–Glacial–Holocene cover along the traced geo-seismic profiles evident that postglacial basins eustatic / isostatic / tectonic dynamic have contacted with till loam deformations and a deposition rate between offshore and near shore–onshore.

The reconstruction of the Late–Glacial–Holocene palaeogeomorphology, internal structure and creating relative sea level curves on the SE Baltic region are the continuous studies of the postglacial history and geodynamic conditions performed using new data, collected in 1993–2008 applying extensive methodical complex of the echo–seismoacustic, geomorphologic,

1 Abbreviations of the Baltic Sea stages are used as follows: Ice Lakes – IL, Baltic Ice Lake – BIL, Yoldia Sea – Y, Ancylus Lake – A, Litorina Sea – L, Post–Litorina Sea – PS.

sediment mapping, marine palinological, and radiometric methods.

The geomorphometry and morphogenetic features of the modern relief were examined using bathymetry at 2 m intervals and echo–seismoacoustic records. Examination of the echograms, calculation of the modern relief gradients, correlation with sediment lithological composition (Md, So), and identification of the submerged fragments of terraces permit to trace different hypsometric levels of subaqueous ancient shore formations. Seismic records of strong reflectors penetrating the Late–Glacial and Holocene sequence allow record differences in lithology, distinguish seismic units and correlate them with litho–biostratigraphy of cores and/or boreholes. Using these data the basic geo–seismic profiles stretching from offshore to onshore were constructed, palaeogeography and depositional–erosional history of the Late–Glacial–Holocene basins fluctuation in the SE Baltic Sea was interpreted (Gelumbauskaitė 2000, 2002; Gelumbauskaitė, Gaidelytė 2003; Gelumbauskaitė, Šečkus 2005a, 2005b).

MORPHOLOGY AND INTERNAL STRUCTURE

Baltic Ice Lake

On the Lithuanian coast, the retreat of the ice sheet front from moraine ridges of Pajūrio Oscillation began about 13500 cal yr BP. First the series of local ice lakes appeared in connection with the ice recession. This ice lakes phase developed until formation classical Baltic Ice Lake phase. In the modern and palaeorelief expression of the geo–seismic profiles, the steps, grooves, fragments of channels were recognized disclosing rather complicate face of the ancient

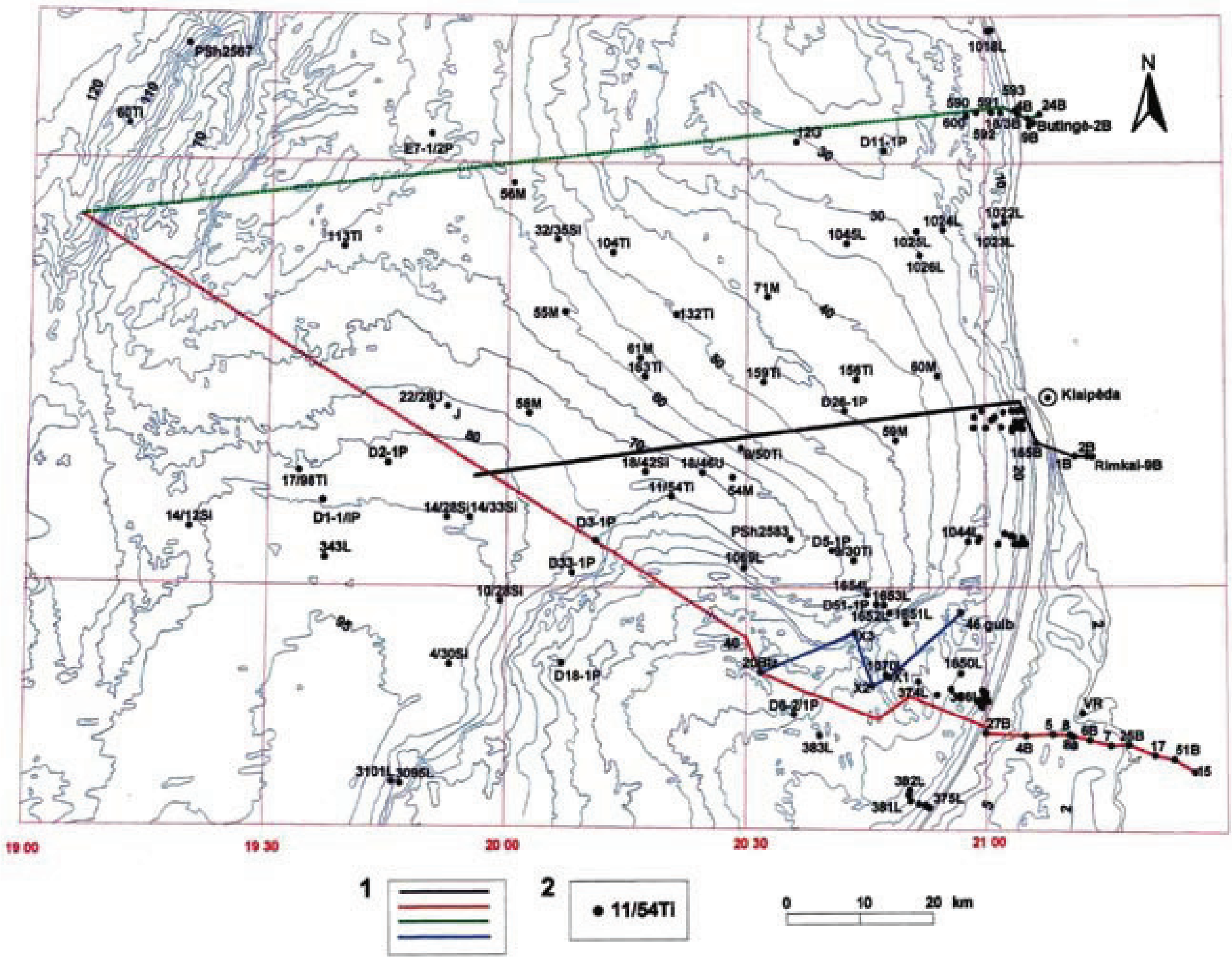


Fig. 1. Location map of the study area. Compiled by L. Ž. Gelumbauskaitė, J. Paškauskaitė and A. Ručys, 2008. 1–geographical bearing of the geo–seismic profiles (seismoacoustic profiling made by 3010–S sub–bottom profiler, R/V "Doctor Lubecki" 1997-1999), I – Nida traverse, II – Klaipėda traverse, III – Šventoji traverse); 2–bore–holes and cores with their numbers: 1B–bore–hole of geological mapping at a scale 1:50000 (Bitinas A. *et al.* 2000, 2004); 59M–bore–holes drilled by R/V "Kimberlite" (Majore *et al.* 1997); 11/54Ti–cores of geological mapping at a scale 1:200000 (Timofeev *et al.* 1975-1978, unpublished); 14/28Si, U–cores of geological mapping at a scale 1:200000 (Šimėnas *et al.* 1989, unpublished; Usaitytė 1998); J–cores of geological mapping at a scale 1:50000 (Repečka *et al.,* 1997, unpublished; Vaikutienė 1999); 1044L–cores from the international programme "Word Ocean" (Gudelis , ed. 1985; Gelumbauskaitė 1982); 20Blz–cores of geological research from the Atlantic Branch of the Russian Oceanology Institute (Blazhichishin 1998); D 26-1P–bore–holes of engineering–geological research "PETROBALTIC" in 1989-1990, unpublished; 600-591–bore–holes drilled by R/V "YUNIKON", 1995, unpublished; PSh–cores from Atlantic Branch of the Russian Oceanology institute, Vaikutienė 1999); isobaths drawn at sea every 5 m, at lagoon every 1 m.

shorelines of the Local Ice Lakes, and the latest its phase Baltic Ice Lake. According to our data it could be stated that lacustrine deposition predominate in the depressions below 50 m NN, and in the pools of shallow and margins only. Submarine plateau tops, as basal till plains were deployed as obstackles.

Start point of the basic geo–seismic profiles was at the –110 m NN of the eastern part of the Gotland depression (Fig. 1). North–eastwards to traverse Šventoji (profile III; green colour) and south–eastwards to traverse Nida (profile I; red colour), the similar morphology and deposition character of the Late–Glacial–Holocene sequences was recognized. On the echo–seismic records a steep, graduated slope with two denudational–erosional levels at 70–68 and 68–65 m b.s.l. was registered, represented by recessional glacio–moraine and glacio–lacustrine sediments. Acoustic stratification on the bottom records and lithostratigraphy of cores shows very thin Late–Glacial cover, where average thickness reaches 0.3–3.0 m (60Ti, 113Ti).[2] In the some marine sampling stations sedimentary bedrock surface inserted in the Devonian strata unveil in the present topography. Holocene depositional complex on the slope is distinguished in the incisions only (PSh 2567; see Figs. 6, 7).

The laminated and homogenous glacio–lacustrine complex well uncovers on the flat of the Gdansk depression, and on the foot of the Klaipėda slope (profile I, Figs. 2, 3; profile II, Figs. 4, 5). The seismic units and litho–biostratigrahy, established from borehole data and short drill cores, allow to describe IL–BIL deposits in detail. This binominal depositional complex, extending from the deepest to shallow zone, is widely spread, average thickness reaches 10 m and maximal 17 m (5.1 m of BIL, and 11.8 m of IL; based on the seismic line and cores: 22/28U, J, D2-1P, 58M, 11/54 54M, 18/46U, Figs. 2, 4). The sediment complex of the Local Ice Lakes, related to local dammed lakes, consists of varved clays, and the Baltic Ice Lake deposits contain homogenous or very fine laminated brown clay. These sediments are lying on the till loam, mostly denudational, surface of the Grūda (Late Weichselian)–Medininkai (Warthe) stadials (Gelumbauskaitė 2000; Gelumbauskaitė *et al.* 2005).

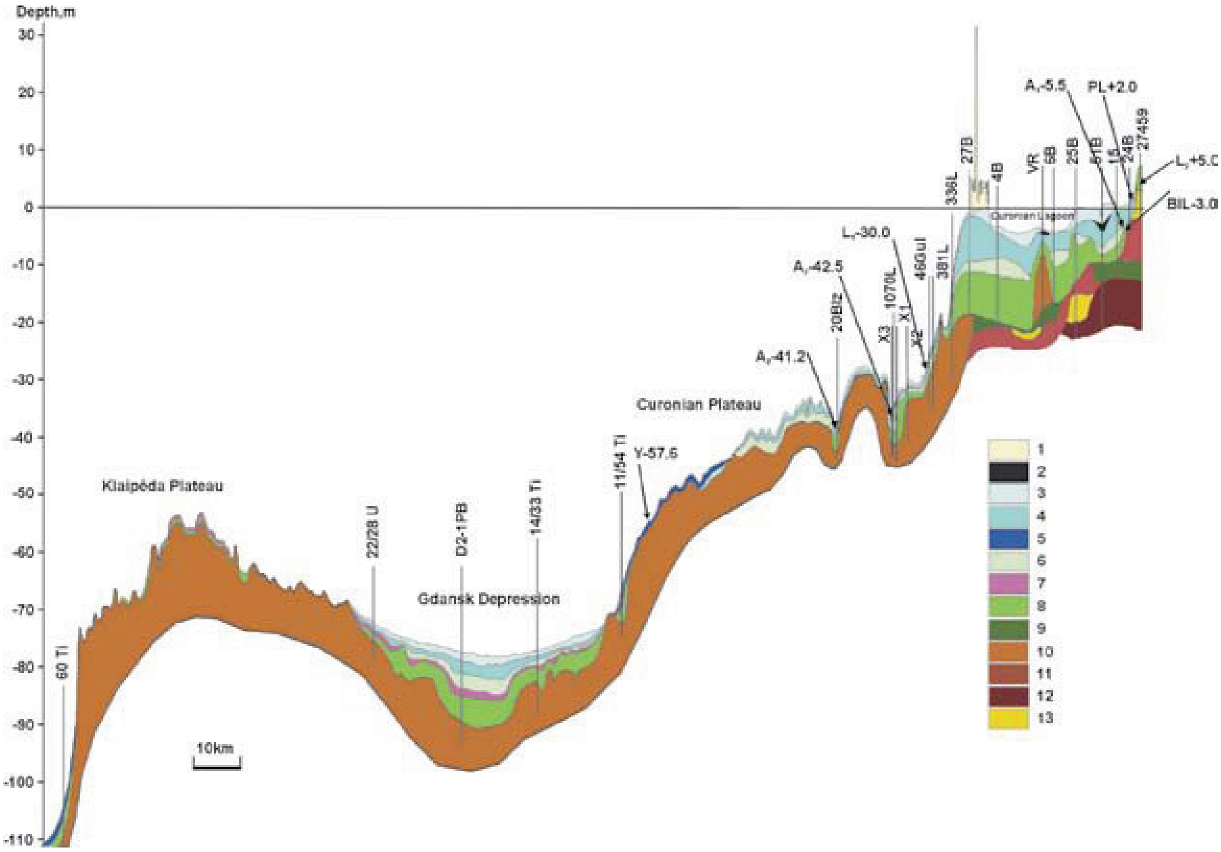


Fig. 2. Geo–seismic section on the traverse Nida. Compiled by L. Ž. Gelumbauskaitė and A. Ručys, 2008. 1–aeolian sand; 2–peat; 3–deposits of Postlitorina Stage; 4–deposits of Litorina$_{1-2-3}$ Sea Stage; 5–deposits of Post-Litorina and Litorina Stages without internal stratification; 6–deposits of Ancylus$_{1-2}$ Lake stage; 7–deposits of Yoldia Sea Stage; 8–deposits of Ice Lakes and Baltic Ice Lake Stage without internal stratification; 9–limnoglacial deposits of Baltija (Pommeranian) Stage; 10–till of Baltija–Grūda Stage (Upper Nemunas–Late Weichselian); 11–till of Medininkai (Warthe) Stage; 12–till of Žemaitija (Warthe) Stage; 13–fliuvioglacial deposits of Grūda Stage; transgression–regression peaks (marked by arrows) of different Baltic Sea stages.

2 Cores and boreholes (bh.) data used in the paper are stored in the database of Marine Geology Section of Institute of Geology and Geography, Vilnius.

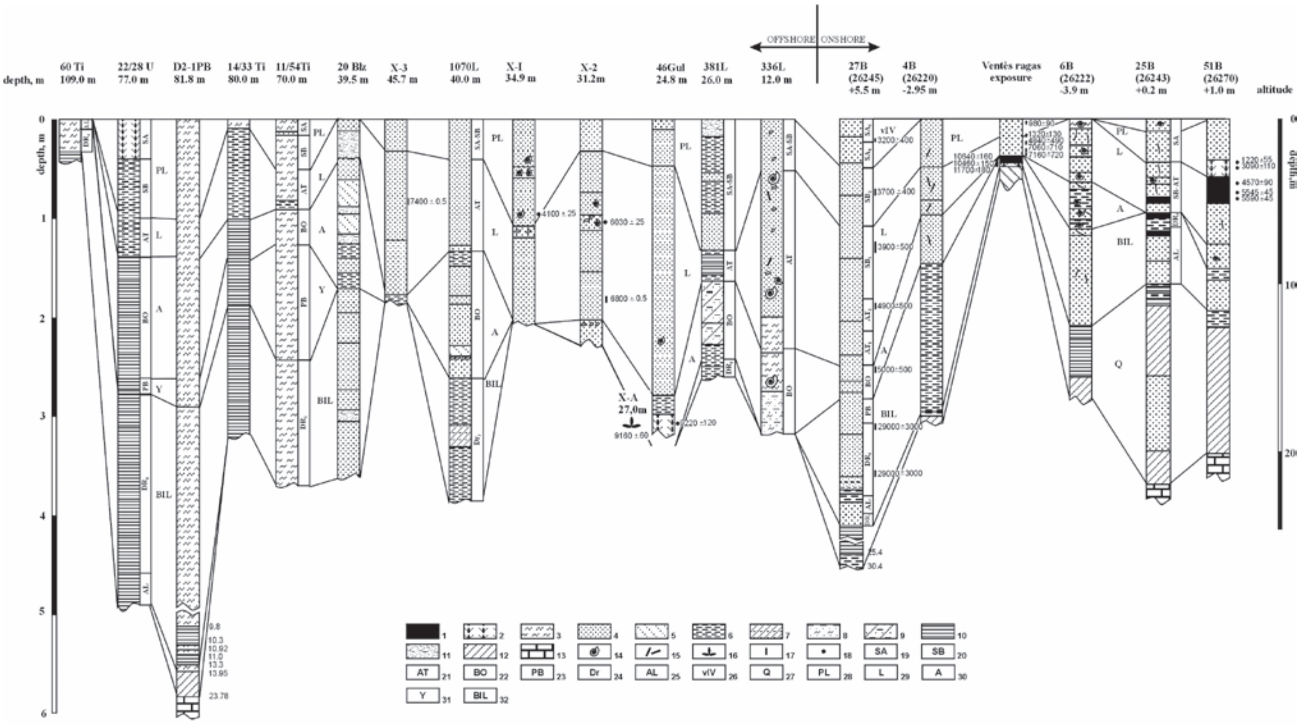


Fig. 3. Geological correlation of the cores and boreholes on the geo–seismic profile I. Compiled by L. Ž. Gelumbauskaitė and J. Paškauskaitė, 2008. 1–peat; 2–gyttja; 3–mud; 4–sand; 5–cross–bedded sand; 6–silt; 7–cross bedded silt; 8–sand, silt, mud laminated; 9–cross bedded sand and silt; 10–clay; 11–gravel; 12–till; 13–sedimentary bedrock; 14–shells; 15–remnants of organic matter; 16–dating of stump remnants; 17–optically stimulated luminescence (OSL) date; 18–radiocarbone date. Chronozones: 19–Sub–Atlantic; 20–Sub–Boreal; 21–Atlantic; 22–Boreal; 23–Pre–Boreal; 24–Dryas; 25–Alleröd; 26–aeolian sands; 27–glacial deposits. Baltic Sea Stages: 28–Post–Litorina Sea; 29–Litorina $_{1\text{-}2\text{-}3}$ Sea; 30–Ancylus$_{1\text{-}2}$ Lake; 31–Yoldia Sea; 32–Baltic Ice lake (BIL+IL).

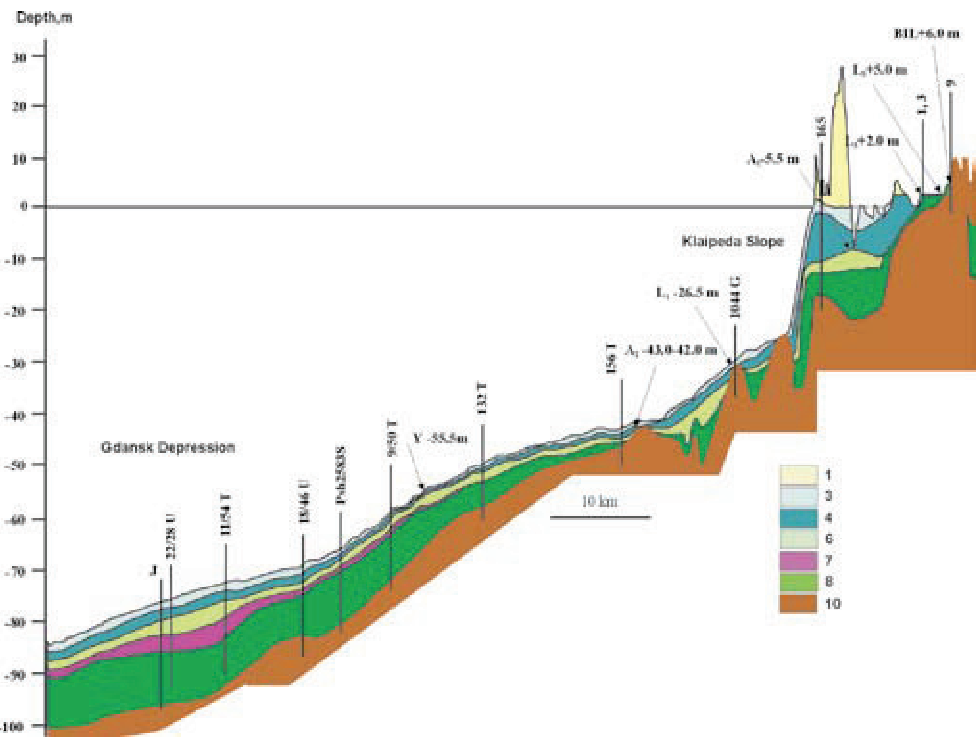


Fig. 4. Geo–seismic section on the traverse Klaipėda.Compiled by L. Ž. Gelumbauskaitė and A. Ručys, 2008. Legend explanation see at the Fig. 2.

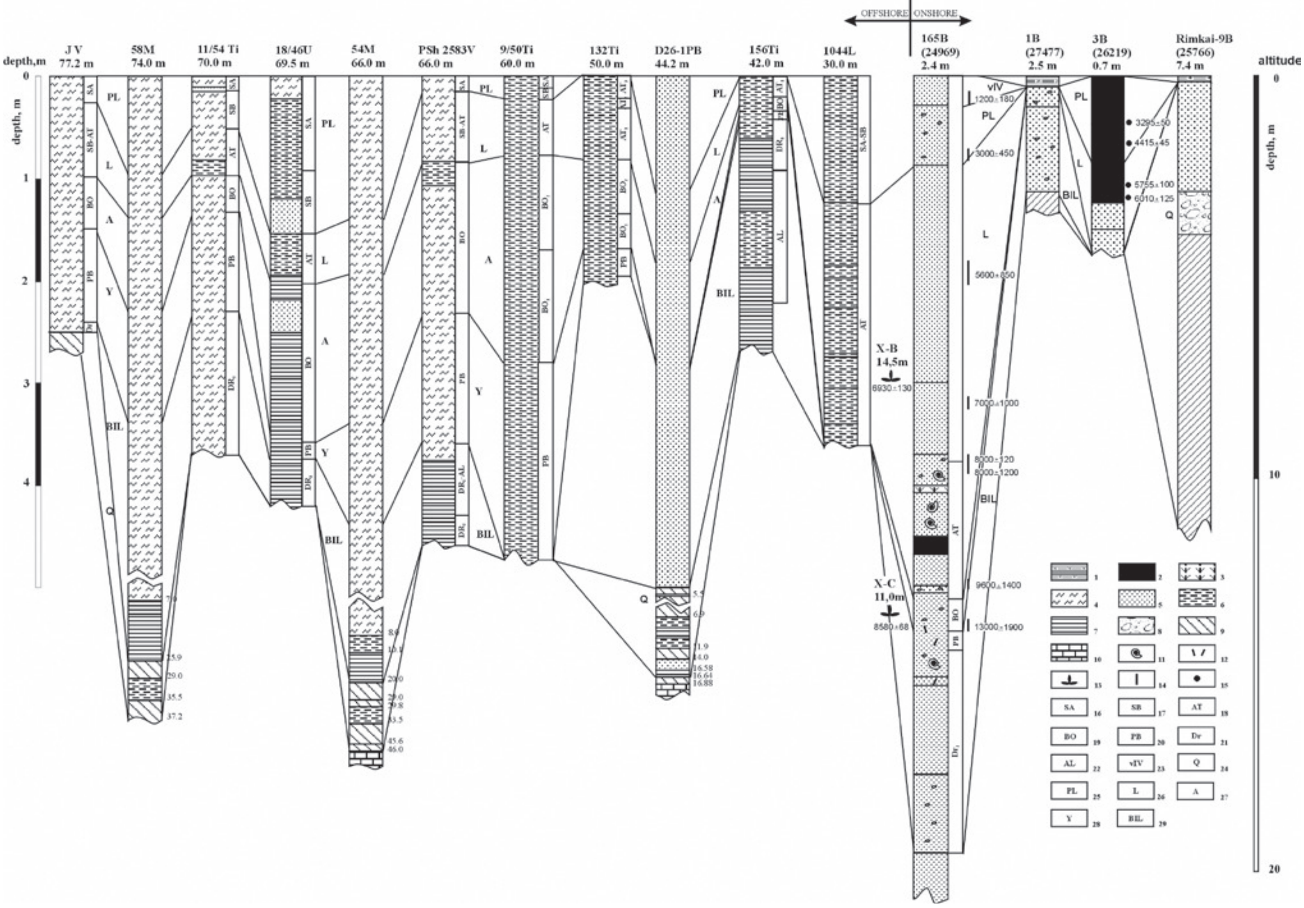


Fig. 5. Geological correlation of the cores and boreholes on the geo–seismic profile II. Compiled by L. Ž. Gelumbauskaitė and J. Paškauskaitė, 2008. 1–soil; 2–peat; 3–gyttja; 4–mud; 5–sand; 6–silt; 7–clay; 8–gravel; 9–till; 10–sedimentary bedrock; 11–shells; 12–remnants of organic matter; 13–dating of tree stumps; 14–optically stimulated luminescence (OSL) date. Chronozones: 15–Sub–Atlantic; 16–Sub–Boreal; 17–Atlantic; 18–Boreal; 19–Pre–Boreal; 20–Dryas; 21–Alleröd; 22–aeolian sands; 23–glacial deposits. Baltic Sea Stages: 24–Post–Litorina Sea; 25–Litorina $_{1-2-3}$ Sea; 26–Ancylus$_{1-2}$ Lake; 27–Yoldia Sea; 28–Baltic Ice Lake (IL+BIL).

Eastwards, the IL–BIL complex is completely missing, at the depth of 50 m NN, where an obstacle of moraine bodies as top of the Curionian plateau is prominent in the present topography. In the near–shore zone, the 8 m thick IL–BIL deposits are recognized as an infill of two bowl–type hollows (traverse Klaipėda, profile II; black colour). These sediments become more similar in the lithozones of its shore–face facies, where it is difficult to separate them using all the methods (based on cores D26-1, 59M, 60M, Psh 2583S, 9/50T, 9/30T, 132T, 156T, 1044L; profile II, Figs. 4, 5). In the area of the northern end of the Curonian Spit and Lagoon, the thickness of the Late–Glacial lithozone reaches 5.9–3.4 m. In the southern part of the Curonian Spit and Curonian Lagoon IL–BIL complex reaches 10 m (bh. 27B, 4B, 5B, 8aB, 6B) and on the Nemunas deltaic plain progressively reduces to 4.3–2.5 m.

After V. Gudelis (1979) Late Dryas manifested itself in a rapid rise in the water level of the BIL. Following recent investigations of the maritime costal plain (Bitinas *et al.* 2001, 2002, 2004), it is determined that coastal bar up to 16 m a.s.l. was formed during BIL transgression phase at the Šventoji environs. BIL transgression peak in the Lithuanian north could be presented by the radiocarbon dating 11270±230 ^{14}C (gyttja) from the nearest area of the coastal plain of Latvia (Veinbergs 1986), where BIL transgression is characterised by higher position, up to 20 m a.s.l., of the water level. Going to the south, at the Palanga environs, height of the terrace level reduces until 9–10 m a.s.l.

At the Klaipėda traverse and following to the south, the highest BIL level is fixed on the slope of the moraine ridges of the Pajūrio Oscillation, at the altitude of 5–7 m, and at the altitude –3.0m NN on the Nemunas deltaic plain area (Figs. 2, 3, 4, 5, 8). The transgression peak occurred at 11700±180 ^{14}C yr BP (outcrop Ventės Ragas, gyttja with peat), at the end of the Older Dryas (Bitinas *et al.* 2002, 2004). Highstand of the Baltic Ice Lake has been dated by OSL testing of sandy deposits from some boreholes, too. According these data BIL transgression have been formed from 15000 to 8000 cal yr BP (35B, profile II, Klaipėda traverse) and 29000±3000 cal yr BP (27B bh., profile III, Nida traverse). Clearly, those datings are overmistake of correlation. The regression trend prevailed in the Baltic

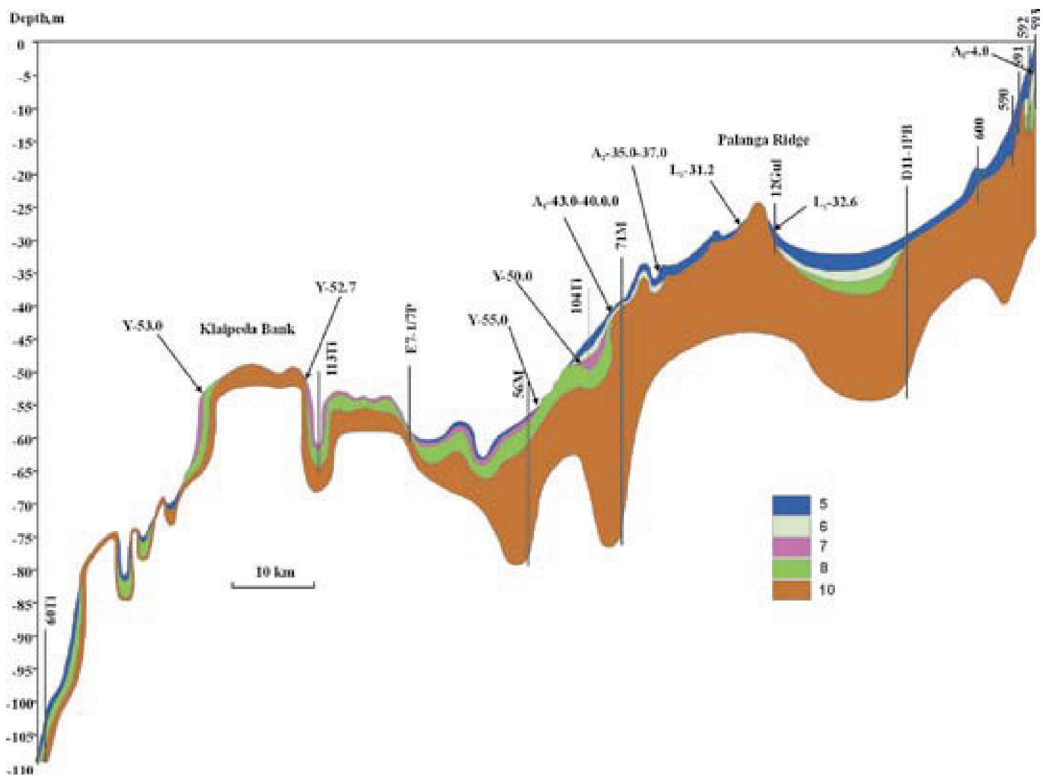
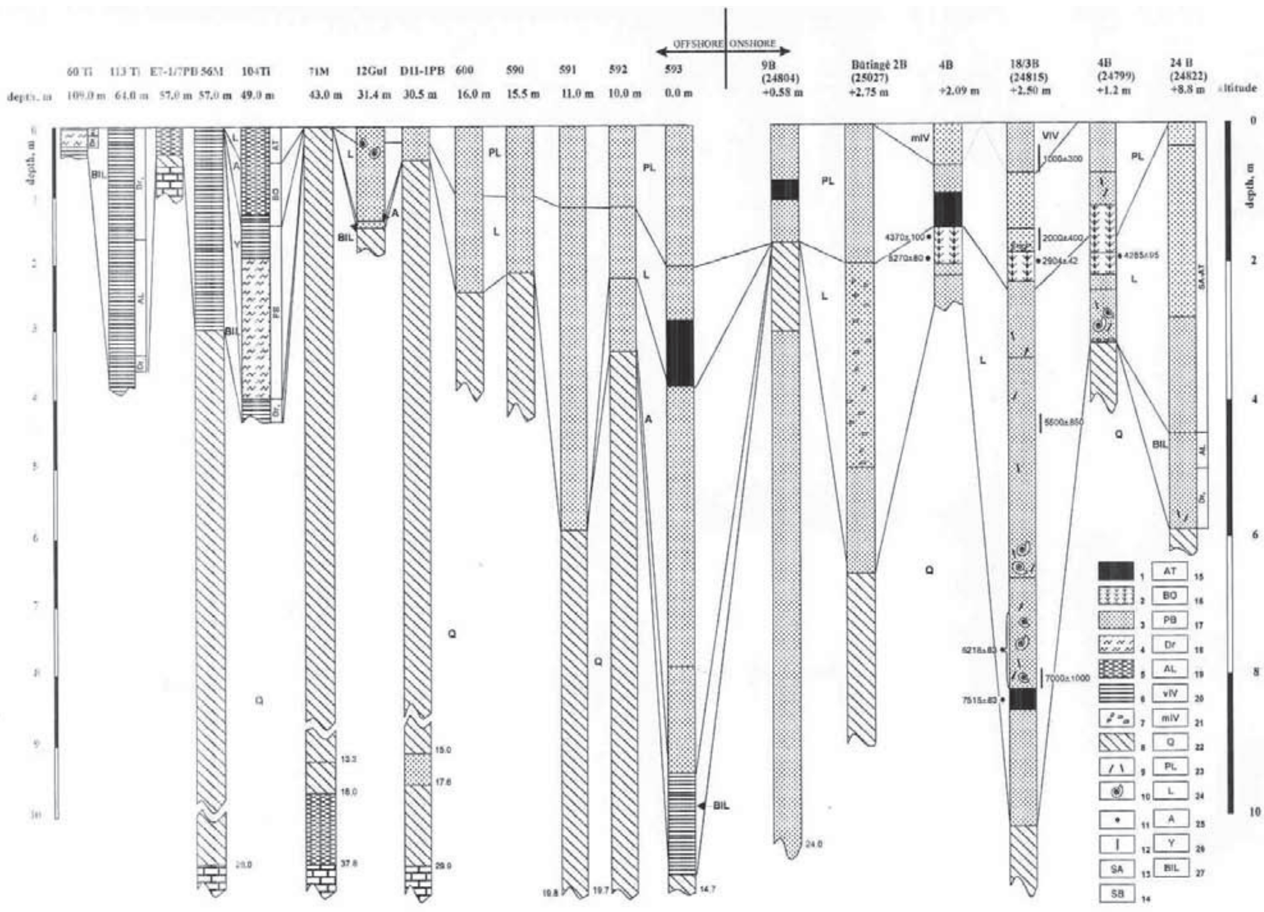


Fig. 6. Geo–seismic section on the traverse Šventoji. Compiled by L. Ž. Gelumbauskaitė and A. Ručys, 2008. Legend explanation see at the Fig. 2.



Ice Lake during the Alleröd. During a rapid regression (after Bjorck *et al.* 1989; 10 300 ^{14}C yr BP), the Baltic Ice Lake was drained, peat formations occupied large territory until 40–45 m b.s.l. on the SE Baltic (–30 NN; 10360±100 ^{14}C yr BP; Blazhchishin *et al.* 1982, 1989). The drop of the sea level during BIL was considerable and reached about –50 m NN.

Yoldia Sea

The outflow of the Baltic Ice Lake waters into the ocean through Billingen Strait is proved for the upper part of the Younger Dryas. The transgression peak of the Yoldia Sea is fixed in the Baltic area at 9600–9500 ^{14}C yr BP (after Björck, 1995). According to I. A. Timofeev (1975-1978, unpubl.), in the SE Baltic area Yoldia Sea stages existed from 10163 to 9185±140 ^{14}C yr BP. During Pre–Boreal time, brackish waters entered the central part of the Baltic proper through Central Sweden. In the Gotland area, the Yoldia Sea stage occurred between 10300 and 9300 ^{14}C yr BP and is manifested by three phases (initial, freshwater–brackish water, and final freshwater; E. Andrén 1999). There could be a direct connection with the Lithuanian coast. The problem of the occurrence of Yoldia Sea deposits in the Lithuanian sector, namely, limit of the higstand, semi–brackish or only fresh–water deposits that predominated during Pre–Boreal time, is still the subject of discussions.

Passing geo–seismic profile III up to Klaipėda Bank top, on the western slope at the depth 65 m b.s.l., the Yoldia Sea basal level can be identified according to sediments and seismic facies (Fig. 6, 7). This residual thin layer, less than of the 0.5 m, overlaps BIL depositional complex and unveils on the present topography in the short interval between altitudes 65–53 m b.s.l. Foregoing this level, a ground moraine plain is displayed on the Klaipėda Bank top morphology. Residual shore–face facies of the Y stages have been fixed also on the eastern slope of the Klaipėda Bank at the same level.

Going onshore two steps as marks of the gradually sea water rise on the slope of the Palanga moraine ridge at the depths –55.0–53.4 m NN were recognised. At the core 104Ti has been described Late–Glacial–Holocene sequence without uninterrupted deposition, where Y thickness increases up to 3.0 m. The boundary in this section between Pre–Boreal and Boreal time according to lithozones correlation with diatoms is identified at the depth 50 m NN, that corresponds 9185±140 ^{14}C yr BP (Timofeev *et al.,* 1975, unpubl.). The palaeogeographical reconstruction of this area shows that during Holocene here existed a local pool that lower part like paleochannel distinguished till sedimentary bedrock (Figs. 6, 7).

In the Gdansk depression at the depth 80–70 m (Klaipėda slope, profiles II and I), the thickness of the Yoldia Sea Stage depositional complex varies from 1.0 to 1.65 m. The sediments consist of mud with silt inter–layers (11/54Ti, 9/50Ti, PSh 25835, D2-1/PB). Foregoing eastwards at the depth 60–50m NN the deposits of the Pre–Boreal time are composed of sand and their thickness decreases to 1.0 m and less (163Ti, 132Ti, 156Ti, 1069L). According to the cores geo–seismostratigraphic and litho–biostratigraphic data, the limit of the Yoldia Sea transgression was traced at –57.6 m NN on traverse Nida, and –55.5 m NN on traverse Klaipėda.

Following to the north from Nida, at the depth 26–28 m, during submarine archaeological expedition three stumps of the trees were taken. After authors, these remnants were dated 9160±60^{14}C yr BP (Vs-1372) age and are recognised as pine's forest appeared in front of the Yoldia sea coast (Bitinas *et al.* 2003; Fig. 3). The pollen and diatom data from the coastal zone (28 bh., Nida) indicate that Pre–Boreal continental deposits occurred at a depth of –33 m NN and that the Yoldia sea transgression level was lower than at –33 m NN (Kabailienė 1999).

Ancylus Lake

The Baltic became a large inland lake, the Ancylus Lake, during Boreal time about 9300–8000 ^{14}C yr BP. The Ancylus Lake stage was represented by transgressive (A_1) and regressive (A_2) phases in the south–eastern part of the Baltic basin. The question of significant water level drop and formation of out-let systems during the regression is the most controversial in the Baltic Sea history (Björck 1995; Björck *et al.* 2008). The analyses of long drill cores from the Bornholm and Gotland basins show that Ancylus Lake stage manifested themselves in the sediments in the Gotland Basin over longer time than in Bornholm and is dated 9400–7400 ^{14}C BP (E. Andrén 1999).

On the Lithuanian coast, several authors studied and discussed the shorelines and displacement shore formations of the A_1 phase at –6–4 m (8700–8500 ^{14}C

Fig. 7. Geological correlation of the cores and boreholes on the geo–seismic profile III. Compiled by L. Ž. Gelumbauskaitė and J. Paškauskaitė, 2008. 1–peat; 2–gyttja; 3–mud; 4–sand; 5–silt; 6–clay; 7–gravel; 8–till; 9–remnants of organic matter; 10–shells; 11–radiocarbone date; 12–optically stimulated luminescence (OSL) date. Chronozones: 13–Sub–Atlantic; 14–Sub–Boreal; 15–Atlantic; 16–Boreal; 17–Pre–Boreal; 18–Dryas; 19–Alleröd; 20–aeolian sands; 21–marine sediments; 22–glacial deposits. Baltic Sea stages: 23–Post–Litorina sea sediments; 24–Litorina$_{1\text{-}2\text{-}3}$ sea sediments; 25–Ancylus$_{1\text{-}2}$ Lake sediments; 26–Yoldia sea sediments; 27–Baltic Ice Lake (IL+BIL) sediments.

BP) and the A_2 at –35–43 m b.s.l. (8000–7800–7450 ^{14}C yr BP) (Gudelis 1979; Kabailienė 1997; Timofeev 1975, unpubl.; Bitinas *et al.* 2002; Gelumbauskaitė 2002; Gelumbauskaitė *et al.* 2005a, 2005b). The considerable drop of the water level on the Lithuanian coast during Ancylus regression phase remains mostly discussing question.

On the traced geo–seismic profiles (II, I) sediments of the $A_{1, 2}$ stage are represented by various clay–silt deposits in the offshore area of the Ancylus Lake proper. The thickness of $A_{1\text{-}2}$ varies from 3.85 m to 0.5 m on the Klaipėda slope (cores 22/28, J, D2-1/BP, 14/33Ti, 11/54Ti, 20BlZ, 1070L, 18/46U, PSh 2583, 9/50Ti; Figs. 3, 5).

The boundary between sediments of the transgression and regression phases and limit of the regression peak at the depth 43–41 m NN was identified in the internal acoustic stratification and traced by geomorphology and litho–biostratigraphy data (cores 162T, 156T, 20Blz, 1070L; profile I, II). Basal level of the A_2 regression phase was identified in the Palaeo–Nemunas delta trunks. The obliquely laminated sand deposits with thin inter–layers of the coarse sand and gravel were accumulated at depth –41.3–42.6 m in core 1070L. According to biostratigraphy data these litho–facies could be stated as shore–face facies composed during Late Boreal time. On the right bank of the delta, at the lower part of the core 46 (–24.8 NN), ^{14}C dating constituted Early Boreal. Silt layer containing sapropel accumulated at the altitude -27.5 m is 9220+120 ^{14}C yr BP (Vs-1657) (see Fig. 3; Trimonis *et al.* 2007). This dating correlates well with wood remains dating (9160+60 ^{14}C yr BP) at the depth –27.0 NN. Correlation of these two datings allows clearly identify PB/B time boundary and evidence Ancylus Lakes transgression

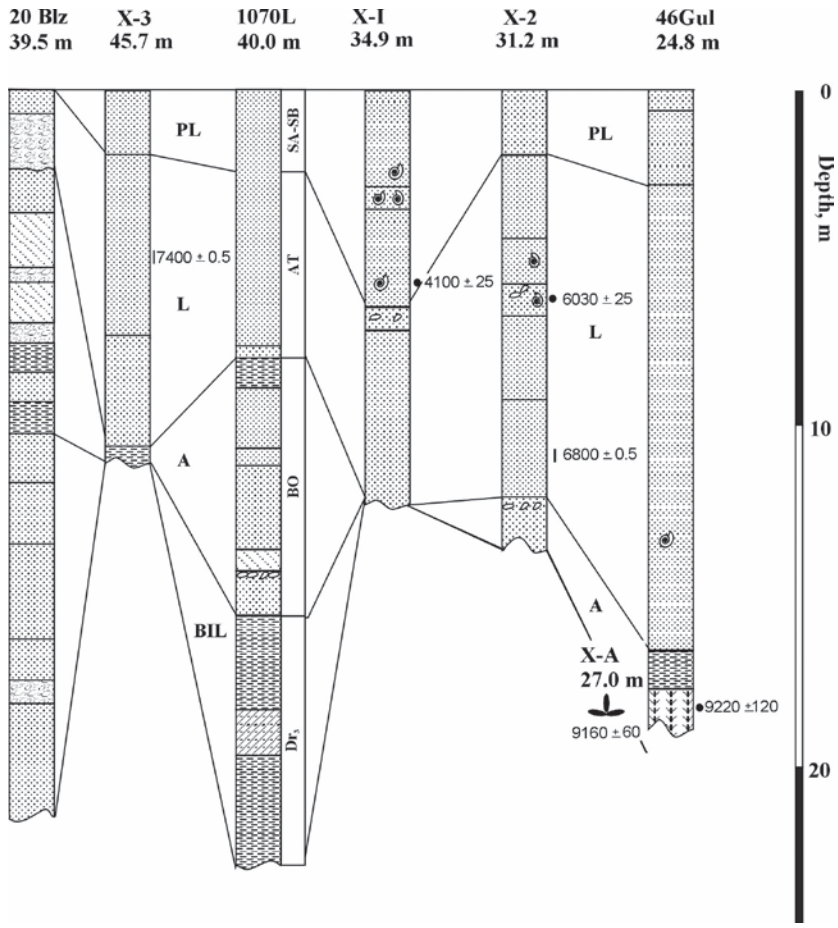


Fig. 8. Geological correlation of the cores on the profile cross the Palaeo-Nemunas delta area. Compiled by L. Ž. Gelumbauskaitė, 2009. Legend explanation see at the Fig. 3.

Table 1. Results of the radiocarbon and optically stimulated luminescence data.

Core	Depth (m)	Samp-ling interval (cm)	$^{14}C/^{13}C$ age	Lab. No.	Calibrated age BP	Dated mate-rial	Reference
IMOR/08-X1	-34.9	90-98	4100±25	UGAMS# 03138	4667±110	Shell	Current study
IMOR/08-X2	-31.2	95-110	6030±25	UGAMS# 03139	6876±45	Shell	Current study
IMOR/08-X3	-45.7	74-80	JR-OSL	RLQG-1881-118	7400±0.5	Sand	Current study
IMOR/08-X2	-31.2	170-185	JR-OSL	RLQG-1882-118	6800±0.5	Sand	Current study
IMOR/07-46	-24.8	277-322	9220±120	Vs-1657	10400±140	Sapro-pel	Trimonis et al., 2007
X-A	-27.0	In situ	9160±60	Vs-1372	10344±76	Stump	Bitinas A. et al., 2003

outset at the depth –27.0 m NN on the latitudes of the Nida–Juodkrantė. Second dating of the stump at the depth –11.0 m (8580±68 ^{14}C yr BP) marks sharp rise of the water level (Figs. 2, 3, 4, 5).

Correlation of the new ^{14}C (AMS) shells and OSL data from the cores X1 (–34.9 NN) 4100±25 ^{14}C yr BP (UGAMS#-03138), X2 (–31.2 NN) 6030±25 ^{14}C yr BP (UGAMS#03139), OSL 6800±0.5 BP (RLQG 1882-118), X3(–45.0 NN), OSL 7400±0.5 BP (RLQG 1881-118), with core 1070L in the Palaeo–Nemunas delta area shows that accumulation at the level –34.0–36.0 m NN worked well in Atlantic–Subatlantic time. Hence the delta trunks (–41.2–42.5 m NN) formed during A_2 regression and its infilling happened during L_{1-2} transgression (profile IV, blue colour; Fig. 8; Table 1). The depositional complex recognised at the depth –40–43 m b.s.l. on the Palaeo–Nemunas delta, and at the depth –27.5–28.3, and 39.9–41.8 m b.s.l. on the delta's banks, confirms previous meaning that A_2 lowstand peak on the Nida traverse could be stated at the present depth –42.5–41.2 m b.s.l.

On the traced profile III, at the Palanga moraine ridge, using data of the geological mapping, were recognised only residual basal layers of the A_2 phase with two steps at the depth –43–40 m and at the depth –37–35 m imprinted in the moraine ridge slope (Figs. 6, 7).

Following to near shore–onshore silt–sand deposits complex of the Ancylus transgression phase increases to 6 m. In the northern part, on the near–shore (profile I) a pool has been identified, were A_1 thickness reaches 6 m. Boundary between A_1/L_1 could be traced at –4.0 m b.s.l. (cores 592, 593).

The similar thickness of the Ancylus depositional complexes has been constituted in the northern part of the Curonian Lagoon along the geo–seismic profile II (bh. 165B, 1B, 2B, 9B). The sequence developed by a progradation of fluvial deposition during early transgression (Y/A boundary) and regression phases (A/L boundary). The thickness of the A_1 grew up until 8–9 m on the eastern borderland of the Curonian Lagoon. Along the traced profile I, on the southern part of lagoon (Figs. 2, 3) thickness of deposits of the Ancylus phases reduces to 4–2 m (bh. 27B, 4B, 6B, 25B, 51B).

The ancient shoreline of maximum transgression of the Ancylus Lake was identified on seismic records on the Curonian Lagoon at the depth of –5.5 m and confirmed by litho–biostratigraphy data from the boreholes of the Curonian Lagoon and Coastal Plain (Gelumbauskaitė 2003, 2005; Fig. 8). Going to the north ancient shoreline of the maximum transgression could be traced by geological mapping data nearly present coastline of the sea at the depth 4.0 m b.s.l. (profile III, Fig. 8).

Litorina Sea

The Litorina Sea is most widespread stage in the Holocene history due to a greater exchange of water between the North Sea and Baltic Sea. Many authors hold on to the opinion that inflow of saline water through the Danish Straits in the Baltic began about 8500–8000 BP when the water level was about 28–20 m below NN. The first Litorina transgression phase occurred between 7800 and 7500 ^{14}C BP. The relative sea–level changes of the Litorina Sea fluctuations correspond to an eustatic rise in the sea level recorded in the North Atlantic region and dated on reefs in the Caribbean region (Mörner 1976, 1980; Fairbanks 1989).

Three transgression phases of the Litorina Sea stage have been described on the Lithuanian coast (Gudelis 1955; Kabailienė 1974; Lukoševičius, Gudelis 1974; Blazhchishin *et al.* 1982) on the basis of the pollen and diatom dating, lithostratigraphy, geomorphology and single radiocarbon data. Using marine data, the sub–surfaces of the terrace fragments at the depth from 30–29 to 20–16 m have been observed and examined for many years. According to geomorphologic and pollen–diatom data (cores 1025L, 381L, 1070L, 341L, 1024L, 336L) the subaqueous shoreline of the L_{1+2} is traced at the depth of about 30–27–20 m as the VI/V pollen zone boundary (Lukoševičius, Gudelis 1974, 1977; Blazhchishin *et al.* 1974; Gelumbauskaitė 1982). Maritime geological mapping data allow suggesting that it could not have been above –13 m NN (Kabailienė 1999, Bitinas *et al.* 2002).

Of late years the Litorina Sea history offshore was reconstructed using geo–seismostratigraphic and biostratigraphic methods on cores (J22/28U, 104Ti, 12Gul., 590-593, 600, 58M, 11/54T, 18/46U, 14/43S, Psh 25583, 9/50T, 132T, 156T, 14/44G, 20Blz, X-3, 1070L, X-12, 46Gul.). Following the geo–seismoacoustic profiles from offshore to onshore areas, the complex of $L_{1,2,3}$ marine deposits is more or less uniform and shows a homogenous structure. The depositional complex is mostly composed of silt on the proper and sand on the shallow. Its thickness is up to 2.0 m on the Klaipėda slope of the Gdansk depression (profiles II, I).

A completely different situation is observed on the plateaus. Here full Litorina–Postlitorina cover could be identified only in pools, in paleo–channel fragments, paleo–delta trunks and on the submarine coastal slope. Thickness of the deposits varies from 4.0–2.0 m (1044L, X-3, 1070L, X-2, X-1, 46Gul., 590-593, 152b) to 0.50–0.20 m (at the sites D11-1PB, 20Blz, 381L, 156; Figs. 2, 3, 4, 5). Ground moraine undulated plains or hilly moraine relief, some times well wave washed, stands in the recent bottom surface on the Curonian and Klaipėda plateaus top (Klaipėda bank, Palanga ridge), at the depth of –28–15 m (Figs. 6, 7).

On the Curonian Spit and Curonian Lagoon as well as onshore Lithuania, the Litorina Sea deposits consist mostly of sands inter–layered with regressional gyttja and peat. Their thickness is up to 10 m in the northern part of the Curonian Spit and Curonian Lagoon. The palaeorelief scheme shows that the formation of the Curonian barrier spit did not come to an end during the period of 6100–4500 cal yr BP. A shallow lagoon that formed during this period at the absolute depth of –6–7 m was separated from the sea by a sandy barrier, which already was dissected by three gaps (Gelumbauskaitė 2002; Gelumbauskaitė, Gaidelytė 2003).

According to these data and data from earlier studies, the L_1 transgression on the Lithuanian coast started during the Early Atlantic, 7760±85 ^{14}C yr BP (at the Nida–Nemunas delta environs, bh. 51B, peat with gyttja), and on the north, 7515±63 ^{14}C yr BP (bh. 18/3, environs Šventoji). Boundary between A_2/L_1 (profile III) could be traced at the depth 39.9 m on the left bank of the Palaeo–Nemunas delta (core 20Blz), at the depth 41.3 m in the Palaeo–Nemunas delta trunks, at the depth 32.6 m, 27.8–27.6 m (cores 1044L, 381L, 46Gul.) on the traverse Juodkrantė and at the depth 32.7 m on the slope of the Palanga moraine ridge (core 12Gul.). New ^{14}C and OSL datings from cores X1, X2, X3 show that active deposition carry out this territory later, in the middle Atlantic (6030±25 ^{14}C yr BP), during L_2 transgression (see Figs. 1, 2, 3).

The shoreline of the L_1 transgression was identified at the depth –29.4–31.5 m on the slope of the Palanga ridge (profile III), at the depth –26.5 NN on the Klaipėda traverse (profile II), and at the depth –29.9 m NN on the Nida traverse (profile I; Fig. 8). According to echo– and seismoacoustic survey data, three terrace sub–surfaces have been recorded at the depths of 28.5–25.7; 25.0–23.0; 22.0–19.0 m NN which is interpreted as marks of sea level rises during the Atlantic between time interval 7760±85 and 7515±63 ^{14}C yr BP.

The maximum of the L_2 transgression (6100–5200 ^{14}C yr BP) has been recognized and interpreted during the last decade on the Lithuanian coast (Kabailienė, Rimantienė 1996, 1999; Bitinas *et al.* 2002, 2003, 2004). Altitude of the terrace plain decreases from north to south and it lies at 0.3–0.4–7.8 m to 10–12 m following Olando Kepurė cape. Going to the Nida and on the Nemunas deltaic plain area L_2 sub–surface is placed at the high 5–6 m. This level is marked by OSL as 6218±63 ^{14}C yr BP, and 5500±850 cal yr BP (18/3, profile III), 6010±125 ^{14}C yr BP (bh. 3B, profile II), and 5590±45 ^{14}C yr BP (bh. 51B, profile I). The L_3 transgression phase (4500 cal yr BP) followed the L_2 regression in the Early Sub–Boreal. After geological mapping data L_3 spread at the high 4.0–2.0 NN. ^{14}C dating gives 4570±90 cal yr BP (bh. 51B) on the south, 4415±45 cal yr BP (bh. 3B) at the traverse Klaipėda, and 4400±90, 4250±60 cal yr BP (lower cultural layer; Rimantienė *et al.* 1971) on the environs Šventoji. The transgression peak was followed by a short regression phase. The water level fell and have been oscillated about 0. It's marked in the region by 4415±45 ^{14}C yr BP with development of bogs (Figs. 2, 3, 4, 5, 6, 7, 8).

Post–Litorina Sea

Post–Litorina Sea (4000 ^{14}C yr BP—present) sediments in deepest area are composed mostly of mud, and in upper part of coarse silt and near–shore sandy facies in the Curonian Spit, Curonian Lagoon and on the coastal lowland. On seismic records, the boundary of the lower and upper levels between L/PS is commonly diffused, and separation of these depositional complexes is possible using biostratigraphic and OSL methods, what causes considerable errors in the near–shore sandy facies. The thickness of Post–Litorina sediments varies from 0.1 m (deepest part of the section) to 5 m (the Curonian Lagoon).

During the transgression peak (4000–3500 cal yr BP), the water level rose up to 1.2 m a.s.l. This event is fixed in the Svencelė Bog peat and in the Nemunas River branches (bh. 1.51, 3; 295±50 ^{14}C yr BP) on the south. On the Klaipėda traverse it marks 3295±50 ^{14}C yr BP (bh. 3B) and on the north 2904±42 cal yr BP (bh. 18/3; Bitinas *et al.* 2002).

RELATIVE SEA-LEVEL CHANGES ON THE LITHUANIAN COAST

The previous investigations of the submarine and supramarine shoreline displacements, glacioisostatic rebound and crustal movements in the south–eastern Baltic during the Late and Post–Glacial period were performed using geomorphologic, litho– and biostratigraphic methods aiming to distinguish ancient submarine–supramarine terrace levels. During the last decade, progress of regional studies has been mostly based on the radiocarbon and OSL data, and modeling of relative sea–level fluctuations in lagoons, borderland lakes and bogs.

It is stated that the model of the Late and Post–Glacial Baltic basin oscillations and regional and local fluctuations is caused by glacioisostazy, neotectonics and diachronous time boundaries, slightly moving northwards or from west to east (Mörner 1980, 1987; Harff *et al.* 2001; Harff & Meyer 2008). Considering the fact that geographical bearing of our region is the eastern part of the Central Baltic Sea, stratigraphy time scale of the Gotland basin have been chosen for correlation and calibration of ancient shore formations displacement on the Lithuanian coast (E. Andrén 1999). Main task of this paper was not only analyses of the ancient shorelines spectrograms but also reconstruction of morphology and internal structure of its according to our study of the Late–Glacial–Holocene depositional complex offshore and onshore.

The BIL transgression is characterized by the highest position, up to 12–16 m NN of the water level, on the Lithuanian north. To the south from Klaipėda, the curve of relative sea–level changes (Fig. 9) marks the BIL transgression peak at the altitude 6.0 m NN on the Pajūrio Oscillation moraine ridge (profile II), and at

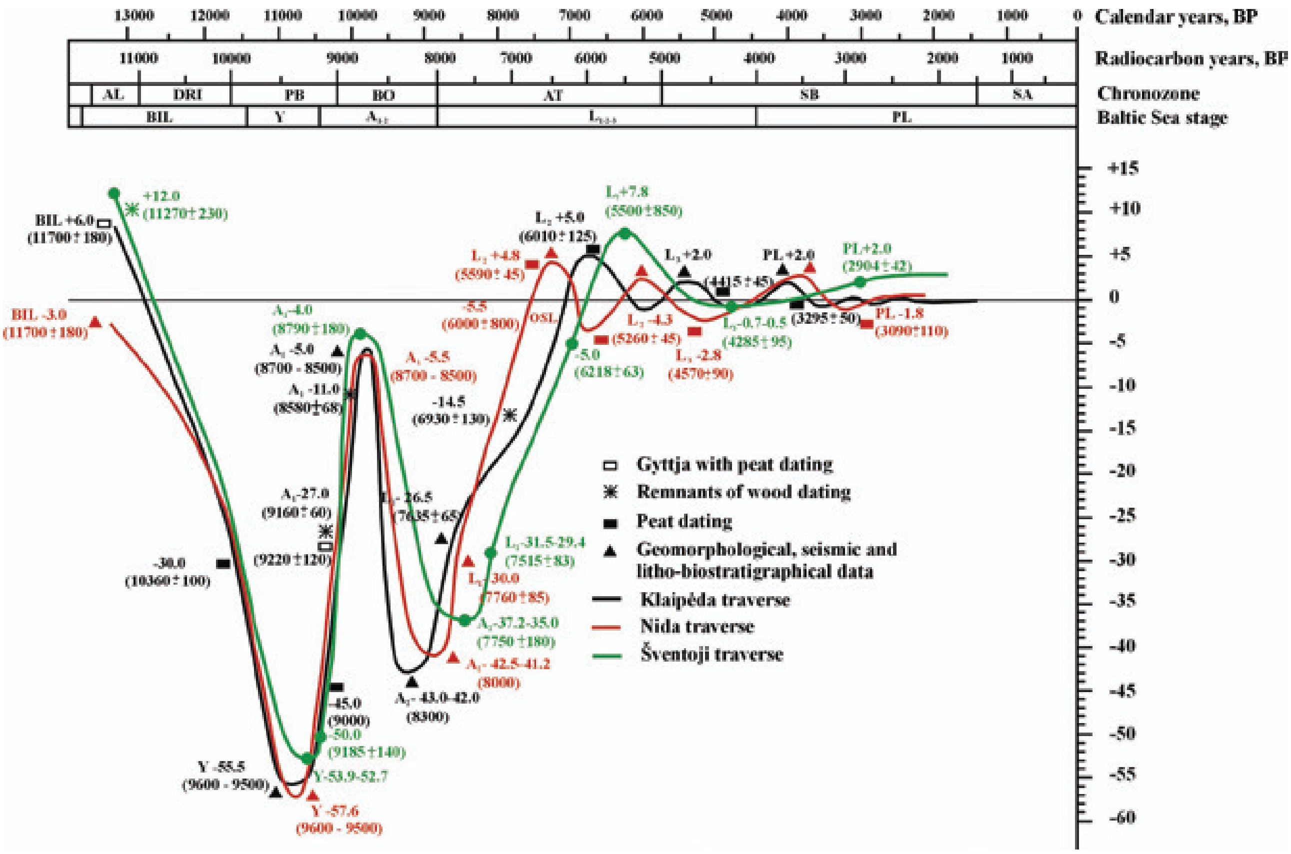


Fig. 9. Curves of the relative sea level changes on the SE Baltic: 1–red – traverse of Nida; 2–black – traverse of Klaipėda; 3–green – traverse of Šventoji.

the altitude –3.0 m NN on the Nemunas deltaic plain area (profile III). Analyses of the IL-BIL depositional complex and expression of the palaeorelief of the BIL transgression shows that BIL shoreline was curved, rich in inlet bays, moraine isles and small separate depressions during the transgression–regression cycle. The transgression/regression boundary on the curve is provided by data from the Ventės Ragas outcrop (11700±180 ^{14}C yr BP). On the north, at the diagram of the relative sea level curves, BIL transgression peak has been represented by the radiocarbon dating from nearest Latvia area 11200±230 ^{14}C yr BP (Veinbergs *et al.* 1974; Veinbergs 1986). During a rapid regression (10300 cal yr BP, after Björck *et al.* 1989), the Baltic Ice Lake was drained until 60–50 m b.s.l. on the SE Baltic. This fact indicates a peat formation on the depth 30 m NN in this area (10360±100 ^{14}C yr BP; Fig. 9).

On the diagram of the curves of the relative sea level changes it could be recognised BIL transgression boundary moving in time (11700±180–11270±230 ^{14}C yr BP) from south to north. The significant tilting of the isobases from –3.0 m following to north until +16.0 m is defined, too (see Fig. 9).

The Pre–Boreal period coincides with the Yoldia Sea stage, when the lowest position of the sea level in the SE Pre–Baltic basin expressed as a shallow estuary was recognized on the north. On the Klaipėda plateau (Klaipėda Bank and Palanga Ridge) slopes the Yoldia Sea highstand has been identified at the altitude –50.0 m NN, that after Timofeev (1975, unpubl.) corresponds to 9185±140 ^{14}C yr BP (profile I). Going to the south the maximum extent of the Yoldia Sea stage could be placed at the altitude of 55.5 m b.s.l (9600–9500 ^{14}C yr BP) on the Klaipėda traverse. On the Nida traverse the limit of the Yoldia Sea is identified at the altitude –57.6 m NN (profile III). The Yoldia Sea isobases are more slightly tilted from north to south than BIL transgression maximum on the study area. Tilting of the Yoldia Sea isobases from south to north has been described and analysed by previous authors (Kolp 1972; Veinbergs 1986; Gudelis 1982).

The Yoldia Sea transgression was followed by the Ancylus Lake transgression. On the relative sea level curves a rapid sea–level rise is fixed. This event is recorded by submarine archaeological investigations. The flooded pine forest has been found at the –27.0 m b.s.l. where stumps of trees (in situ) signed by 9160±60 ^{14}C yr BP which correlates well with dating from gyttja 9220±120 ^{14}C yr BP on the same depth level.

The maximum extent of the A_1 is clearly traced in the eastern part of the Curonian Lagoon. The ancient shoreline on the latitude of Dreverna settlement is at 5.5 m b.s.l at the Pra–Minija–Dreverna mouth, and the transgression peak is about 8700–8500 cal yr BP (Kabailienė 1996, 1999). On the north (profile I) ancient shoreline of the Ancylus maximum extension has been traced at the altitude –4.0 m in the cores, nearly borderland. The rapid transgression was modified by a regression that left a numerous of submarine shore–zone landforms observed in the modern morphology at the depth of 35–45 m b.s.l.

The Ancylus regression was followed by significant fluvial erosion that determined a progradation of the delta front sediments and made the Boreal deposition complex thicker. The limit of the regression took place about 8300 BP (Kabailienė 1996, 1999). New data of the Palaeo–Nemunas delta allow specify previous meaning that A_2 lowstand peak on the Nida traverse could be stated at the 42.5–41.2 m b.s.l. On the Šventoji traverse, A_2 peak is fixed by two steps at the 43.0–40.0, 37.0–35.0 m b.s.l. It should be noted that significant sea level drop during Ancylus regression phases could be determined not only on the Lithuanian coast. Passing to the north, on the Estonian coast Ancylus stage maximum is fixed at the altitude 45–32 m NN (8595±75 ^{14}C yr BP). Next, L_1 transgression (7505±165 ^{14}C yr BP) is characterized by low position of the water level at the altitude 12.0 m only (Veinbergs 1986). The considerable inclination of the isobases of $A_{1\text{-}2}$ is not fixed on the Lithuanian coast. It could be caused by going out glacioizostasy and growing tectono–eustatic component manifestation itself (Gudelis 1979; Kolp 1982; Mörner 1987).

Many authors (Berglund 1964; E. Andrén 1999) claim that the inflow of saline water to the Baltic proper via the Danish Straits began 8500 BP and set up in the Gotland depression 8000 ^{14}C BP Litorina Sea. The depth level started from about 25–28 m b.s.l. (Mörner 1980, 1981). The knowledge on the eustatic changes of the ocean level from North–West Europe–North–East Atlantic region (Fairbridge 1961; Fairbanks 1989; Mörner 1980) confirms that about 8000 cal yr BP, when the first Litorina phase commenced in the south–eastern area of the Baltic Sea, the World ocean eustatic level did not reach –20 m NN. The new ideas about Ancylus–Litorina transition problem have revealed by Björck *et al.* 2008.

The first Litorina Sea phase has been recognized in the Lithuanian area at a depth of –29.4–31.5 m (7515±83 ^{14}C yr BP), on the slope of the Palanga Ridge at the depth –26.5 m b.s.l. (7635 ±65 ^{14}C yr BP; core 34B nearly profile II), on the Klaipėda traverse and on the Nida traverse at the depth –29.9 b.s.l. (7760±85 ^{14}C yr BP). The maximum transgression as terrace plain is displaced on the borderland. The altitude of the terrace is highest at the Klaipėda traverse (12.0 m a.s.l.). Going to the north the sea level falls till 0.3–0.4 m, and going to the south until 5.0–6.0 m a.s.l. This level is marked between 6218±63 ^{14}C yr BP–5500±850 cal yr BP. L_3 transgression has been identified at the height 4.0–2.0 m and is marked by 4570±90–4250±60 ^{14}C yr BP. The maximum of the Post–Litorina stage on the Lithuanian coast is at +2 m (3295±50–2904±42 ^{14}C yr BP) on the relative sea–level curve. The Litorina$_{1\text{-}2\text{-}3}$ shoreline displacements on the diagram show significant diachronity going from south to north and significant deformation in the L_2 terrace level passing from south to north.

CONCLUSIONS

Using a large complex of the geomorphologic, geo–seismic and radiometric methods surveying the subsiding SE Baltic coast allow to recognise and investigate not only fragments of ancient shore levels but also to reconstruct an internal structure and morphology of the ancient shore formations, to identify boundaries and oscillation peaks of the Late–Glacial–Holocene basins. According these data the model of the relative sea level changes on the Lithuanian coast following from south to north has been constructed.

On diagram of the relative sea level curves diachronity dimension of time boundaries of the Late–Glacial–Holocene basins oscillations at the Lithuanian coast has been revealed. The significant discrepancies on the diagram are marked by $L_{1\text{-}2\text{-}3}$ shorelines. The considerable tilting of shorelines, that is linked with glacioisostatic rebound, could be recognised until Boreal (Ancylus stage) time on the Lithuanian coast.
The deformation of the hypsometric levels of the ancient shorelines of the Ancylus–Litorina stages could be explained by manifesting itself tectono–eustatic factors.

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References

Andrén E., 1999. Holocene environmental changes recorded by diatom stratigraphy in the southern Baltic Sea. *Meddelanden fran Stockholms Universitets Institution för Geologi och Geokemi 302,* 5-22.

Björck S., 1995. A review of the history of the Baltic Sea, 13.0–8.0 ka BP. *Quaternary International 27,* 19-40.

Björck S, Andrén T., Jensen J., 2008. An attempt to resolve the partly conflicting data and ideas on the Ancylus-Littorina transition. *Proceedings of the Workshop "Relative sea level changes", Polish Geological Institute Special Papers 23*, 21-26.

Bitinas A., Damušytė A., Hütt G., Jaek I., Kabailienė M., 2001. Application of the OCL dating for stratigraphic correlation of the Late Weichselian and Holocene sediments in the Lithuanian Maritime region. *Quaternary Sciences Review 20,* 767-772.

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

Bitinas A., Žulkus V., Mažeika J., Petrošius R., Kiselienė D., 2003. Tree remnants of the bottom of the Baltic Sea : the first results of investigations. *Geologija 43,* 43-46.

Bitinas A., Damušytė A., 2004. The Litorina Sea at the Lithuanian Maritime region. *Polish Geological Institute Special Papers 11,* 37-46.

Blazhchishin A. I., Davidova N. N., Kvasov D. D., Khomutova V. I., 1974. Pollen and diatom analysis of the four bottom sediment cores from the Southern and Central Baltic. *Baltica 5,* 119-126.

Blazhchishin A. I., Boldyrev V. L., Efimov A. N., Timofeev I. A., 1982. Ancient shore lines and shore formations of the South–Eastern Baltic Sea. *Baltica 7,* 57-64.

Blazhchishin A. I., Gaigalas A. I., Iospina L. F., 1989. Peat dating on the bottom of the South–Eastern Baltic. *In* Abstracts of the VIII Radionuclids and Geochemistry Conference, 13. Vilnius. [In Russian].

Blazhchishin A. I., 1998. *Palaeogeography and evolution of Late Quaternary sedimentation in the Baltic Sea.* Yantarnii Skaz, Kaliningrad, 160 pp.

Fairbidge R. W., 1961. Eustatic changes in sea level. *In* L.H. Ahrens et al. (eds.), Physic and Chemistry of the Earth 4, London, Pergamon Press, 99-185.

Fairbanks R. G., 1989. A 17000–year glacio–eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep ocean circulation. *Nature 342,* 637-642.

Gelumbauskaitė Ž., 1982. Methods and results of the study of the deformations of ancient shore levels of the South-Eastern part in the Baltic Sea. *Baltica 7,* 95-104.

Gelumbauskaitė L. Ž., 1999. Sub–Quaternary surface of the south–eastern Baltic Sea. *Baltica 12,* 15-17.

Gelumbauskaitė L. Ž., 2000. Late– and Postglacial palaeogeomorphology on the Klaipėda submarine slope, southeastern Baltic Sea. *Baltica 13,* 36-43.

Gelumbauskaitė L. Ž., 2002. Holocene history on the northern part of the Kuršių Marios (Curonian) Lagoon. *Baltica 15,* 3-12.

Gelumbauskaitė L. Ž., Šečkus J., 2005. Late Quaternary shore formations of theBaltic basins in the Lithuanian sector. *Geologija 52,* 34-45.

Gelumbauskaitė L. Ž., Šečkus J., 2005. Late–Glacial–Holocene history in Curonian Lagoon (Lithuanian sector). *Baltica 18/2,* 77-82.

Gelumbauskaitė L. Ž., Gaidelytė K., 2003. Paeogeography of the northern part of the Kuršių Marios in Late Glacial and Post–Glacial periods. *In* Rapid transgressions into semi–enclosed basins 8-10 May 2003, Gdansk–Jastarnia, Abstracts and excursion guide book, 75.

Gelumbauskaitė Ž., Grigelis A., 1997. Paleogeomorphological reconstruction of the sub–Quaternary surface of the Central Baltic Sea. *In* Proceedings of the Fourth Marine Geological Conference—The Baltic, Uppsala, 51-56.

Gudelis V., 1957. The establishment of the distinctiveness of the vertical crustal movements using epeirogenetic ancient shoreline spectrograms. *Proceedings of the Lithuanian Academy of Sciences, Series B, T. 1,* 59-64. [In Russian].

Gudelis V., Lukoševičius L., Kleimionova G. J., Vishnevskaya E. M., 1977. Geomorphology and Late– and Postglacial bottom deposits of the South–Eastern Baltic. *Baltica 6,* 245-256.

Gudelis V., 1979. The Quaternary history of the Baltic (Lithuania). *In* V. Gudelis and L.-K. Konigsson (eds.), The Quaternary history of the Baltic, Uppsala, 159-173.

Gudelis V., 1982. Neotectonic and recent crustal mouvments on the South–Eastern coast of the Baltic Sea. *Baltica 7,* 179-186.

Gudelis V. (ed.), 1985. *Litho- and biostratigraphy of the Baltic Sea bottom sediments*. Academy of Sciences of the Lithuanian SSR Department of Geography, Academy of Sciences of the USSR Institute of Oceanology, Vilnius, 204 pp.

Gudelis V., 1997. Litorina maximum transgression on the southeast coast of the Baltic Sea. *Baltica 10,* 5-8.

Harff J., Frischbutter A., Lampe R., Meyer M., 2001. Sea level changes in the Baltic Sea: Interrelation of climate and geological processes. *In* L.C. Gerherd, W.E. Harrison and B.M. Hanson (eds.), Geological perspectives of global climate changes, AAPG-Studies in geology, 47, 231-550.

Harff J., Meyer M., 2008. Changing sea level and sinking coasts. *Proceedings of the Workshop "Relative Sea Level Changes", Polish Geological Institute Special Papers 23*, 39-45.

Kabailienė M., 1974. On the character of transgression and diatoms flora pecularities of the Litorina Sea on the territory of the South–Eastern Baltic area. *Baltica 5,* 71-77.

Kabailienė M., 1997. Shore line displacement, palaeoecological conditions and human impact on the south–eastern coast of the Baltic Sea. *In* A. Grigelis (ed.), The Fifth Marine Geological Conference, Abstracts, 114-122. Vilnius.

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

Kessel H., Raukas A., 1982. On geological development of the Baltic Sea in Late–Glacial time on the basis of the East Baltic evidence. *Peribalticum II,* 131-143. [In Russian].

Kolp O., 1982. Eustatic and isostatic vertical movement in the Southern Baltic. *Peribalticum II,* 121-130. [In Russian].

Lukoševičius L., Gudelis V., 1974. The subaqueous Late– and Post–Glacial shorelines in the South–Eastern area of the Baltic Sea (The paleo–Holocene shorelines). *Baltica 5,* 113-118.

Majore J., Rinke R., Savvaitov A., Veinbergs I., 1997. Lithostratigraphical identification of tills in the south-eastern part of the Baltic Sea by the method of the rounded hornblende grains. *Baltica 10,* 9-12.

Mörner N.-A., 1976. Eustatic changes during the last 8000 years in view of radiocarbon calibration and new information from the Kattegatt region and other north-western European coastal areas. *Palaeogeography, Palaeoclimatology, Palaeoecology 19,* 63-65.

Mörner N.-A., 1980. Late Quaternary sea–level changes in the north–western Europe: a synthesis. *Geologiska Föreningens i Stockholm Förhandlingar 100,* 381-400.

Mörner N.-A., 1987. Models of global sea–level changes. *In* Sea level changes, ed. by M. J. Tooley and I. Shennan, 333-355. Basil Blackwell.

Rudowski S., 1979. The Quaternary history of the Baltic (Poland). *In* V. Gudelis and L.-K. Königsson (eds.), The Quaternary history of the Baltic, 175-185. Uppsala.

Vaikutienė G., 1999. Characteristics of development stages of the southeastern part of the Baltic Sea based on the diatom analysis. *The Geographical Yearbook XXXII*, 149-157.

Veinbergs I., Grinbergs E., Danilans I., Ulst V., 1974. Investigation of the Late– and Post–Glacial history of the Baltic on the Latvian coast. *Baltica 5,* 89-93.

Veinbergs I. G., 1986. *Ancient coast of the eastern Baltic and other SSSR seas.* Riga, Zinatne, 167 pp.

Trimonis E., Gulbinskas S., Blažauskas N., Kuzavinis M., Visakavičius E., 2007. Composition and formation of sand massifs in the Curonian—Sambian submarine plateau (Baltic Sea). *Geologija 60*, 39-50.