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Late Quaternary shore formations of the Baltic basins in the Lithuanian sector

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A study of the palaeogeomorphology, depositional-erosional history and sea level fluctuations of the Late-Glacial and Holocene Baltic basin shore formation was performed on a gentle Klaipëda submarine slope with three steps at the depth of 71, 52, 27 m, respectively, conforming to deformations of the offshore sub-Quaternary surface, the northern end of the Kurðiø Nerija (Curonian Spit) and Kurðiø Marios (Curonian Lagoon) and Coastal (Pajûrio) Plain onshore. Along the traced profile, the Late-Glacial–Holocene cover is very uneven, implying fluctuation of postglacial basins related to till loam deformations. The curve of relative sea level changes on the Klaipëda–Dreverna traverse is compared with the curve constructed by Kabailienë and Rimantienë (1996) and Kabailienë (1999) according to diatoms, archaeological and radiocarbon data, and with the curve constructed by Bitinas et al. (2004) according to ^{14}C BP and OSL dating (conv. ^{14}C BP) (Fig. 5). Authors found a direct correlation of the curves presented in this article with the curves of the eustatic changes in the North-West Europe and the Atlantic–Caribbean region. Deviations of the curve presented by authors on the basic curve could be explained by the glacio-isostatic rebound and geometry of vertical crustal movements. According to our investigations, marine and lacustrine deposition predominates only on the lower step (to –50 m below sea level) offshore, in the BIL, Y, $A_{1–2}$ and $L_{1–2–3}$ proper on the Lithuanian coast. On the shallow, nearshore and onshore, the Late-Glacial and Post-Glacial depositional complex is more variable, truncated, caused by fluvial processes. In the modern and paleorelief expression inlets, grooves, islands, fragments of channels are recognised, therefore the reconstructed face of the ancient shorelines is very complicated. According to the traced geoseismic section, the ancient shore levels of the transgression–regression peaks have been constituted: BIL maximum transgression (11,700 ± 180 ^{14}C BP) refers to +6 m NN, Y max. transgr. (9,600–9,500 ^{14}C BP) to –55.5 m NN, A_1 max. transgr. (8,700–8,500 ^{14}C BP) to –5.5 m; A_2 regression peak (8,300 ^{14}C BP) to –46.5 m, $L_{1–}$ (7,800 ^{14}C BP) to –26.5 m, L_2 max. (6,100 ± 125 ^{14}C BP) to +5.0 m, L_3 (4,500–4,415 ± 45 ^{14}C BP) and PL (4,000–3,500–3,295 ± 50 ^{14}C BP) to +2.0 m.

Key words: Late Quaternary, shore formation, Baltic basin, Lithuanian coast

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INTRODUCTION

The Lithuanian seacoast in general is of the accumulative type (Gudelis et al., 1997). Northwards and southwards from the Klaipėda, several ancient beach bars, ridges and cliffs corresponding to the Baltic Ice Lake and Litorina Sea transgression phases are expressed. Going inland, the terrace plain of the Litorina$_2$ Sea Stage is displaced at +3.0–6.0 m above sea level (a.s.l.). Northwards an absolute height of the terrace decreases and it passes to the terrace plain up to 10–12 m of the Baltic Ice Lake Stage. Southwards from Klaipėda, the slightly curved coast of the Curonian Spit barrier, formed at the Subboreal time (5,000–4,000 BP), consists of a wide beach, high foredune, blowaway plain and a large dune ridge. Ancient submarine shoreline formations of the Baltic Ice Lake (+5–+7 m) and Ancylus Lake (–5 m) transgressions, the Litorina$_{2\text{-}3}$ maximum transgression, and Post–Litorina (+4–+6 m) sea transgression have been developed on the area of the Curonian Lagoon and coastal lowland including the River Nemunas delta. Ancient shorelines of the first Litorina (L$_1$) transgression phase, Ancylus Lake regression (A$_2$) phase, Yoldia Stage (Y) are recognised at 27–28, 38–47, 50–60 m below sea level (b.s.l.), respectively. All shorelines are tilted southwards. After Gudelis (1979) the shoreline displacement during Late- and Post-Glacial time ranges 70 m.

De Geer published the first palaeogeographical schemes of the Baltic Sea phases in 1896. In Lithuania, detailed geomorphologic-geological investigations started in the mid of the 20th century. These investigations resulted in compiling spectrograms and curves of the shoreline displacement on the South-Eastern Baltic area and attempting separate eustatic, isostatic and tectonic factors (Gudelis, 1957, 1979, 1982; Lukoðevièius, Gudelis, 1974; Blazhchishin et al., 1982; Veinbergs et al., 1974; Kabailienë, 1974; Kessel and Raukas, 1982; Kolp, 1982; Rudowski, 1979; Gelumbauskaitë, 1982). Important results were obtained in 1970–1990 when a geological mapping program was started on the Eastern Baltic, at a scale 1:500,000, and later at a scale 1:200,000, and the geological-geophysical research performed by the Atlantic Branch of the Institute of Oceanology, Kaliningrad (Grigelis et al., 1991). Very intensive marine geology studies were carried out and important results were obtained in 1990–2000 within international research and national marine geological programs carried out offshore and onshore. The reconstruction of Late-Glacial and Post-Glacial conditions of the Baltic Sea development and geodynamics has be-

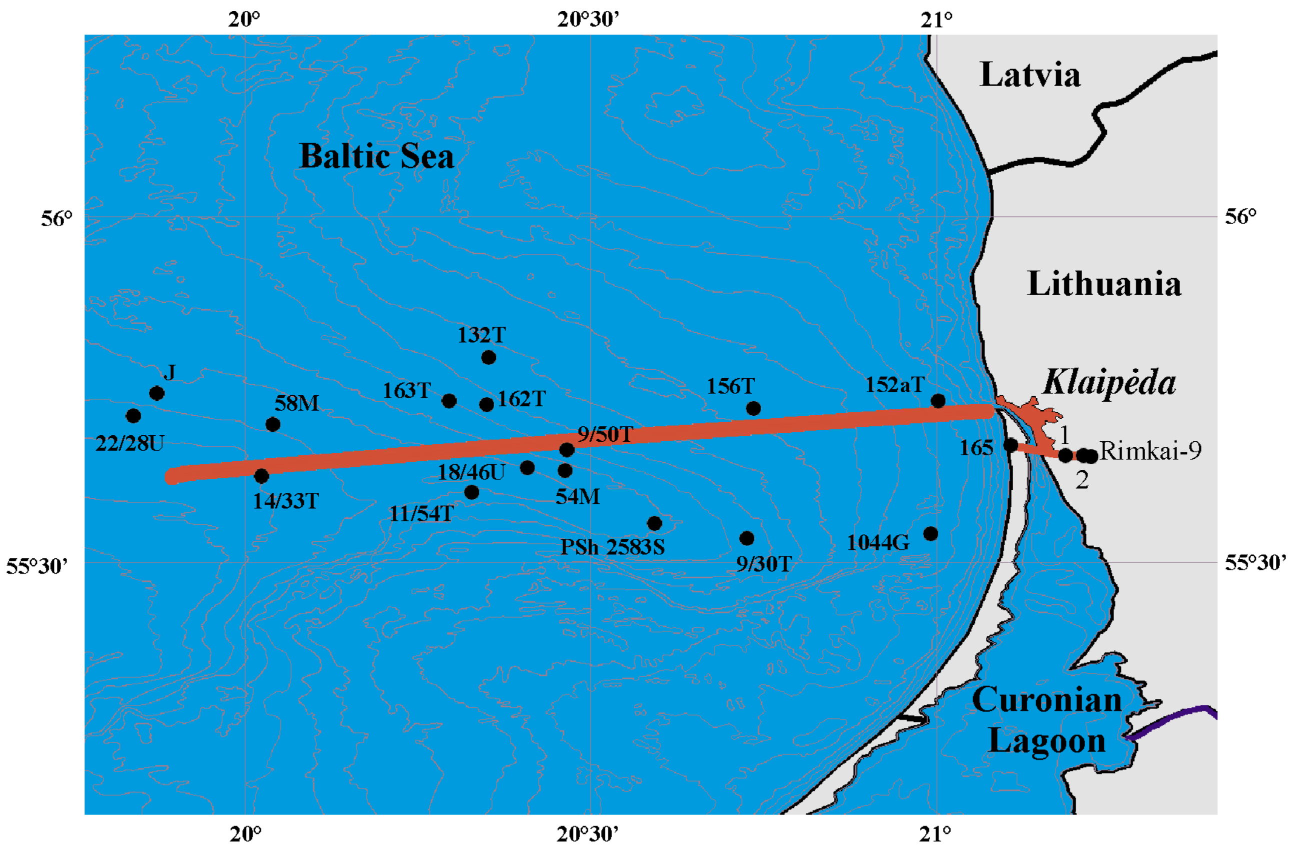

Fig. 1. Scheme of the working area; red line marks location of the seismogeological profile, black dots point cores and their numbers. Isobaths are drawn on the sea every 5 m, on the lagoon every 1 m

1 pav. Tyrimø rajonas: raudona linija þymi seismologinius profilius, juodi taðkai – kolonëliø vietà ir jø numerá; jûroje izobatos iðvestos kas 5 metrai, lagûnoje – kas metrà en dealt with by different authors (Kabailienë, 1997, 1999; Gelumbauskaitë, 2000, 2002, 2004; Gelumbauskaitë and Gaidelytë, 2004; Bitinas et al., 2001, 2002, 2004).

MATERIALS AND METHODS

Echosounding, seismoacoustic and geological data were collected in 1993–2003 within several EU projects (GOBEX, BASYS, INCO-COPERNICUS MASS), the Lithuanian Science and Studies Foundation project (KAMO) and the national marine and maritime geological mapping program at a scale 1:50,000. Echosounding records were made with the FURUNO FE-881 MK-II, DESO-15, LOWRANCE X-16 200 kHz echosounders. Seismoacoustic profiling was done with a 3010-S subbottom profiler (Maritime Institute, Gdansk, Poland), Boomer System (UWAK Tape 01, NAUTIK GmbH, Kiel, Germany) and with a single channel seismic reflection equipment, based on a PAR-600B airgun (Stockholm University, Sweden) (Gelumbauskaitë, 2000). Geological data were taken from different sources, such as six borehole sections made by the Geological Survey of Lithuania during the geological mapping of the Lithuanian Maritime region at a scale 1:50,000 (Bitinas et al., 2004), four offshore cores from reports of the geological mapping (scale 1:500,000) made by I. A. Timofeev in 1975 and 1978, five boreholes drilled by the R/V “Kimberlite” (Majore et al., 1997), some cores described by Ðimënas and Repeèka (1989, 1997), where spore–pollen and diatom analysis was performed by Kabailienë, Stanèikaitë, Savukynienë, Usaitytë, Vaikutienë, optically stimulated luminescence (OCL) analyses tested in the Tallinn laboratory, radiocarbon dating (^{14}C) in the laboratory of the Institute of Geology and Geography (GGI), Vilnius (Bitinas et al., 2000) (Fig. 1).

The geomorphometry and morphogenetic features of the modern relief were examined using bathymetry at 2 m intervals and echo- and seismoacustic records of the profiling submarine coastal zone and the Curonian Lagoon with a grid of 500 m. Examination of the echograms, calculation of the modern relief gradients and correlation with the lithological composition (median diameter, Md, mm; sorting coefficient, So), distinguishing the submerged fragments of terraces permit to trace different hypsometric levels of subaqueos ancient shore formations. Seismic records of strong reflectors penetrated into the Late-Glacial and Holocene sequence allow to recognise differences in lithology, to distinguish seismic units and to correlate them with litho- and biostratigraphy. The seismogeological offshore profile constructed earlier (Gelumbauskaitë, 2000) added new details to its structure using new cores and seabed sampling of the study area. The onshore profile was made using boreholes (Nos. 24969, 27477, 27478, 25766) and were connected with the palaeogeographical reconstruction data on the Curonian Lagoon, based on the geoseismic investigations (Gelumbauskaitë, 2002, 2003). Geoseismic units were interpreted as geological units by interpretation of the cores and boreholes where spore and pollen and diatom analysis was performed. Later the offshore geoseismic profile and the onshore geological profile were compiled together, and a seismogeological profile stretching from West to East through the Baltic Sea–Curonian Spit–Curonian Lagoon–Lithuanian onshore was done (length about 100 km; Figs. 2, 3). The horizontal scale of the profile is 1:150,000 and the vertical one 1:500.

A study of palaeogeomorphology, depositional–erosional history and sea level fluctuations of the Late-Glacial and Holocene Baltic basins, shore formations has been performed with the aid of an extensive methodical complex and geomorphologic, seismoacoustic, lithological, marine palinological analysis, as well as radiocarbon and OCL dating. Differences between marine and continental investigations of the Lithuanian coast are analyzed.

GEOLOGICAL SETTING

According to our previous data it could be stated that the sub–Quaternary topography of the Lithuanian shallow contains denudation levels of three steps inserted in the Upper Triassic/Jurassic/Cretaceous basement at 95–70, 65–50, 45–35 m b.s.l., slightly tilted south-westwards and reshaped by ridges. The quaternary thickness varies from 40 to 15–5 m on the peneplaine ridges. Following the borderland, the thickness of the quaternary cover increases and reaches on average 50–60 m.

The study area represents the gentle Klaipëda submarine slope with three steps at a depth of 71, 52, 27 m, respectively, and conforms to deformations of the offshore sub-Quaternary surface, the northern part of the Curonian Spit, the Curonian Lagoon, and the maritime plain on the lowland. Along the traced profile, the Late-Glacial–Holocene cover is very uneven (Figs. 1, 2). It is evident that postglacial basin fluctuations are related with till loam deformations. On the Klaipëda submarine plain, the average thickness of the Holocene sediments is only 3 m. On the other side, the thickness of the Local Ice Lakes and Baltic Ice Lake sediments here exceeds 17 m. The other data on the Late-Glacial–Holocene sequence could be recognised going onshore. The holocene depositional complex on the nearshore, in the palaeochanels and on the Curonian Lagoon bottom makes up 25 m.

LOCAL ICE LAKES AND BALTIC ICE LAKE (IL-BIL 13,500–10,300 CAL. YR. BP)

On the Lithuanian coast, the retreat of the ice sheet front from moraine ridges of the Pajûris Phasial be-

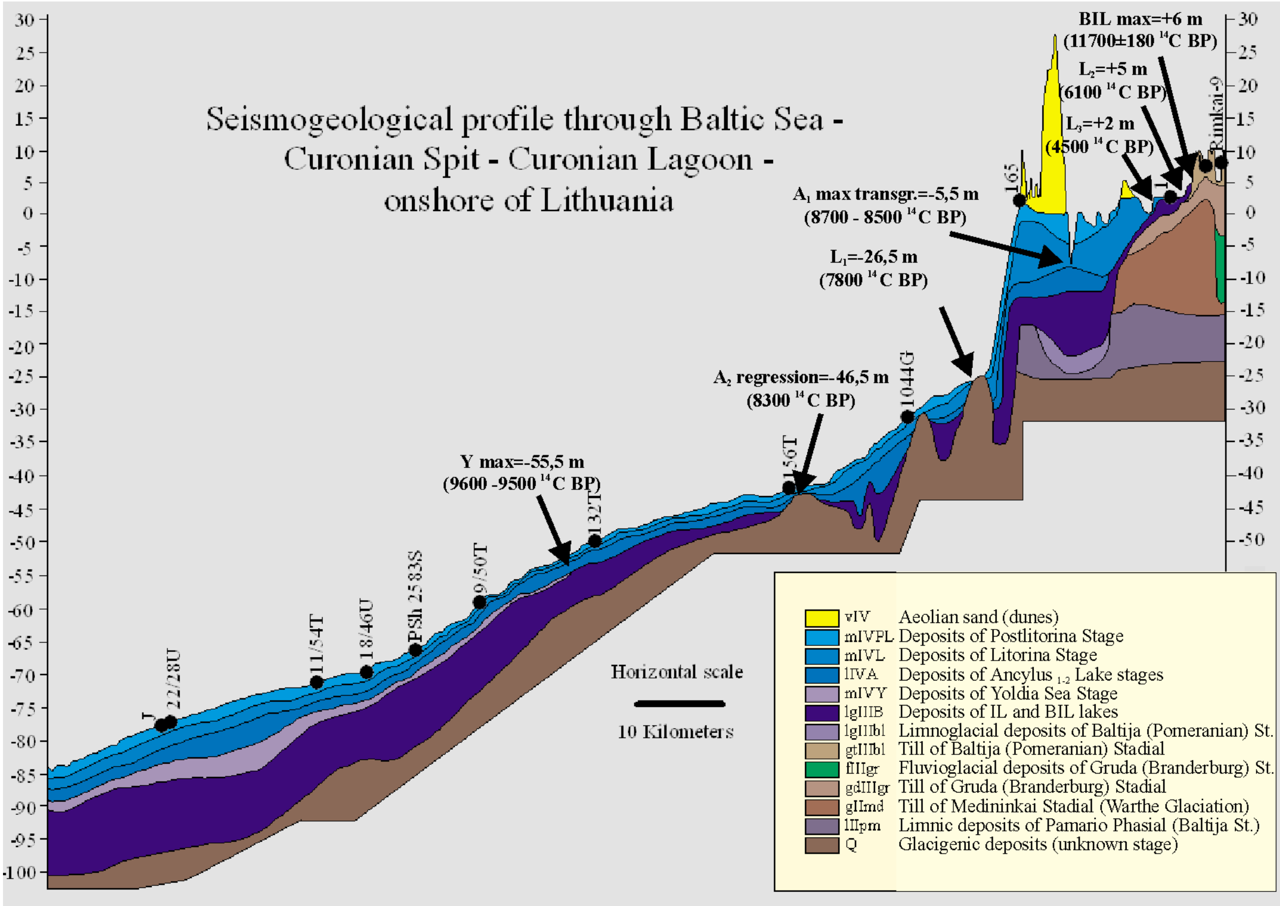

Fig. 2. Seismogeological profile showing transgression–regression peaks (marked by arrows) of different Baltic Sea stages
2 pav. Seismologinis profilis, atspindintis Baltijos jûros stadijø maksimalø iðplitimà (parodyta rodyklëmis)

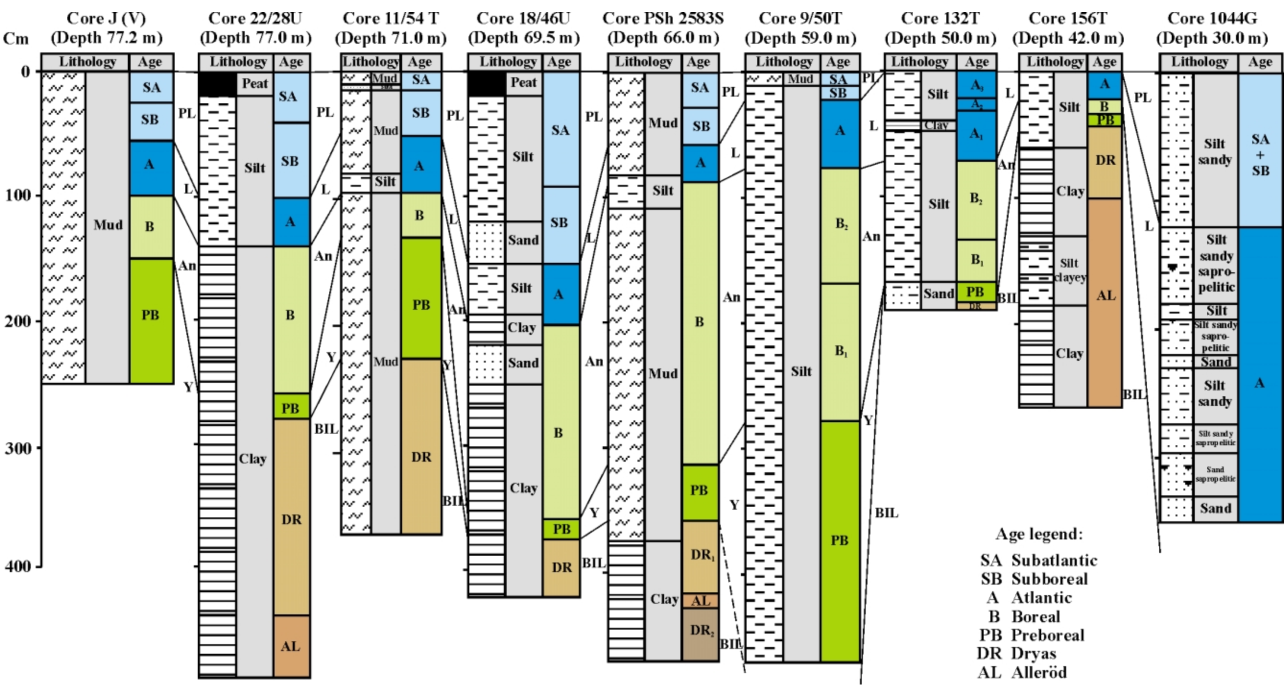

Fig. 3. Biostratigraphy of core sections based on spore–pollen and diatom analysis
3 pav. Kolonëliø biostratigrafinis suskirstymas pagal þiedadulkes ir diatomijas

gan about 13,500 cal. yr. BP. First the dammed Local Ice Lakes were formed. Later, the lakes developed into the Baltic Ice Lake phase. Ancient supramarine shore formations of the BIL are slightly inclined from north (Ðventoji) to south (Nida). The inclination makes 8–10 m with respect to the $Litorina_2$ shoreline (Gudelis, 1957, 1974).

At the Klaipëda traverse, a highest BIL level is fixed on the borderland at an altitude of 5–7 m. The transgression peak is constituted at 11,700 ± 180 ^{14}C BP, at the beginning of the Allerød (Bitinas et al., 2002). The Baltic Ice Lake regression prevailed during the Allerød. The drop in the sea level of BIL was considerable and reached about –50 m NN.

On the geoseismic profile offshore, seismic records demonstrate an uninterrupted Late-Glacial–Post-Glacial depositional–erosional structure. The distinguished and subdivided seismic units calibrated with the litho- and biostratigrahy of the boreholes and short cores allowed to describe in detail the IL–BIL depositional complex. This binominal depositional complex, going from the deepest part to the shallow one, is widely spread and reaches 17 m (5.1 m BIL, and 11.8 m IL) (based on the seismic line and cores 58M, 54M, 22/28U, 18/46U; Figs. 1, 2, 3). The local Ice Lakes sediment complex related to the local dammed lakes consists of varved clays on the lower step offshore and commonly of the sand, gravel and pebble deposits on the upper step, nearshore and onshore. These sediments lye on the till loam, mostly denudational, surface of Grûda–Medininkai stadials (Late Weichselian–Warthe deglaciation). The Baltic Ice Lake deposits, at the lower step, contain homogeneous or very finely laminated brown clay and overlay the varved complex offshore. Eastwards, the IL–BIL complex is completely missing on the middle step, at a depth of 43 m, where an obstacle of moraine bodies is prominent in the present topography. On the nearshore zone, IL–BIL deposits are recognized as filling in two bowl type hollows and are 8 m thick. These sediments become more similar in the lithozones of their shoreface facies, where it is difficult to separate them by any methods (based on cores D 26–1, 59M, 60M, PSh 2583S, 9/50T, 9/30T, 132T, 156T, 1044G; Figs. 1, 2, 3). On the area of the Curonian Spit and Lagoon, the thickness of the Late-Glacial lithozone reaches 5.9–3.4 m. According to the traced geoseismic profile, the ancient shoreline of the maximum transgression of the Baltic Ice Lake was stated at +6 m a.s.l., at the slope of the moraine ridges of the Pajûris Phasial (Baltija–Pomeranian Stadial).

YOLDIA SEA (Y 10,300–9,300 ^{14}C BP)

The outflow of the Baltic Ice Lake into the ocean through Billingen is stated in the second part of the Younger Dryas. The transgression maximum of the Yoldia Sea is fixed on the Baltic area at 9,600–9,500 ^{14}C BP (after Björck, 1995). During the Pre-Boreal time brackish water entered the central part of the Baltic proper through Central Sweden. On the Gotland area, the Yoldia Sea Stage placed from 10,300 to 9,300 ^{14}C BP, was expressed by three phases (initial, freshwater–brackish water, and final freshwater phases; Andrén, 1999) and could have a direct connection with the Lithuanian coast.

The lowest level of this event in the Baltic Sea history is stated on the S–SE area about –50 m during Pre-Boreal, when the Yoldia Sea Stage was spread. The question of the occurrence of semi-brackish or only fresh Yoldia Sea deposits in the Lithuanian sector, prevailing in the Pre-Boreal time is still subject of discussions. First, the submerged shore formations–terraces of the Yoldia Sea were stated at a depth of 60 m, southward from Nida and on the Klaipëda Bank slope, detected by echo-seismoacoustic, lithological-facial mapping and pollen–diatom dating of the cores 1625, 9/50, 9/30 (Blazhchishin et al, 1974, 1982). North from Klaipëda, during geological mapping at a scale 1:200,000 (mapped by I. A. Timofeev et al., 1975), the limit of the Yoldia Sea was traced at –50 m according to the litho- and biostratigraphy of cores 132, 168 and their geomorphology. Later, according to pollen and diatom data from the coastal zone (borehole 28, Nida) continental deposits of the Pre-Boreal age were found to occur at a depth –33 m NN, and the Yoldia Sea level had to be lower than –33 m (Kabailienë, 1999).

According to the basic geoseismic profile on the Klaipëda–Dreverna traverse, the seismic unit IV is recognized as a lithozone of the Yoldia Sea. Its deposits are 1.65 m thick (core 11/54T) seawards, at the lower step. Eastwards the thickness increases at a depth of –70 m NN to 3.85 m (mud and silt interlayer), at the middle step decreases to 1.60 m (core 9/50 1.59 m, 162T 1.0 m) and is composed of sand. On the step at a depth of –52 m this lithozone completely wedges out, its top making an absolute altitude of –55.5 m, what corresponds to the Yoldia stages (Fig. 2).

ANCYLUS LAKE TRANSGRESSION–REGRESSION PHASES ($A_{1–2}$ 9,300–8,000 ^{14}C BP)

As a result of the land uplift in Central Sweden, the Baltic Sea basin was isolated from the Ocean. The Baltic became a large inland lake, Lake Ancylus. It happened in the Boreal time about 9,300–8,000 ^{14}C BP. The Lake Ancylus stage was represented by transgressive and regressive phases in the south-eastern part of the Baltic basin. The analyses of long sediment cores from the Bornholm and Gotland Basins showed that Lake Ancylus stages were reflected in the sediments on the Gotland Basin longer than in the Bornholm Basin and marked 9,400–7,400 ^{14}C BP (E. Andrén, 1999).

Several authors investigated and discussed the displacement of shorelines and shore formations on the Lithuanian coast of the A_1 phases at –6–4 m (8,700–8,500 ^{14}C BP) and A_2 at –38–45 m b.s.l. (8,300 ^{14}C BP) (Gudelis, 1979; Kabailienë, 1967, 1996; Kunskas, 1996; Bitinas et al., 2002; Gelumbauskaitë, 2002).

The sediments are recognised by various clays–silts offshore, in Lake Ancylus proper, and by silts–sands nearshore and onshore, in the local coastal lakes, lows and channels spread on the shallow and in the Curonian Lagoon. In the second half of the Boreal time, Lake Ancylus retreated and the process of bogging started in some places. During the prolonged regression, the water level dropped some metres; sand, later silt and clay accumulated (Kabailienë, 1999). The character of the infilling of the lower Holocene depositional complexes, reflected on the seismic records, is variable in the northern part of the Curonian Lagoon. The sequence grew from a progradation of fluvial deposition during the early transgression (Y/A boundary) and regression phases (A/L boundary).

The thickness of $A_{1–2}$ varies from 3.85 m to 0.5 m offshore and to 6 m in the northern part of the Curonian Lagoon, where the Klaipëda–Dreverna geoseismic profile is traced (Figs. 2, 3). Going from the deepest part to the borderland, on the lower step of the recent morphology, a very thin, less than 1.0 m, $A_{1–2}$ sediment complex prevails, which becomes thicker in the middle step of the recent morphology. The boundary between sediments of the transgression and regression phases in the internal acoustic stratification cannot be clearly identified, but a wedge-out of the upper subunit is recognised at a depth –43 m NN, near the moraine cupola. Hence, the top of this subunit at an altitude of –46.5 m, after correlation with litho- and biostratigraphy of the cores 162T, 156T, can be interpreted as a limit of the A_2 and supported by geomorphology–lithozone structure data of the Klaipëda submarine slope.

The ancient shoreline of Lake Ancylus maximum transgression was recognised on the seismic records in the Curonian Lagoon at a depth of –5.5 m NN, and a delta front silty sandy sediments of the Pra-Minija–Dreverna River was revealed on the seismic facies.

LITORINA SEA TRANSGRESSION PHASES ($L_{1–2–3}$ 7,800–6,100–5,200–4,500 ^{14}C BP)

The more widely spread in the Holocene history, caused by a greater exchange of water between the North Sea and the Baltic Sea, is the Litorina Sea Stage. Many authors are of the opinion that inflow of saline water through Danish Straits in the Baltic began about 8,500–8,000 BP when the water level was about –28–20 m NN. The first Litorina Sea transgression phase was stated in the Gotland Basin at 8,000 ^{14}C BP (Andrén, 1999). The relative changes of the Litorina Sea level correspond to the eustatic rise in the global sea level recorded in the North Atlantic region and dated on the reefs in the Caribbean region (Mörner, 1976, 1980; Fairbanks, 1989).

On the Lithuanian coast, three transgression phases of the Litorina Sea Stage have been established (Gudelis, 1955; Kabailienë, 1974; Lukoðevièius and Gudelis, 1974; Blazhchishin et al., 1982) on the basis of pollen–diatom dating, lithostratigraphy, geomorphology and single radiocarbon data. Comparison of the diatom and pollen data from the boreholes and cores on the shallow indicates that L_1 was placed between 8,000–7,800 ^{14}C BP and the sea level was approximately on –4–10 m NN (Kabailienë, 1974, 1999). The recent maritime geological mapping suggests that it could not have been above –13 m NN (Bitinas et al., 2002). Within the marine investigation programs, subsurfaces of the terrace fragments at a depth of –30–29 – –20–16 m were observed and examined for many years. The subaqueuos shoreline of the $L_{1+2,}$ according to geomorphological and pollen–diatom data (cores 1025, 381, 1070,341, 1024, 336) is traced at a depth of about –30–27–20 m as a boundary between pollen zones VI and V (Lukoðevièius and Gudelis, 1974, 1977; Blazhchishin et al., 1974; Gelumbauskaitë, 1982).

Within the marine geological mapping programs, widely spread sediments and morphological expression of the Litorina Sea phases were studied, and the Litorina Sea Stage history was reconstructed by geoseismostratigraphic methods and biostratigraphy of the cores J, 22/28U, 11/54T, 18/46Ue, 14/43S PSh 25583S, 9/50T, 132T, 156T, 14/44G. According to these data and data from earlier studies, L_1 transgression was fixed during the Early Atlantic (8,000–7,800 ^{14}C BP) and marked at a depth of 29–27 m b.s.l. southwards from Klaipëda and at a depth of –30–28 m northwards from Klaipëda. According to biostratigraphical data, the average thickness of this depositional complex does not reach 0.5 m.

During geomorphological mapping three, sometimes four terrace level fragments of the Litorina Sea transgression lying below sea level at a depth of –30–19 m have been observed and examined (Gelumbauskaitë, 2003). The maximum of the L_2 transgression (6,100–5,200 ^{14}C BP) is recognised on the Lithuanian coast and has been investigated and interpreted during the last decade (Kabailienë and Rimantienë, 1996, 1999; Bitinas et al., 2002, 2003, 2004). Its terrace plain altitude inclines from north to south and is placed at 0.3–0.4 to 10–12 m. The L_3 transgression phase (4,500 ^{14}C BP) followed the L_2 regression in the Early Sub-Boreal, and its shoreline is fixed at 4 m a.s.l on the basic profile. The Litorina Sea sediments are composed of silt on the proper and sand on the shallow.

Following the geoseismoacoustic profile from the offshore to onshore, the $L_{1,2,3}$ marine deposit complex is more or less uniform, of a homogenous structure, its thickness reaching 2.0 m on the lower and middle levels. A completely different view could be stated on the upper level. Here a full L/PL cover could be stated only in small depressions. The thickness of deposits varies from 4.0 m in the site 152b to 0.20 in the site 156 (see Figs. 2, 3). At a depth of 28–26 m the hilly relief stands as an obstacle for the moraine in the recent bottom surface. The shoreline of the L_1 transgression was recognised on this slope and fixed at the altitude –26.5 b.s.l. According to echo- and seismoacoustic survey data, three terrace subsurfaces have been described at a depth of –29–19 m NN (28.5–25.7; 25.0–23.0; 22.0–19.0 m) and interpreted as marks of the sea level rises in the Atlantic between 7,800–7,400 ^{14}C BP. On the Curonian Spit and in the Curonian Lagoon, as well as on the Lithuanian onshore the Litorina Sea mostly contains sandy sediments interlayered with regressional gyttja and peat. The thickness of this stage makes up 10 m in the northern part of both the Curonian Spit and Curonian Lagoon. The scheme of the palaeorelief shows that the Curonian barrier spit did not complete its formation in 6,100–4,500 ^{14}C BP years. A shallow lagoon formed during this period at an absolute depth of –6–7 m was already separated from the sea by a sandy barrier, which was dissected by three gaps.

The transgression peak was followed by a short regression phase which is faced in the maritime region by bog development. The water level fell by 4–5 m and was marked at +2 m (4,415 ± 45 ^{14}C BP, Svencelë Bog– the Nemunas River lowland; Bitinas et al., 2002).

THE POSTLITORINA SEA (PL 4,000 ^{14}C BP – PRESENT)

Postlitorina Sea sediments in the deepest part are composed mostly of mud and in the upper part by coarse silt and shore sandy facies in the Curonian Spit, the Curonian Lagoon and the coastal lowland. On the seismic records, the boundary of the lower and upper levels between L/PL is commonly diffu-

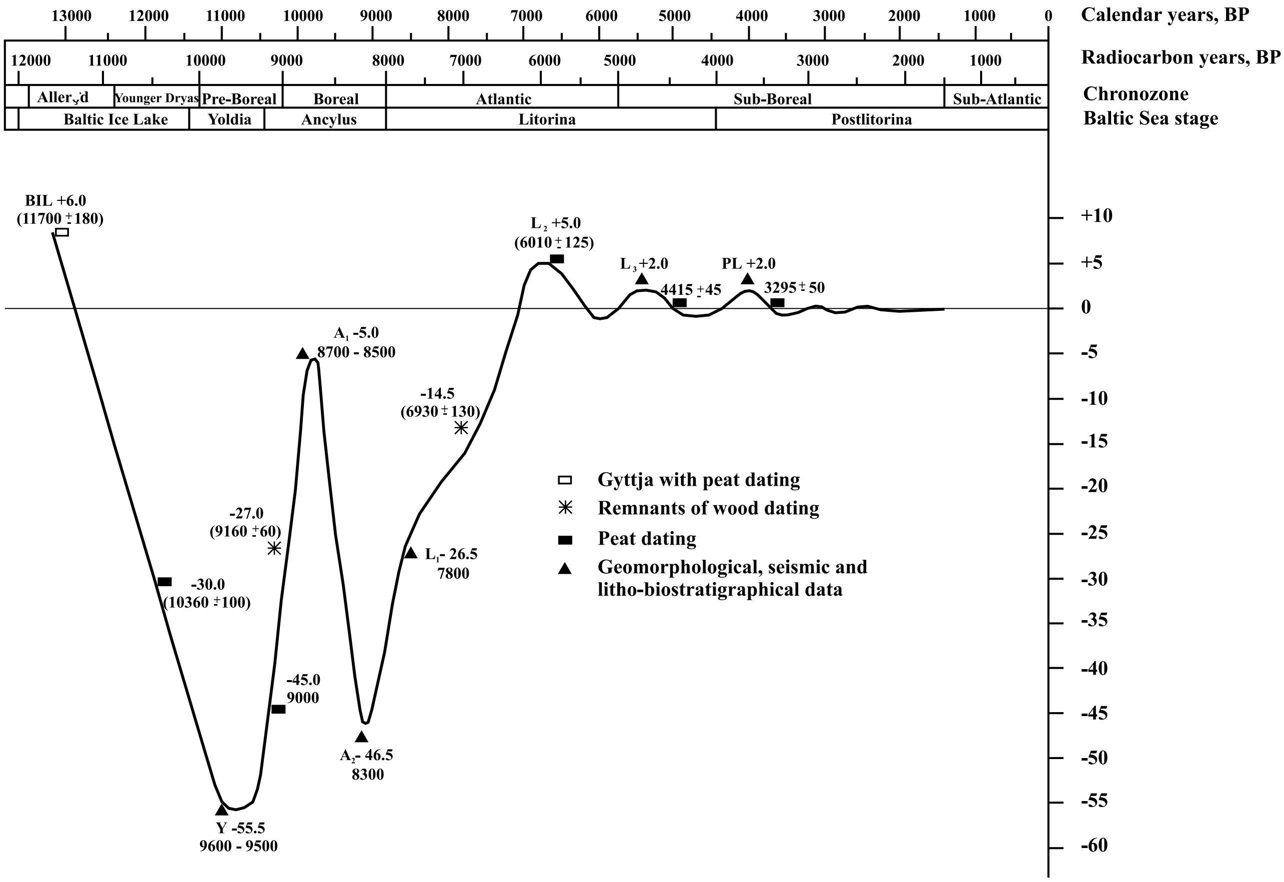

Fig. 4. Relative sea level changes in the south-eastern Baltic Sea (Klaipëda traverse). Compiled by Gelumbauskaitë, 2005; age is given in calendar years BP and conventional radiocarbon years BP after Andrén, 1999; Kabailienë and Rimantienë, 1996; Kabailienë, 1999; isostatic factor is not separated

4 pav. Reliatyvaus vandens lygio svyravimai pietrytinëje Baltijoje (Klaipëdos platumoje). Sudaryta pagal Gelumbauskaitë, 2005; kalendoriniai ir radiokarboniniai metai pagal Andrén, 1999; Kabailienë and Rimantienë, 1996; Kabailienë, 1999; izostatinis veiksnys neiðskirtas sed, and it is possible to separate this depositional complex only by biostratigraphy and OCL, which in the shore sandy facies makes considerable errors. The thickness of Postlitorina sediments varies from 0.1 m (deepest part of the section) to 5 m (the Curonian Lagoon). During transgression peak (4,000–3,500 ^{14}C BP) the water level rose up by 1.2 m a.s.l. This evidence is fixed in the Svencelë Bog peat and in the Nemunas River branches (boreholes 1, 51; 3,295 ± 50 ^{14}C BP; Bitinas et al., 2002).

RELATIVE SEA LEVEL CHANGES ON THE LITHUANIAN COAST

Previous investigations of the submarine and supramarine shoreline displacement curves, glacioisostatic rebound, crustal movements in the South-eastern Baltic throughout the Late- and Post-Glacial had been performed using geomorphological, litho- and biostratigraphical methods to distinguish ancient submarine–supramarine terrace levels. During the last decade, the regional studies were mostly based on the radiocarbon and OCL data and the modeling of the relative sea level fluctuations in the lagoons, borderland lakes and bogs.

Considering the fact that the model of the Late- and Post-Glacial Baltic basin oscillations and regional and local fluctuations is quite complicated, caused by glacioisostazy, neotectonics and diachronous time boundaries slightly moving northwards or from west to east, a stratigraphy–time scale of the Gotland Basin (E. Andrén, 1999) has been chosen for the calibration and correlation of shoreline displacement on the Lithuanian coast; also, a eustatic curve created on the base of the South Scandinavian shoreline and Kattegatt Strait data (N.-A. Mörner, 1980) was used (Fig. 4).

A peak of BIL transgression has been fixed on the curve of the relative sea level changes at the altitude +6 m NN on the moraine ridge of the Pajûris Phasial. The shoreline of the BIL 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 presented according to data from the Ventës Ragas outcrop (11,700 ± 180 ^{14}C BP). During a rapid regression (after Björck et al., 1989; 10,300 ^{14}C BP), the Baltic Ice Lake was drained; peat formations (–30.0 m, 10,360 ± 100 ^{14}C BP) and later birch forests occupied a vast territory. The second, Pre-Boreal period coincides with the Yoldia Sea Stage when the lowest position of the sea level, expressed as a shallow estuary, was recognised on the submarine Klaipëda slope. The maximum extension could

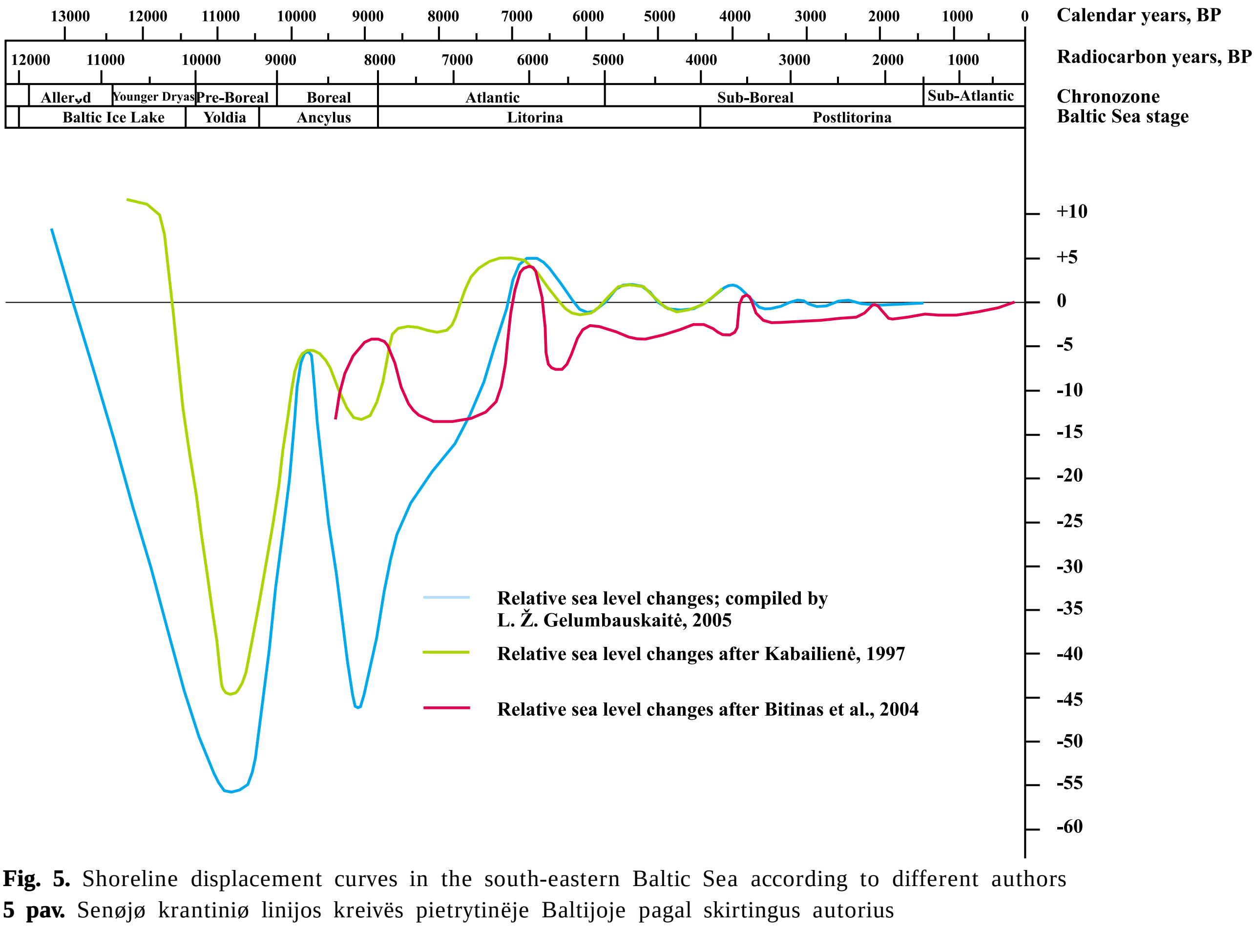

Fig. 5. Shoreline displacement curves in the south-eastern Baltic Sea according to different authors
5 pav. Senøjø krantiniø linijos kreivës pietrytinëje Baltijoje pagal skirtingus autorius

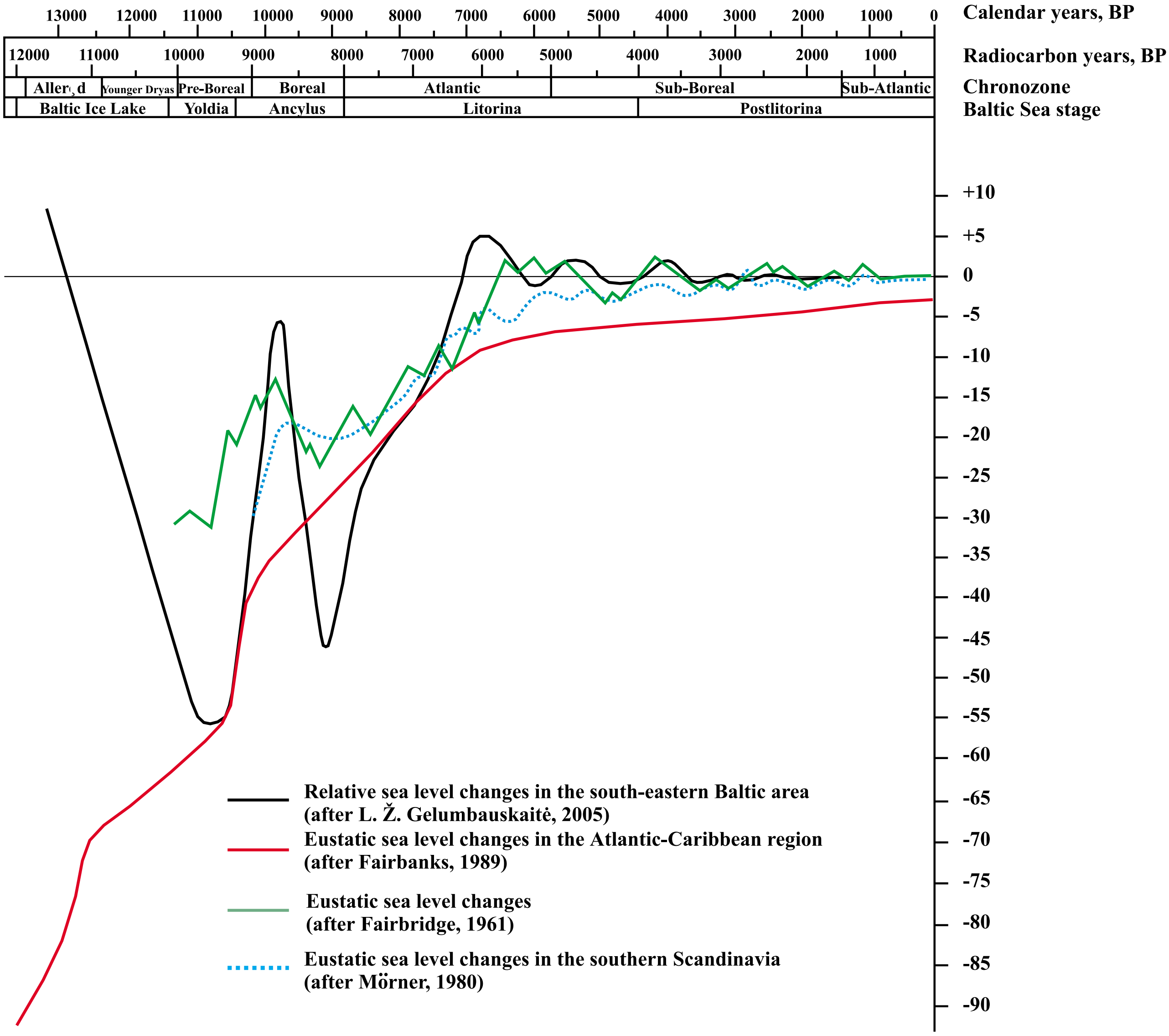

Fig. 6. Comparison of relative sea level changes in the south-eastern Baltic Sea and eustatic changes in the Nort-West Europe and Atlantic–Caribbean region

6 pav. Reliatyvaus vandens lygio svyravimø pietrytinëje Baltijoje palyginimas su Ðiaurës Vakarø Europos ir Atlanto–Karibø regionu

be placed at 9,600–9,500 ^{14}C BP, at an altitude of 55.5 m b.s.l. The Yoldia Sea transgression was followed by the Ancylus Lake transgression. A rapid sea level rise flooded the forests (–27.0 m; 9160 ± 60 ^{14}C BP) and occupied large areas. According to internal seismoacoustic stratification, the maximum extension of the A_1 is traced on the eastern part of the Curonian Lagoon. The ancient shoreline on the traverse Dreverna settlement is fixed at 5.5 m b.s.l at the Pra-Minija–Dreverna mouth, and the peak of the transgression is stated at about 8,700–8,500 ^{14}C BP (Kabailienë, 1996, 1999). The rapid transgression was changed by a slight regression which left a lot of submerged shore zone forms expressed in the modern morphology at a depth of 35–45 m b.s.l. The Ancylus Lake regression was followed by a significant fluvial erosion which determined a progradation of the fore front sediments and made the Boreal deposition complex thicker. The regression limit at the geoseismic profile is fixed at an altitude of 46.5 m b.s.l., and it happened about 8,300 ^{14}C BP (Kabailienë, 1996, 1999).

The Litorina Sea Stage at the time when the Baltic was finally connected with the World Ocean is significant in its history. Many authors (Berglund, 1964; Andrén, 1999) maintain that the inflow of saline water in the Baltic proper via the Danish Straits began at 8,500 BP and set up in the Gotland depression at 8,000 ^{14}C BP. The depth level became about –25–28 m b.s.l. (Mörner, 1980, 1981). The knowledge on the eustatic changes of the ocean level from the North-west Europe–North-east Atlantic region (Fairbridge, 1961; Fairbanks, 1989; Mörner, 1980) confirms that about 8,000 BP, when the first

Litorina phase was outset on the south-eastern part of the Baltic, the World Ocean eustatic level did not reach 20 m b.s.l. The first Litorina Sea phase has been recognized at a depth of 26.5 m b.s.l. (7,800 ^{14}C BP), the maximum transgression at an altitude of +4 m (6,100–5,200 ^{14}C BP), and the third phase at +2.0 m (4,700 ^{14}C BP) in the coastal lowland. The Post-Litorina Stage on the Lithuanian coast on the relative sea level curve is fixed at +2 m (4,000–3,500 ^{14}C BP).

The curve of relative sea level changes on the Klaipëda–Dreverna traverse was compared with the curve constructed by Kabailienë and Rimantienë (1996) according to diatoms, archaeological and radiocarbon data, and with the curve constructed by Bitinas and Damuðytë (2004) according to ^{14}C BP and OCL dating (conv. ^{14}C BP) (Figs. 5, 6). In general, an outline of interdependence and correlation is found between two of the first curves, and the discrepancy is recognised with the third curve, which specifies the beginning of L_1, location and shoreline displacement at 6–7 m b.s.l on the Lithuanian coast (Bitinas et al., 2003). Authors support the prevailing opinion that the Litorina Sea transgression began about 8,000 ^{14}C BP in the Gotland depression, 7,800 ^{14}C BP in the Lithuanian waters, and the L_1 shorelevel couldn't be higher than 20 m b.s.l. Authors found a direct correlation of the curves presented in this article with the curves of eustatic changes in the North–west Europe and Atlantic–Caribbean area (see Fig. 6). Deviations of the curve presented by authors on the basic curve could be explained by the glacio-isostatic rebound and geometry of the vertical crustal movements.

CONCLUSIONS

The reconstruction of the complete and uninterrupted Late-Glacial and Post-Glacial palaeogeography on the Klaipëda–Dreverna geoseismic section and a correlation with data southwards and northwards from Klaipëda enable to recognise and specify ancient coastal formations of the Baltic basins and its shorelevel fluctuations.

According to our investigations, marine and lacustrine deposition prevailed only on the lower step (until 50 m b.s.l.) offshore, in the BIL, Y, $A_{1–2}$ and $L_{1–2–3}$ propers on the Lithuanian coast.

On the shallow, nearshore and onshore, the Late–Glacial and Post-Glacial depositional complex is more variable, truncated, caused by fluvial processes. In the modern and paleorelief expression, inlets, grooves, islands, fragments of channels are recognised, therefore the reconstructed face of the ancient shorelines is very complicate.

According to the traced geoseismic section, the ancient shorelevels of the transgression–regression peaks have been reconstructed: the BIL maximum transgression (11,700 ± 180 ^{14}C BP) refers to +6 m NN, $Y_{max.}$ transgr. (9,600–9,500 ^{14}C BP) to –55.5 m NN, A_1 max. transgr. (8,700–8,500 ^{14}C BP) to –5.5 m; A_2 regression peak (8,300 ^{14}C BP) to –46.5 m, L_1 (7,800 ^{14}C BP) to –26.5 m, L_2 max. (6,100 ± 125 ^{14}C BP) to +5.0 m, L_3 (4,500–4,415 ± 45 ^{14}C BP) and PL (4,000–3,500–3,295 ± 50 ^{14}C BP) to +2.0 m.

The curve of the relative sea level changes on the traverse Klaipëda–Dreverna and its correlation with the other curves of the eustatic changes revealed conformities and discrepancies in the eustatic mechanism of the Lithuanian coast.

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VËLYVOJO KVARTERO BALTIJOS BASEINØ KRANTO DARINIAI LIETUVOS SEKTORIUJE

S a n t r a u k a

Geomorfologiniais, seismoakustiniais, litologiniais metodais, taip pat remiantis santykinio (sporø ir þiedadulkiø analizë) ir absoliutaus datavimo (OSL ir ^{14}C) duomenimis, iðtirtas vëlyvojo ledynmeèio ir holoceno paleogeomorfologiniø ir sedimentaciniø-eroziniø sàlygø poveikis Pietrytinës Baltijos baseinø kranto linijos pokyèiams. Ðiame darbe jûriniø tyrinëjimø duomenys interpretuoti lyginant su sausumoje atliktø tyrimø rezultatais.

Tyrimø teritorija apima nuoþulnø Klaipëdos povandeniná ðlaità su trimis pakopomis (atitinkamai 71, 52 ir 27 m gyliuose), Kurðiø nerijos ðiaurinæ dalá, Kurðiø marias bei pakrantës lygumà sausumoje. Išilgai profilio vëlyvojo ledynmeèio – holoceno nuosëdø danga yra kintanèio storio. Tai árodo, kad poledyniniø baseinø svyravimai yra susijæ su morenos kraigo pavirðiumi.

Autoriø vandens lygio svyravimo kreivë buvo palyginta su kreive, sudaryta remiantis diatomëjø analizës, archeologiniais bei absoliutaus datavimo duomenimis (Kabailienë et al., 1996), taip pat su kreive, sudaryta pagal absoliutaus datavimo OSL ir ^{14}C duomenis (Bitinas et al., 2004).

Autoriai nustatë, kad vandens lygio svyravimo kreivë sutampa su analogiðkomis kreivëmis Ðiaurës vakarø Europoje bei Atlanto ir Karibø regione. Neatitikimai tarp ðiø kreiviø galëtø bûti interpretuoti kaip glacioizostazijos bei tektoniniø Þemës plutos judesiø iðdava. Remiantis ðiø tyrimø duomenimis, galima bûtø teigti, kad Baltijos ledyniniø eþerø, Joldijos, Ancyliaus$_{1–2}$, Litorinos$_{1–2–3}$ faziø metu jûrinë bei eþerinë sedimentacija vyko ne sekliau kaip 50 m gylyje.

Dabartinëse pakilumose, pakrantëse bei krante vëlyvojo ledynmeèio – holoceno laikotarpio sedimentacinis kompleksas nëra iðtisinis, paveiktas fliuvialiniø-eroziniø procesø. Remiantis sudarytu profiliu nustatyti tokie transgresijø ir regresijø pikai: BIL trangresijos maksimumas (11 700 ± 180 ^{14}C BP) yra +6 m virð jûros lygio; Y maksimali transgresija (9,600–9500 ^{14}C BP) atitiktø –55,5 m þemiau jûros lygio; A_1 (8700–8500 ^{14}C BP) – –5,5 m; A_2 (8300 ^{14}C BP) –

–46,5 m; L$_1$ (7800 ^{14}C BP) – –26,5 m, L$_2$ maksimali transgresija (6100 ± 125 ^{14}C BP) – +5,0 m, L$_3$ (4500–4415 ± 45 ^{14}C BP) bei PL (4000–3500–3295 ± 50 ^{14}C BP) – +2,0 m.

Ëåîíîðà-Æèâèëå Ãåëóìáàóñêàéòå, Éîíàñ Øå÷êóñ

ÏÎÇÄÍÅ×ÅÒÂÅÐÒÈ×ÍÛÅ ÁÅÐÅÃÎÂÛÅ ÎÁÐÀÇÎÂÀÍÈß ÁÀÑÑÅÉÍÎÂ ÁÀËÒÈÊÈ Â ËÈÒÎÂÑÊÎÌ ÑÅÊÒÎÐÅ

Ðåçþìå

Ïî äàííûì, ïîëó÷åííûì ãåîìîðôîëîãè÷åñêèìè, ñåéñìîàêóñòè÷åñêèìè, ëèòîëîãè÷åñêèìè ìåòîäàìè, à òàêæå â ðåçóëüòàòå ñïîðîâî-ïûëüöåâîãî àíàëèçà è àáñîëþòíîãî äàòèðîâàíèÿ (ÎSL è ^{14}C), èçó÷åíî âëèÿíèå ïàëåîãåîìîðôîëîãè÷åñêèõ è ñåäèìåíòàöèîííî-ýðîçèîííûõ óñëîâèé íà èçìåíåíèÿ áåðåãîâîé ëèíèè áàññåéíîâ þãî-âîñòî÷íîé ÷àñòè Áàëòèêè âî âðåìÿ ïîçäíåëåäíèêîâüÿ è ãîëîöåíà. Ïîëó÷åííûå â õîäå èçó÷åíèÿ ìîðÿ äàííûå èíòåðïðåòèðîâàíû ñ ó÷åòîì ðåçóëüòàòîâ èññëåäîâàíèé, ïðîâåäåííûõ íà ñóøå.

Òåððèòîðèÿ èññëåäîâàíèé – Êëàéïåäñêèé îòìåëèñòûé ïîäâîäíûé ñêëîí ñ òðåìÿ óñòóïàìè íà ãëóáèíå 71, 52 è 27 ì, ñåâåðíàÿ ÷àñòü Êóðøñêîé êîñû, Êóðøñêèé çàëèâ è ïðèáðåæíàÿ ðàâíèíà íà ñóøå. Ìîùíîñòü ïîêðîâà îñàäêîâ ïîçäíåãî ëåäíèêîâüÿ è ãîëîöåíà âäîëü ïðîôèëÿ ÿâëÿåòñÿ íåîäèíàêîâîé. Ýòî ìîæåò ñ÷èòàòüñÿ äîêàçàòåëüñòâîì òîãî, ÷òî êîëåáàíèÿ óðîâíÿ ïîçäíåëåäíèêîâûõ áàññåéíîâ áûëè ñâÿçàíû ñ ïîâåðõíîñòüþ êðîâëè ìîðåíû.

Ñîñòàâëåííàÿ àâòîðàìè êðèâàÿ êîëåáàíèÿ óðîâíÿ ìîðÿ ñðàâíèâàëàñü ñ êðèâîé, ñîñòàâëåííîé íà îñíîâàíèè äèàòîìîâîãî àíàëèçà, àðõåîëîãè÷åñêèõ äàííûõ è àáñîëþòíîãî äàòèðîâàíèÿ (Kabailienë et al., 1996), à òàêæå ñ êðèâîé, ïîëó÷åííîé ñ èñïîëüçîâàíèåì äàííûõ àáñîëþòíîãî äàòèðîâàíèÿ ÎSL è ^{14}C (Bitinas et al., 2004).

Íàìè ïîëó÷åííàÿ êðèâàÿ êîëåáàíèÿ óðîâíÿ ìîðÿ ñîâïàäàåò ñ àíàëîãè÷íûìè êðèâûìè, ñîñòàâëåííûìè äëÿ Ñåâåðî-Âîñòî÷íîé Åâðîïû è Àòëàíòè÷åñêî-Êàðèáñêîãî ðåãèîíà. Íåñîâïàäåíèÿ ìîæíî îáúÿñíèòü ðåçóëüòàòàìè ãëÿöèîèçîñòàçèè è ïðîöåññîâ òåêòîíè÷åñêèõ äâèæåíèé çåìíîé êîðû. Íà îñíîâàíèè ýòèõ èññëåäîâàíèé ìîæíî óòâåðæäàòü, ÷òî ìîðñêàÿ è îçåðíàÿ ñåäèìåíòàöèÿ âî âðåìåíà Áàëòèéñêîãî ëåäíèêîâîãî îçåðà, Éîëüäèåâîãî ìîðÿ, Àíöèëîâîé $_{1-2}$ è Ëèòîðèíî-âîé $_{1-2-3}$ ôàç ïðîèñõîäèëà íà ãëóáèíå íå ìåíåå 50 ì.

Íà ñîâðåìåííûõ ïîäíÿòèÿõ, íà ïîáåðåæüå è íà áåðåãó êîìïëåêñ îñàäêîâ ïîçäíåëåäíèêîâîãî è ãîëîöåíîâîãî âðåìåíè íå ÿâëÿåòñÿ ñïëîøíûì è ïîäâåðæåí âîçäåéñòâèþ ôëþâèàëüíî-ýðîçèîííûõ ïðîöåññîâ. Íà îñíîâå ñîñòàâëåííîãî ïðîôèëÿ óñòàíîâëåíû ñëåäóþùèå çíà÷åíèÿ òðàíñãðåññèé è ðåãðåññèé: ìàêñèìóì òðàíñãðåññèè ÁËÎ (11700 ± 180 ^{14}C BP) +6 ì íàä óðîâíåì ìîðÿ; ìàêñèìóì òðàíñãðåññèè Éîëüäèåâîãî ìîðÿ (9600–9500 ^{14}C BP) ñîîòâåòñòâîâàë áû –55,5 ì íèæå óðîâíÿ ìîðÿ; ìàêñèìóì òðàíñãðåññèè A$_1$ (8700–8500 ^{14}C BP) –5,5 ì; ìàêñèìóì ðåãðåññèè A$_2$ (8300 ^{14}C BP) –46,5 ì; ìàêñèìóì òðàíñãðåññèè L$_1$ (7800 ^{14}C BP) –26,5 ì, ìàêñèìóì òðàíñãðåññèè L$_2$ (6100 ± 125 ^{14}C BP) +5,0 ì, L$_3$ (4500–4415 ± 45 ^{14}C BP) è PL (4000–3500–3295 ± 50 ^{14}C BP) +2,0 ì.