THE LITTORINA SEA AT THE LITHUANIAN MARITIME REGION

Albertas BITINAS¹, Aldona DAMUŠYTÉ¹

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 ¹⁴C years BP, the second (maximal) — in 6200–5900 and the third — in 5300–4000 conv. ¹⁴C years BP. The Post-Littorina Sea maximum was in about 3600–3400 conv. ¹⁴C 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, Rupliūnaitė, 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.

¹ Geological Survey of Lithuania, 35 S. Konarskio St., LT-2600 Vilnius, Lithuania; e-mails: albertas.bitinas@lgt.lt; aldona.damusyte@lgt.lt
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 palaeontologically and palaeobotanically 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. Usaitienė) 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. Palaeontologically the molluscs were analysed at the Geological Survey of Lithuania (by A. Damušytė). Ac-

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
The Littorina Sea at the Lithuanian Maritime region

Table 1

Results of radiocarbon (14C) dating

<table>
<thead>
<tr>
<th>Number of borehole</th>
<th>Altitude (m a.s.l.)</th>
<th>Latitude N</th>
<th>Longitude E</th>
<th>Investigated interval (depth, cm)</th>
<th>Conventional radiocarbon (14C) age in years BP (calibrated data)</th>
<th>Dated material</th>
<th>Laboratory code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.0</td>
<td>52°29'34&quot; 21°16'16&quot;</td>
<td>144 – 146</td>
<td>2345±70 (BC 445–380)</td>
<td>Peat</td>
<td>T-10958</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.7</td>
<td>55°29'42&quot; 21°17'33&quot;</td>
<td>127 – 129</td>
<td>3295±50 (BC 1650–1525)</td>
<td>Peat</td>
<td>T-10961</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.2</td>
<td>56°03'10&quot; 21°05'33&quot;</td>
<td>190 – 200</td>
<td>4285±95 (BC 3025–2710)</td>
<td>Gyttja</td>
<td>T-10965</td>
<td></td>
</tr>
<tr>
<td>4B</td>
<td>2.1</td>
<td>56°03'51&quot; 21°03'59&quot;</td>
<td>160 – 170</td>
<td>4370±100</td>
<td>Gyttja</td>
<td>Vs-1199</td>
<td></td>
</tr>
<tr>
<td>18/3</td>
<td>2.5</td>
<td>56°03'30&quot; 21°04'18&quot;</td>
<td>200 – 209</td>
<td>5270±80</td>
<td>Gyttja</td>
<td>Vs-1200</td>
<td></td>
</tr>
<tr>
<td>28/1</td>
<td>0.5</td>
<td>55°17'42&quot; 20°59'56&quot;</td>
<td>7000 – 12400</td>
<td>6130±105 (BC 5089–4760)</td>
<td>Carbonaceous gyttja</td>
<td>Vs-1159</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>8.0</td>
<td>55°37'30&quot; 21°18'02&quot;</td>
<td>420 – 460</td>
<td>1380±65 (AD 420–553)</td>
<td>Silty gyttja</td>
<td>Vs-1172</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>6.3</td>
<td>55°35'30&quot; 21°18'02&quot;</td>
<td>870 – 890</td>
<td>7120±90 (BC 6027–5920)</td>
<td>Gyttja</td>
<td>Vs-1174</td>
<td></td>
</tr>
<tr>
<td>49B</td>
<td>1.4</td>
<td>55°57'36&quot; 21°04'12&quot;</td>
<td>60 – 70</td>
<td>3760±50</td>
<td>Peat</td>
<td>Vs-1289</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>1.0</td>
<td>55°17'40&quot; 21°23'22&quot;</td>
<td>230 – 250</td>
<td>1220±55 (AD 768–886)</td>
<td>Gyttja</td>
<td>Vs-1171</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>– 0.4</td>
<td>55°19’00’ 21°24’34”</td>
<td>250 – 270</td>
<td>5260±45 (BC 4086–3992)</td>
<td>Peat</td>
<td>Vs-1177</td>
<td></td>
</tr>
<tr>
<td>52B</td>
<td>1.2</td>
<td>55°57'06&quot; 21°04'02&quot;</td>
<td>90 – 120</td>
<td>3730±70</td>
<td>Peat</td>
<td>Vs-1282</td>
<td></td>
</tr>
<tr>
<td>70B</td>
<td>3.7</td>
<td>55°55'32&quot; 21°03'31&quot;</td>
<td>275 – 290</td>
<td>3600±40</td>
<td>Peat</td>
<td>Vs-1290</td>
<td></td>
</tr>
<tr>
<td>9a</td>
<td>5.0</td>
<td>55°45'25&quot; 21°05'22&quot;</td>
<td>820 – 930</td>
<td>5353±63</td>
<td>Mollusc</td>
<td>Tln-2069</td>
<td></td>
</tr>
<tr>
<td>917</td>
<td>3.9</td>
<td>55°51'13&quot; 21°04'53&quot;</td>
<td>105 – 120</td>
<td>3255±100</td>
<td>Peat</td>
<td>Vs-1010</td>
<td></td>
</tr>
</tbody>
</table>

* 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 (δ18O) of Litorina Sea molluscs of 3 boreholes (key-sections) were determined by R. Vaišnā, Institute of Geology of Tallinn Technical University, Estonia). The measured δ18O 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 (Būtinas et al., 2000).

Radiocarbon (14C) dating. The sediments related to Littorina Sea stage and younger were dated in 15 boreholes (Table 1). Radiocarbon (14C) 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, laboratory code Vs-), and Institute of Geology of Tallinn Technical 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 14C years) have been used in this paper. Two radiocarbon data of archaeological findings in Kuršiškės are used for palaeogeographic reconstructions as well: (Vs-321) 4630 ±120 conv. 14C years BP (3023–2751 years BC) and (Vs-631) 4620 ±110 conv. 14C years BP (3002–2750 years BC) (Rimantienė, 1999).
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 SeaShoreline 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 (Kabaliene, 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. 14C years BP (Berglund, 1964; Krog, 1979). The sediment complex of the first Littorina Sea transgression was detected at the altitudes of −6 to −8 metres in the northern part of the Lithuanian Coast (Fig. 3, geol. profile I–I’), at −4 to −5 metres in the central part (Fig. 3, geol. profile II–II’) and below −13 metres in the Kuršiu 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 to −4 m a.s.l. (Fig. 4, L1). After the first transgression, the water level dropped (about 7900–7800 conv. 14C years BP) at least up to −13 metres a.s.l.: the freshwater carbonaceous gyttja was formed above this level in the Kuršiu 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 to 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 existence of steep cliff (Fig. 3, geol. profile II–II’). The second Littorina Sea transgression manifested very sharply at approximately 6200–5900 conv. 14C years BP (Fig. 4, L2). 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 subsided in
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, L3). 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.14C 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. 14C 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. 14C 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).

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: L₁ — the first, L₂ — the second (maximal), L₃ — the third; PL — Post-Littorina Sea sediments
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 glacioisostatic rebound. According to V. Gudelis (1997), the “axis” of crustal tilting of the Littorina maximum shoreline crosses the central part (Lithuanian half) of Kurši/Nerija Spit. Our data (Fig. 4) show a big difference of Littorina Sea coastlines (especially the maximal (L2) 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. 14C 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; L1, L2 and L3 — 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 Coast 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 (Ušćinowicz, 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 glacio-tectonic rebound of the whole Lithuanian Maritime region.

The shoreline displacement curve of 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.

Acknowledgements. The authors are very grateful to their colleagues — geologists and technicians of Quaternary Geology Division of Geological Survey of Lithuania — with whom they worked in the Lithuanian Maritime region, who helped in the preparation and layout of graphical material for this paper. We give our cordial thanks to the whole crew of scientists of different countries and different geological institutions whose analyses and datings were of great importance for our work.

REFERENCES


KABAILIENĖ M., 1959 — Development of Baltic Maritime of Lithuania and Southern Latvia according to data of diatom investigations [in Lithuanian with Russian and Germany summaries]. Geology, Geography, 10, 2: 175–214.

KABAILIENĖ M., 1967 — The development of the Spit of Kuršių Nerija and the Kuršių Marių Bay [in Russian with Lithuanian and English summaries]. In: On some problems of geology and

KABAILIENĖ M., 1998 — Vegetation history and climate changes in Lithuania during the Late Glacial and Holocene, according to pollen and diatom data. *PACT*, 54: 13–30.


