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THE LITTORINA SEA AT THE LITHUANIAN MARITIME REGION

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Abstract. In the recent decade a number of data of different investigations (pollen, diatom, molluscs analysis, lithological investigations, dating by methods of absolute geochronology, etc.) have been collected during the large-scale geological mapping of Lithuanian Maritime region (Lithuanian Coast). The results of investigations confirmed that there were three Littorina Sea transgressions at the Lithuanian Coast: the first manifested approximately in 8500–7800 conventional ^{14}C years BP, the second (maximal) — in 6200–5900 and the third — in 5300–4000 conv. ^{14}C years BP. The Post-Littorina Sea maximum was in about 3600–3400 conv. ^{14}C years BP. The Littorina Sea shoreline displacement curves were carried out. The present-day positions of shorelines of the Littorina Sea as well as other Baltic basins are displaced in different altitudes in separate parts of the Lithuanian Coast due to oscillatory neotectonic movements of Earth crust blocks during Late Glacial and Holocene.

Key words: coastline, transgression, neotectonic, Littorina Sea, Post-Littorina Sea.

INTRODUCTION

Geological structure of Quaternary of the West Lithuania (Lithuanian Maritime region or Lithuanian Coast) is closely related to the Baltic Sea, i.e. its geological development from the Baltic Ice Lake up to the present-day sea. Sediments of the Baltic Ice Lake, the Littorina Sea and the Post-Littorina Sea are reliably detected in the Lithuanian Maritime region on the basis of different investigations. Coastal positions and sediments of these basins are traced onshore of the Baltic. The water level of the Yoldia Sea and the Ancylus Lake was lower if compared to the present-day sea level, so coastal lines of these basins are not expressed onshore. The Littorina Sea — one of the widespread Baltic Sea developing stages — left the most significant traces on the Lithuanian Coast (Fig. 1). An understanding of geological history of the development of Lithuania Coast in the period from Littorina Sea up to the present-day is interesting from the scientific point of view: the Kuršių Nerija Spit has been formed during this stage, there the first Neolithic settlements were established, etc. On the other hand, the Littorina Sea sediments have a big practical interest: they serve as a background for a number of towns and settlements including the major part of Klaipėda town and its harbour, they contain the groundwater that is used for water supply, all resources of Lithuanian amber are explored in these sediments, etc.

The Littorina Sea stage of development of the Baltic Sea and its sediments have been examined by a number of investigators. The most intensive investigations started in the second half of the last century and continue up to the present time (Basalykas, 1961; Červinskas and Kunskas, 1982; Gelumbauskaitė, 2002; Gudelis, 1979, 1997, 1998; Gudelis and Klimavičienė, 1990a, b, 1993; Kabailienė, 1959, 1967, 1998, 1999; Kunskas, 1996; Savukynienė, Ruplėnaitė, 1999; and others). In the recent years, a great number of new data has been collected during the large-scale geological mapping of Lithuanian Maritime region. It enabled to develop new ideas about geological history of this region during the Late Glacial and Holocene, to compile more detailed palaeogeographic reconstructions (Bitinas *et al*., 2000, 2001, 2002). The geological history of the Lithuanian Coast during the Littorina Sea stage were corrected and detailed as well.

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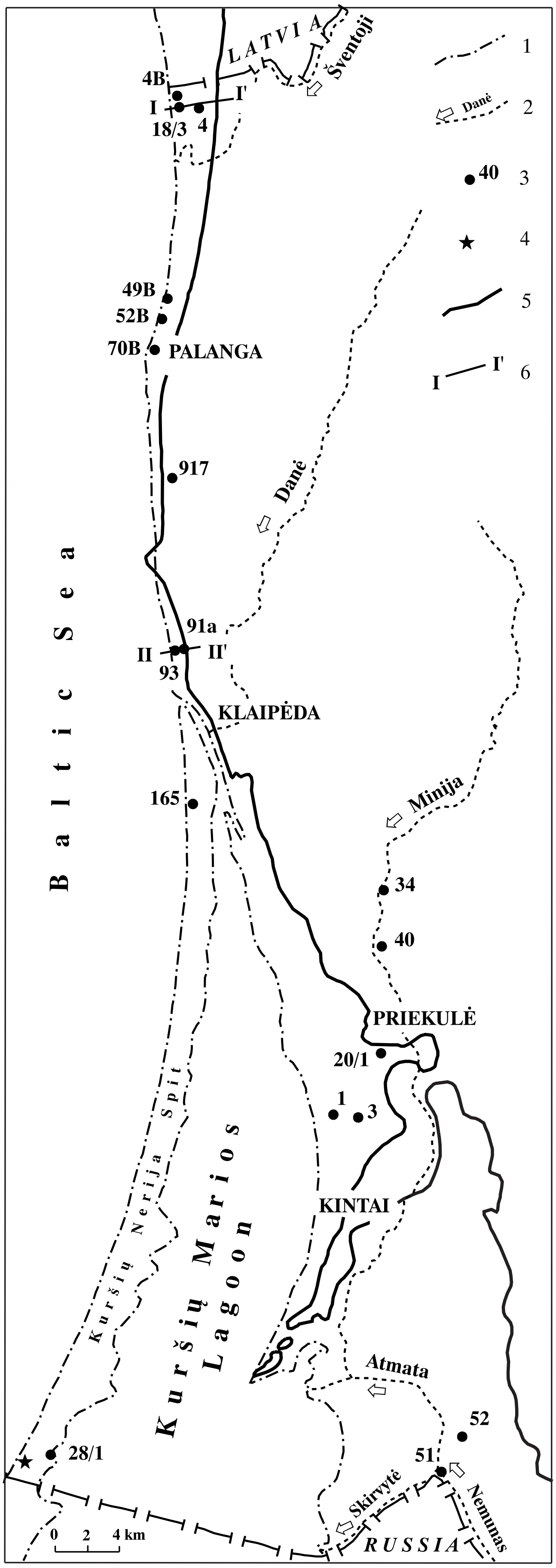

Fig. 1. Situational scheme of investigated area

1 — present-day coastline, *2* — present-day river, *3* — borehole with investigated sediments (key-section), *4* — dated archaeological findings, *5* — limit of the Litorina Sea during their maximal extension, *6* — line of geological profile

METHODS OF INVESTIGATIONS AND THEIR RESULTS

The factual data for this paper was collected during a few projects of Geological Survey of Lithuania. It was an integrated geological mapping of the whole Lithuanian Maritime region (so-called Kretinga and Šilutė areas) at a scale of 1:50 000 (1993–2000) and Geological atlas of the Lithuanian Coast of the Baltic Sea (1999–2003). Several hundreds of different boreholes (from a few metres up to 25–30 metres deep) have been drilled and used for reconstruction of changes of palaeogeographical conditions during Littorina Sea stage on the Lithuanian Coast. The most important boreholes (key-sections) have been studied palaeontologicaly and palaeobotanicaly as well as by methods of absolute geochronology (except for the traditional lithological investigations that have been done in all borehole sections). A few most important key-sections and results of their investigations are presented in the Figure 2.

Spore and pollen analysis. These investigations have been made for 20 boreholes of Maritime region. Spores and pollen analysis was performed at the Lithuanian geological institutions: Geological Survey of Lithuania (by M. Stančikaitė), Vilnius University (by M. Kabailienė, D. Ūsaitytė) and the Institute of Geology and Geography, Vilnius (by O. Kondratienė). The local pollen assemblage zones singled out in the each spore and pollen diagram were correlated with those regional and characteristic of the whole territory of Lithuania (Kabailienė, 1998), and latter correspond to the Late Glacial and Holocene chronozones of Northwest Europe (Mangerud *et al*., 1974).

Diatom analysis. Diatoms from 18 boreholes were analysed at Vilnius University (by M. Kabailienė) and Institute of Geology and Geography (by G. Vaikutienė). According to these data, the palaeoecological conditions of sedimentation (brackish or freshwater, deep or shallow basin) were detected. According to the diatom species, the sediments have been subdivided into those formed in the Littorina Sea or Post-Littorina Sea (Vaikutienė, 2003). The main problem of this method (as well as of spore and pollen analysis) is the absence of well-preserved diatoms in many intervals of borehole sections. So, only in a few sections where full diatom diagrams have been worked out, it was possible to reconstruct the whole dynamics of sea level fluctuations (Fig. 2, borehole 20/1).

Mollusc analysis and determination of isotopic composition. Subfossil mollusc remnants are sparse in sediments of Lithuanian Coast; they were found only in 24 boreholes and in a few outcrops. Palaeontologicaly the molluscs were analysed at the Geological Survey of Lithuania (by A. Damušytė). Ac-

Table 1

Results of radiocarbon (^{14}C) dating

Number of bore-hole	Altit. (m a.s.l.)	Latitude N Longitude E	Investigated interval (depth, cm)	Conventional radiocarbon (^{14}C) age in years BP (calibrated data)	Dated material	Laboratory code
1	3.0	52° 29’ 34” 21° 16’ 16”	144 – 146	2345±70 (BC 445–380)	Peat	T-10958
			204 – 206	4005±105 (BC 2650–2440)	Peat	T-10957
3	0.7	55° 29’ 42” 21° 17’ 33”	127 – 129	3295±50 (BC 1650–1525)	Peat	T-10961
			182 – 184	4415±45 (BC 3100–2950)	Peat	T-10962
			287 – 289	5755±100 (BC 4760–4500)	Peat	T-10963
			315 – 317	6010±125 (BC 5090–4780)	Peat	T-10960
4	1.2	56° 03’ 10” 21° 05’33”	190 – 200	4285 95 (BC 3025–2710)	Gyttja	T-10965
4B	2.1	56° 03’ 51” 21° 03’ 59”	160 – 170	4370±100	Gyttja	Vs-1199
			190 – 200	5270±80	Gyttja	Vs-1200
18/3	2.5	56° 03’ 30” 21° 04’ 18”	200	2904±42	Gyttja	Tln-2061
			710 – 800	6218±63	Molluscs	Tln-2067
			820 – 850	7515±83	Peat	Tln-2064
28/1*	0.5	55° 17’ 42” 20° 59’ 56”	7000 – 12400	6130±100 (BC 5089–4940)	Carbonaceous gyttja	Vs-1159
			7000 – 12400	6500±90 (BC 5483–5323)	Carbonaceous gyttja	Vs-1158
			7000 – 12400	7380±105 (BC 6255–6115)	Carbonaceous gyttja	Vs-1160
34	8.0	55° 37’ 30” 21° 18’ 02”	420 – 460	1580±65 (AD 420–553)	Silty gyttja	Vs-1172
			700 – 730	6400±100 (BC 5389–5262)	Gyttja	Vs-1170
			740 – 770	7320±105 (BC 6217–6011)	Gyttja	Vs-1183
			800 – 830	7635±65 (BC 6483–6379)	Gyttja	Vs-1182
			850 – 880	7000±75 (BC 5844–5761)	Gyttja	Vs-1184
40	6.3	55° 35’ 30” 21° 18’ 02”	870 – 890	7120±90 (BC 6027–5920)	Gyttja	Vs-1174
			890 – 910	6685±120 (BC 5633–5447)	Gyttja	Vs-1169
49B	1.4	55° 57’ 36” 21° 04’ 12”	60 – 70	3760±50	Peat	Vs-1289
			90 – 100	5090±90	Gyttja	Vs-1303
51	1.0	55° 17’ 40” 21° 23’ 22”	230 – 250	1220±55 (AD 768–886)	Gyttja	Vs-1171
			260 – 270	3090±110 (BC 1448–1195)	Gyttja	Vs-1173
			360 – 380	4570±90 (BC 3244–3101)	Peat	Vs-1179
			410 – 430	5545±45 (BC 4451–4420)	Peat	Vs-1175
			450 – 470	5590±45 (BC 4428–4364)	Peat	Vs-1176
52	– 0.4	55° 19’ 00” 21° 24’ 34”	250 – 270	5260±45 (BC 4086–3992)	Peat	Vs-1177
			380 – 400	7760±85 (BC 6622–6457)	Peat with gyttja	Vs-1178
52B	1.2	55° 57’ 06” 21° 04’ 02”	90 – 120	3730±70	Peat	Vs-1282
			130 – 140	6290±110	Gyttja	Vs-1298
70B	3.7	55° 55’ 32” 21° 03’ 31”	275 – 290	3600±40	Peat	Vs-1290
9a	5.0	55° 45’ 25” 21° 05’ 22”	820 – 930	5353±63	Molluscs	Tln-2069
917	3.9	55° 51’ 13” 21° 04’ 53”	105 – 120	3255±100	Peat	Vs-1010

* The samples for radiocarbon dating have been taken from carbonaceous gyttja pressed out from under the sandy dune due to gravitation pressure of sand mass. The occurrence *in situ* of carbonaceous gyttja has been tested by two boreholes (28/1 and 28/2) drilled in the neighbourhood

cording to palaeontological evidence, the sediments formed in the brackish water of the Litorina Sea (*Littorina littorea, Macoma balthica, M. calcarea, Cerastoderma glaucum* and *C. edule*) were detected in 16 boreholes (Fig. 2). The isotopic composition of oxygen ($\delta^{18}O$) of Litorina Sea molluscs of 3 boreholes (key-sections) were determined (by R.Vaikmäe, Institute of Geology of Tallinn Technological University, Estonia). The measured $\delta^{18}O$ values ranging from – 5.7 to – 4.1‰ suggest that all the studied subfossil mollusc shells were formed in a brackish water environment, i.e. confirm the data of palaeontological investigations (Bitinas *et al*., 2000).

Radiocarbon (^{14}C) dating. The sediments related to Littorina Sea stage and younger were dated in 15 boreholes (Table 1). Radiocarbon (^{14}C) analysis of 36 bulk samples was carried out by specialists of Trondheim University, Norway (by S. Guliksen, laboratory code T-), Institute of Geology and Geography, Vilnius (by J. Mažeika, R. Petrošius, laboratory code Vs-), and Institute of Geology of Tallinn Technological University (by T. Martma, laboratory code Tln-). The calibration has been used for a part of the radiocarbon dates only, so for discussing the age of the dated material and palaeogeography of the Littorina Sea development, the uncalibrated datings (conventional ^{14}C years) have been used in this paper. Two radiocarbon data of archaeological findings in Kuršių Nerija Spit (charcoal) were used for palaeogeographic reconstructions as well: (Vs-321) 4630 ±120 conv. ^{14}C years BP (3023–2751 years BC) and (Vs-631) 4620 ±110 conv. ^{14}C years BP (3002–2750 years BC) (Rimantienė, 1999).

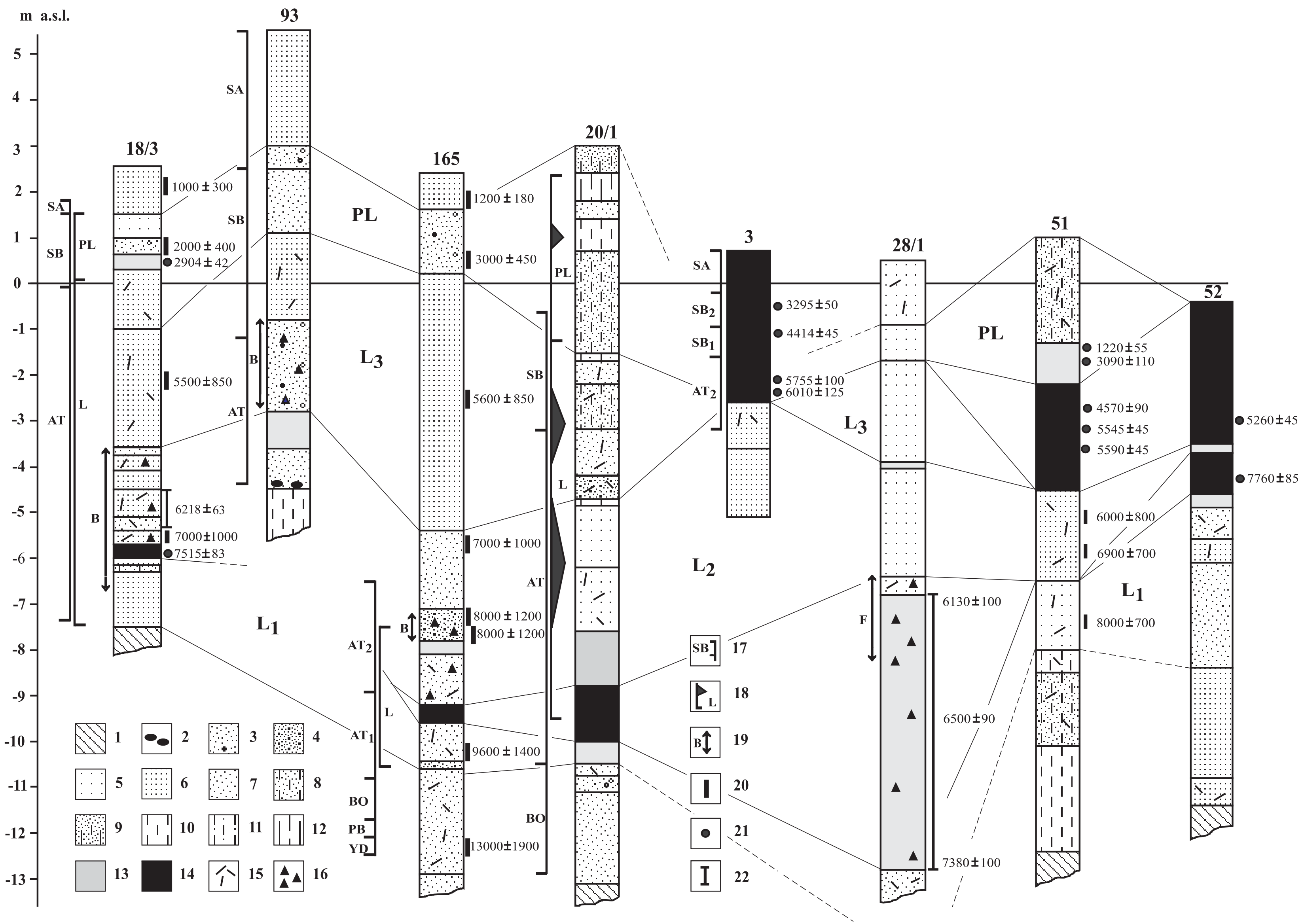
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Fig. 2. Key-sections of Littorina Sea sediments

1 — till, *2* — boulders, *3* — sand with gravel, *4* — various-grained sand, *5* — medium-grained sand, *6* — fine-grained sand, *7* — very fine-grained sand, *8* — silty sand, *9* — clayey and silty sand, *10* — silt, *11* — sandy silt, *12* — clay, *13* — gyttja, *14* — peat, *15* — remnants of organic matter, *16* — mollusc shells, *17* — chronozones according to palynological data, *18* — paleobasins according to diatom data (L — Littorina Sea, PL — Post-Littorina Sea; black triangle shows the uplift of water level in basin), *19* — palaeoecological conditions according to mollusc data (F — freshwater basin, B — brackish basin), *20* — optically stimulated luminescence (OSL) date, years BP; radiocarbon date, conv. ^{14}C years BP: *21* — point sample, *22* — sample from interval; symbols of chronozones: YD — Younger Dryas, PB — Pre-Boreal, BO — Boreal, AT — Atlantic (AT_1 — Early Atlantic, AT_2 — Late Atlantic), SB — Sub-Boreal (SB_1 — Early Sub-Boreal, SB_2 — Late Sub-Boreal), SA — Sub-Atlantic; symbols of correlated layers: L_1, L_2, and L_3 — sediment complexes of the first, second and third Littorina Sea transgressions, PL — sediment complex of the Post-Littorina Sea transgression

Optically stimulated luminescence (OSL) dating. Age determination of sediments of 16 boreholes and 4 outcrops was carried out at the Institute of Geology of Tallinn Technological University (by G. Hütt, A. Molodkov). Due to big bias, the results of OSL dating have only subsidiary meaning for stratigraphic correlation of borehole sections (Bitinas *et al*., 2000, 2001). Generally, it helped to identify the dependence of sandy deposits of basin terraces (without organic layers suitable for radiocarbon dating) for Littorina Sea or Baltic Ice Lake in a few problematic areas. In some borehole sections this method has also been used for section separation into sediments of Littorina Sea and Post-Littorina Sea (Fig. 2, borehole 165).

Lithological investigations. The granular composition of the major part of the drilled borehole sections has been determined. It enabled to make the detailed examination of sediment sequences (to identify the transgressive and regressive sequences of sediments) for reconstruction of sea level fluctuations.

Interpretation of aerophotoimages. In order to detect the ancient coastlines onshore of the Baltic Sea, the aerial photographs taken in 1958 (scale 1:17 000), 1973 (scale 1:18 750) and in 1993 (scale 1:21 400) as well as a space panchromatic orthophoto digital map of 1993 (M 1:50 000) were interpreted.

Complex analysis of the results of investigations enabled to separate Littorina Sea sediments into the sediment complexes and to correlate them (Figs. 2, 3). The Littorina Sea shoreline displacement curve on the Lithuanian Coast (Fig. 4) was based generally on the radiocarbon dates of sediments formed in different conditions of sedimentation (freshwater gyttja, lagoonal gyttja, marine mollusc shells, peat).

LITTORINA SEA SEDIMENTS AND PALAEOGEOGRAPHY

Results of geochronological, palaeobotanic, palaeontological analysis and examination of sediment sequences brought to the conclusion that water level of the Littorina Sea (Atlantic and Early Subboreal chronozones) was unstable: it is possible to separate sediment complexes of a few transgressions and regressions (Fig. 2 and 3). In a few sections these sediment complexes are separated by peat layers that obviously indicate the sea level dropping (Fig. 2 and 3, boreholes 18/3, 19, 20/1, 91, 52, 165). In some cases it is possible to recognise the sea level fluctuations only according to the data of diatom analysis (Fig. 2, borehole 20/1). Generally, it confirms the position of former investigations that during the Littorina Sea stage there were three transgressions and regressions (Kabailienė, 1998, 1999). The new data enabled to detect their time and sea level fluctuations more precisely.

The Littorina Sea was initiated by erosion of the outlet due to eustatic sea level rise submerged Store Belt Strait and shallower Öresund Strait. It happened, according to different authors, around 8500–8000 conv. ^{14}C years BP (Berglund, 1964; Krog, 1979). The sediment complex of the first Littorina Sea transgression was detected at the altitudes of –6 ÷ –8 metres in the northern part of the Lithuanian Cost (Fig. 3, geol. profile I–I'), at –4 ÷ –5 metres in the central part (Fig. 3, geol. profile II–II') and below –13 metres in the Kuršių Nerija Spit (Fig. 2, borehole 28/1). It is difficult to establish precisely the coastline positions of the first Littorina Sea transgression because they were destroyed and buried during the latest transgressions, but they did not exceed approximately –2 ÷ –4 m a.s.l. (Fig. 4, L_1). After the first transgression, the water level dropped (about 7900–7800 conv. ^{14}C years BP) at least up to –13 metres a.s.l.: the freshwater carbonaceous gyttja was formed above this level in the Kuršių Nerija Spit (Fig. 2, borehole 28/1).

The sediment complex of the second (maximal) Littorina Sea transgression has been detected from 10 m a.s.l. in the northern part of Lithuanian Coast (Fig. 3, geol. profile I–I'), until 1–2 m a.s.l. in the southern one. The coastal position during this transgression in the central part (as well as during previous and latest transgressions) is problematic because of existing of steep cliff (Fig. 3, geol. profile II–II'). The second Littorina Sea transgression manifested very sharply at approximately 6200–5900 conv. ^{14}C years BP (Fig. 4, L_2). The water level subsidence was not equal and had some recessions; it is possible to observe a few recessional coastlines and terraces near Kintai settlement (Fig. 1). It is problematic to establish the lowest water level of this regression. According to the peat layers that started to form after the water level subsidenced in

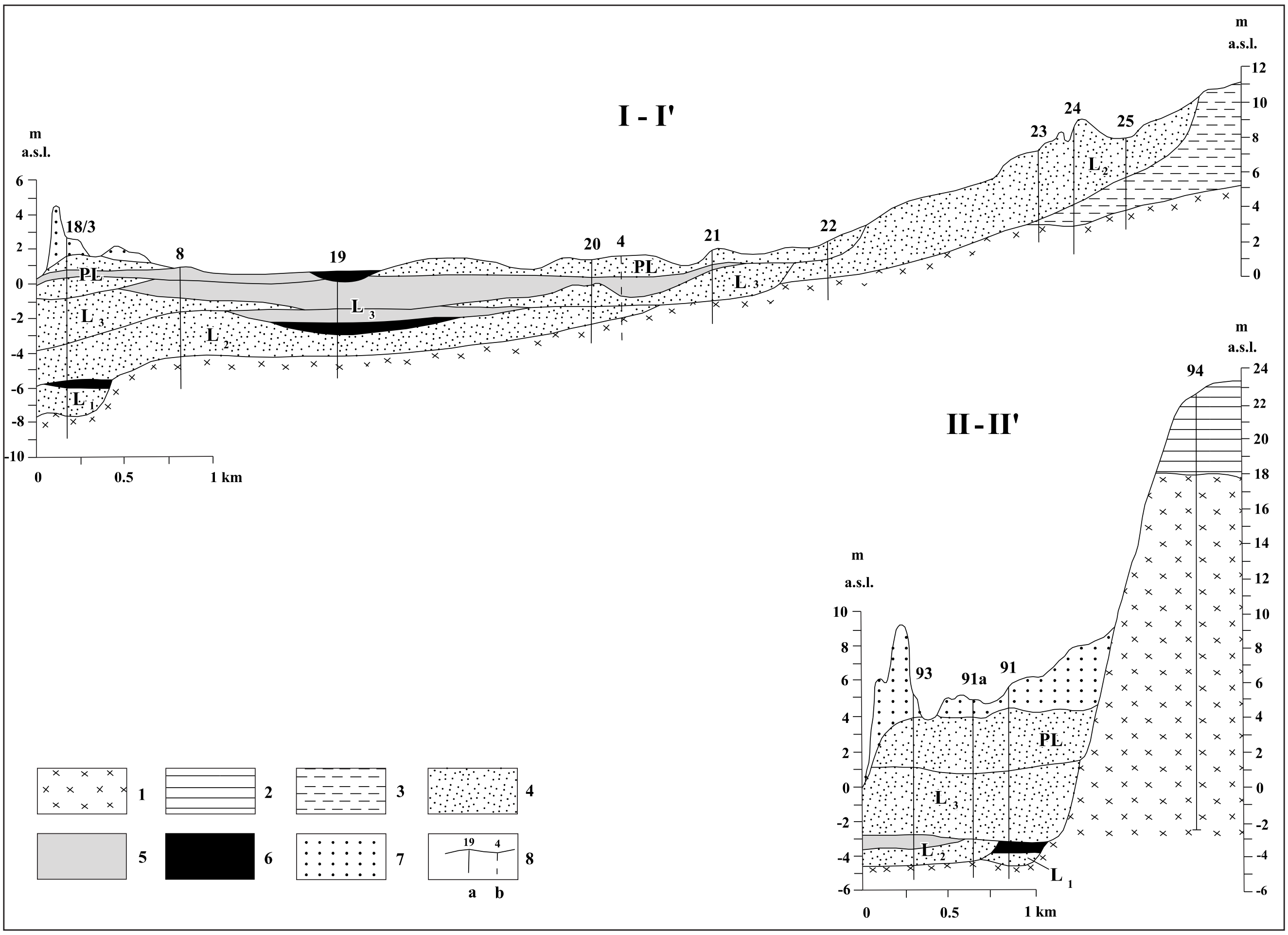

Fig. 3. Littorina Sea sediment complexes in the northern (geological profile I–I') and central (II–II") part of the Lithuanian Coast

1 — till, *2* — glaciolacustrine sediments, *3* — sediments of the Baltic Ice Lake, *4* — marine sediments, *5* — lagoonal gyttja, *6* — peat, *7* — present aeolian deposits; *8* — boreholes (a — on the line of geological profile, b — near the profile) and their numbers; sediments of Littorina Sea transgressions: L_1 — the first, L_2 — the second (maximal), L_3 — the third; PL — Post-Littorina Sea sediments

the southern part of Lithuanian Coast, it was lower than –5 m a.s.l. (Fig. 2, boreholes 51, 52).

The sediments of the third Littorina Sea transgression overlap the sediments of the previous transgression in some places only partly (Fig. 3, geol. profile I–I'). This sea level rising has not been so powerful and did not exceed 2–3 metres (Fig. 4, L_3). In the southern part, the most powerful peat-lands have not been submerged by water (Fig. 2, boreholes 3, 51, 52). The third transgression could start at about 5300 and continue until 4100–4000 conv. ^{14}C years BP. There are not enough data on subsidence of water level after this transgression. It is possible to conclude that a significant part of the Kuršių Nerija Spit has been formed at this time (it is confirmed by the dated archaeological findings). Due to this reason the coastal zone of the Littorina Sea was dual: it was an open coast sea with brackish water in the northern and central part of the region and a semiclosed freshwater lagoon (with temporary influence of brackish water) in the southern part.

Some investigators (Gudelis, 1997; Kabailienė, 1998, 1999) noted at least two sea water level fluctuations during Post-Littorina time on the Lithuanian Coast. Our data also confirm this point of view. Post-Littorina transgression manifested approximately at 3600–3400 conv. ^{14}C years BP and was a bit more powerful than the last Littorina Sea transgression (Fig. 4, PL). The sea level subsidence, as well as later maximal Littorina Sea transgression, has recessional character. It is possible to observe weakly expressed coastlines near the Lithuanian border with Latvia. Later, probably between 2200 and 2000 conv. ^{14}C years BP, it was a small sea level fluctuation. In some areas lagoonal gyttja are covered by sandy deposits (Fig. 2, boreholes 18/3, 51).

COASTLINE POSITIONS, GLACIOISOSTATIC REBOUND AND NEOTECTONIC MOVEMENTS

The present-day positions of shorelines of Littorina Sea are at various levels in different parts of Lithuanian Coast due to glacioizostatic rebound. According to V. Gudelis (1997), the "axis" of crustal tilting of the Littorina maximum shoreline crosses the central part (Lithuanian half) of Kuršių Nerija Spit. Our data (Fig. 4) show a big difference of Littorina Sea coastlines (especially the maximal (L_2) transgression) between northern and southern parts of Lithuanian Cost (more than 5 metres). On the other hand, the consequent trend of coastline from south to north, as shown in some publications (Gudelis, 1979, 1997), does not exist. It was observed that when the coastline crosses a latitudinal fault (or so-called "neotectonically active zone") the altitude of the coastline often suddenly changes (arises or falls down). For example, such "steps" with amplitude up to 2 metres of maximal Littorina coastline are observed at Palanga town and at the Šventoji River mouth area (Fig. 1). In the southern part of Lithuanian Coast the similar "step" has been detected in the vicinities of Priekulė: while northwards the coastline of Baltic Ice Lake is higher than the Littorina Sea one, to the south this coastline is sharply falling and is covered by Littorina Sea sediments. It is obvious that oscillatory neotectonic movements of Earth crust blocks had a significant influence on the development of Littorina Sea as well as on other Baltic basins during Late Glacial and Holocene.

According to our opinion, the character of shoreline displacement curve (Fig. 4) shows that during the existence of Littorina and Post-Littorina Seas the northern part of Lithuanian Coast have been generally affected by intensive uplift, while the southern part

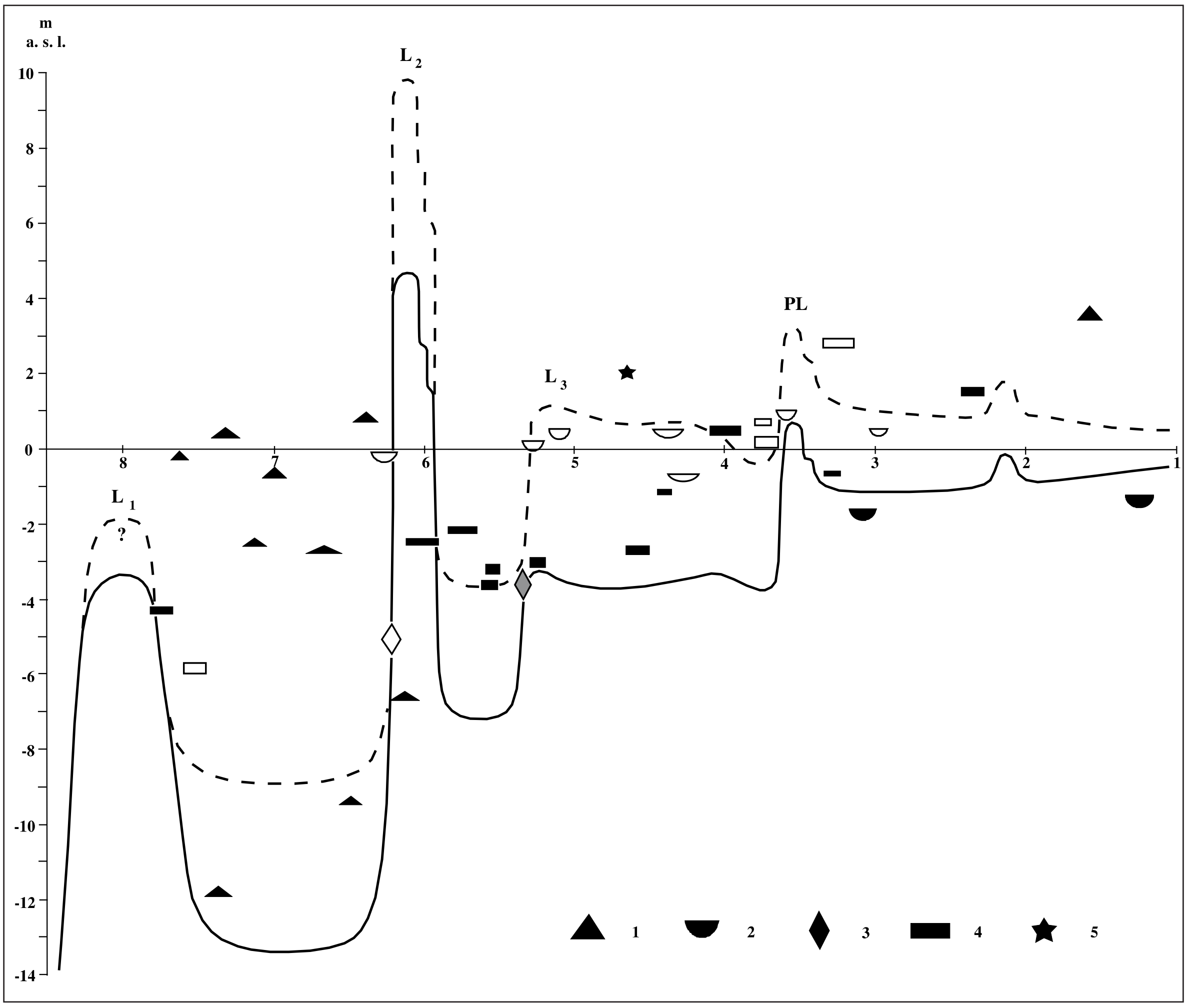

Fig. 4. Shoreline displacement curve for the northern (dashed line) and southern (solid line) part of the Lithuanian Coast (without correction on the glacioisostatic rebound); on the x-axis indicated conv. ^{14}C ka BP

Objects of radiocarbon dating: *1* — freshwater gyttja, *2* — lagoonal gyttja, *3* — peat, *4* — mollusc shells, *5* — archaeological findings; colour of sign indicated position of object on the Lithuanian Coast: non-coloured — in the northern part, grey — in the central part, black — in the southern part; L_1, L_2 and L_3 — the first, second and third Littorina Sea transgressions, PL — Post-Littorina Sea transgression has experienced sinking. Only from the third Littorina Sea transgression in the southern part of Lithuanian Coast, sinking has been changed by stabilisation, and lately, during Post-Littorina Sea stage, it was changed by a relatively slow uplift.

The shoreline displacement curve of Lithuanian Cost for the period of 8000–1000 conv. ^{14}C years BP (Fig. 4) is generally in good correlation (except details) with similar reconstructions in the neighbouring Baltic regions, as Rügen Island (Schumacher, Bayerl, 1999; Schumacher, 2002) as well as with curves of relative sea level changes of Southern Baltic (Uścinowicz, 2000; Lampe, 2002).

CONCLUSIONS

Detailed complex analysis of borehole sections of Lithuanian Maritime region confirm that there were three Littorina Sea transgressions at the Lithuanian Coast: the first manifested approximately at 8500–7800 conv. ^{14}C years BP, the second (maximal) — at 6200–5900 and the third — at 5300–4000 conv. ^{14}C years BP. The Post-Littorina Sea maximum was at about 3600–3400 conv. ^{14}C years BP, minor sea level uplift at probably between 2200 and 2000 conv. ^{14}C years BP was detected as well.

The present-day positions of shorelines of Littorina Sea as well as other Baltic basins are displaced at separate altitudes in different parts of Lithuanian Coast not only due to glacio-isostatic rebound but also due to oscillatory neotectonic movements of Earth crust blocks that were active during Late Glacial and Holocene. These movements operated in background of glaciotectonic rebound of the whole Lithuanian Maritime region.

The reconstruction of the eustatic curve for the Lithuanian Coast of Baltic is problematic due to above mentioned complicated neotectonic movements of the Earth crust blocks. It could be carried out only in future after the more detailed investigations including drilling of additional boreholes and complex investigations of their sections.

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