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POST-GLACIAL GEOLOGICAL HISTORY OF THE LITHUANIAN COASTAL AREA

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VILNIAUS UNIVERSITETAS
GAMTOS TYRIMŲ CENTRAS
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INTRODUCTION

From a geological point of view, the south-eastern periphery of the Baltic Sea – the Lithuanian coastal area – is a region with a complicated relief formed by different geological processes. The last – Upper Nemunas (Weichselian) – continental glaciation was the main factor in the formation of the upper part of the Quaternary deposits. The Baltic Sea is an epicontinental sea separated from the Atlantic Ocean by the Scandinavian Peninsula in the NW and by Jutland in the SE. Its post-glacial history was not only influenced by the world ocean and climate fluctuations, but also by neotectonic events: subsidence and uplift of the Earth crust or oscillatory movements their blocks, and glacio-isostasy. The influence of the Baltic Sea on the Lithuanian coastal area has been felt since the Nemunas (Weichselian) Late Glacial Substage when, as a result of increasing precipitation and glacial melting, the global sea-level rose. Although it is situated deep in the continental area, the Baltic Sea has undergone fluctuations of water level, temperature and salinity. The Lithuanian coastal area bears the marks of these fluctuations.

Research project. The Lithuanian coastal area represents a specific region of great economic and recreational importance which is very sensitive both to natural changes and changes arising from human invasion. For this reason, the knowledge of the geological structure and geological history of the region, as well as an understanding of the geological processes operating, have been and undoubtedly will continue to be of considerable relevance to society.

This research has been focused on a few tens of kilometres of the wide continental coastal sector, the northern parts of the Curonian Spit coast and the Curonian Lagoonal area (within Lithuanian territory). The reconstruction of the Baltic sea-level fluctuations during postglacial time has also been based on the examination of the results of tree remains (stumps) recently uncovered on the Baltic seashore.

The examination of macro- and micro-remains of fossil plants and animals found in the deposits has played an especially important role in the reconstruction of the palaeoecological conditions in the Baltic Sea basins. The remains of molluscs and diatoms are of particular importance in this context. Pollen and spores are also important for the evaluation of the palaeoclimatic conditions. The importance of molluscs for reconstruction of palaeoecological conditions in the Baltic Sea basins has been proved and reported by many researchers who examined mollusc remains in Estonia (Kessel 1958; Кессел 1985, Tavast 2000), Poland (Skompski 1991, 1996), Denmark (Petersen 1987, 2004), Germany (Glöer, Meier-Brook 1998), Russia (Даниловский 1955) and other circum-Baltic Sea countries. Scientific publications not only contain descriptions of the species composition of molluscs but also the evaluations of palaeoclimatic conditions, based on the investigation of molluscan remains, and reconstructions of the natural environment of the basins. In Lithuania, investigations of this kind have not yet been carried out. For this reason, investigation of fossil remains as indicators of ecological conditions of palaeobasins comprises an important part of the present research.

Practical importance. The new abundant geological material has been accumulated by the author during individual field investigations. Employment of absolute dating of deposits and fossil molluscs, characterisation of fossil molluscs, recent results of palaeobotanical investigations and other rich geological information, have allowed determination of the shoreline fluctuations of the Baltic Sea palaeobasins through the Late Glacial and Holocene. From this work a series of palaeogeographical reconstructions, in the form of sketch maps of Baltic Sea-stages and approaching the post-glacial geological history of the Lithuanian coastal area from essentially new positions have been compiled.

Main objective. The main objective of the present research was the reconstruction of the geological history of the Baltic Sea coastal area beginning in the Late Glacial up to historical times using the newest research data. The following **main tasks** have been undertaken: 1) stratigraphical classification of Late Glacial and Holocene coastal deposits based on molluscan investigation evidence and comparison of individual observations with that of diatom and pollen analysis obtained by other authors; 2) palaeosedimentological analysis of borehole sections to attempt to distinguish between transgressive and regressive sequences of deposits; 3) specification of the water-level fluctuations in the Baltic Sea stages based on the latest information available; 4) specification of the history of the Baltic Sea palaeobasins through the Late Glacial and Holocene and the compilation of palaeogeographical schemes for these basins on the Lithuanian coastal area; 5) elaboration of the geological history of Curonian Spit, Curonian Lagoon and Nemunas Delta. The solution of these tasks has allowed the formulation of the following defended statements:

– the proglacial lakes, the Baltic Ice Lake, the Litorina and Post-Litorina seas played a decisive role in the geological history of Lithuanian coastal area through the Late Glacial and Holocene;

– the Lithuanian coastal area contains deposits and landforms that represent three Litorina Sea transgressions (which took place approximately 8,300–8,000 (L_1), 7,500–7,000 (L_2) and 4,700–4,100 (L_3) years BP) and one Post-Litorina Sea transgression (3,700–2,400 years BP);

– the landscape was most strongly remodelled causing the thickest sediment stratum deposited during the second maximal Litorina Sea transgression (L_2). This event produced the greatest impact on the Lithuanian coastal area;

– the formation of the Curonian Spit started no later than 8,500–8,300 years BP during the transgression of Ancylus Lake or the first transgression of Litorina Sea (L_1), whereas the main geological–geomorphological features of the modern spit developed approximately 6,900–6,300 years BP, i.e. during the regression that followed the maximal transgression of Litorina Sea (L_2);

– during the Late Glacial, the fossil molluscs so far recovered from the Lithuanian coastal area only inhabited the local fresh-water bodies. However during the Holocene, they inhabited only the Litorina and Post-Litorina seas and their coastal water bodies;

– the present sector of the Nemunas Delta in Lithuania, including the Rusnė Island and the surrounding areas, emerged late in the Holocene, i.e. in historic times approximately 1,100 years ago.

Originality of the research. For the first time, the fossil molluscs of the Late Glacial and Holocene have been analysed and characterised. Based on the evidence obtained, the stratigraphical distribution of sediment sections has been determined. The geological material and results of absolute dating (by radiocarbon (^{14}C) and optically stimulated luminescence methods (OSL) collected from numerous sediment samples have served as the basis for the essential specification of the boundaries, age, genesis and palaeo-sedimentation conditions at different Baltic Sea development stages. New data concerning the formation and development of the Curonian Spit, the Curonian Lagoon and the Nemunas Delta have been obtained and systematised. For the first time, palaeogeographical schemes characterising the basins of the Baltic Sea in the Lithuanian coastal area have been compiled. Only the calibrated results of radiocarbon dating and dating by the optically stimulated luminescence method have been applied during this work. The time scale before present (BP) was used for dating the Baltic Sea stage-events.

The history of the present research. The research was begun in 1993. For some years, the author (working at the Lithuanian Geological Survey) participated in the implementation of large-scale (1:50,000) geological mapping of the Lithuanian coastal area. In 2002, she participated in the engineering geological mapping (at a scale 1:5,000) of the terrestrial and aquatic area of the Klaipėda port. In 2006, the author began her extra-mural doctoral studies at the Institute of Geology and Geography. The present research is based on the new geological information individually collected by the author during her participation in the mapping of the Baltic coastal area and through close cooperation with the specialists from Klaipėda University and researchers from the Vilnius University and Institute of Geology and Geography. It is also based on the evidence reported by other researchers. For the palaeogeographical schemes of the Baltic Sea stages and the reconstruction of post-glacial water-level fluctuations, 81 radiocarbon (^{14}C) dates and 104 absolute age dates, determined by the optically stimulated luminescence method (OSL), were used. Deposits from 4 outcrops and 79 boreholes have been analysed.

Presentation of the research work. Since 1994, the first presentation at a scientific conference, the author has reported the research results at twenty-nine international (in Byelorussia, Estonia, Spain, Italy, the USA, the UK, China, Latvia, Poland, Norway, France, Russia, Finland, the Ukraine, and Germany) and eleven Lithuanian scientific conferences. These presentations were made individually or jointly with co-authors. From these presentations, seventeen articles, including nine articles in periodicals included in the list of Web of Science of journals of the Institute of Scientific Information (ISI), have been published.

Extent and structure. This dissertation is composed of an introduction, six chapters, conclusions, a list of references (180 sources) and a list of the author's publications (66). The dissertation comprises 163 pages of text, 41 illustrations and 18 tables.

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1. SURVEY OF THE GEOLOGICAL INVESTIGATIONS

J. Schumann (1861), G. Berendt (1869), A. Tornquist (1910), H. von Wichdorff (1919) and E. Kraus (1925) were the first researchers to examine the Lithuanian coastal area. Their studies were devoted to the geological stucture of the coastal sedimentary rocks and bedding patterns of the deposits. Many research works have considered the formation of the Curonian Spit and its geological structure. Already in the 19th century, G. Berendt (1869) had proved the importance of aeolian processes in the coastal formation. At the same time, N. Sokolov (1896) developed the main principles of coastal dune formation and described their environmental importance.

In 1954, Ch. Brockmann published a monograph containing the results of investigations carried out before World War I based upon diatom analysis of Litorina and Ancylus Lake sediments from boreholes collected in the southern part of the Curonian Lagoon and Spit.

The Lithuanian coastal area became an object of particular interest in the second half of the 20th century. During this period many research works were devoted to the reconstruction of the palaeogeographical and palaeoecological situation at different development stages of the Baltic Sea (Gudelis 1955, 1979, 1993, 1997, 1998; Gudelis 1989-1990; Gudelis, Klimavičienė 1982; Kabailienė 1959a, 1959b, 1996, 1997a, 1997b, 1999; Кабайлене 1967, Микалаускас, Гайгалас 1973; Gaigalas 1996). Other researchers focused on the analysis of different issues related to the stratigraphy and geological structure of the coastal Quaternary deposits (Кондратене 1971, Kondratienė 1976; Kondratienė, Damušytė 2009; Гайгалас, Саладжюс 1974; Дицявичене, Гялумбаускайте 1975; Репечка 1980; Малинаускас и др. 1986; Bitinas *et al.* 1999, 2000b, 2001), the last deglaciation and formation patterns of recent landscape (Basalykas 1965, 1977; Басаликас 1961, 1967, 1969; Česnulevičius 1993; Микалаускас и др. 1986).

The morphogenesis and morphodynamics of the Curonian Spit coast were investigated by R. Žaromskis (1989-1990), J. Dolotov, V. Kirlys (Долотов и др. 1982). L. Ž. Gelumbauskaite and J. Šečkus (Gelumbauskaitė 2000, 2002, 2003, 2009; Gelumbauskaitė, Gaidelytė 2003; Gelumbauskaitė, Šečkus 2005) applied geophysical, lithostratigraphical and geomorphological methods in their studies of Curonian Lagoon and Baltic Sea coasts during the Nemunas Late Glacial and Holocene.

The early studies of the Lithuanian coastal area in the second half of the 20th century were associated with the research work of V. Gudelis and M. Kabailienė. Since 1959, V. Gudelis has published a series of reports concerning the main stages of coastal geological development during the Late Glacial and Holocene and coastal relief. This author also touched upon the issues of neotectonic activity in the region under consideration. A scheme of the shoreline positions at all development stages of the Baltic Sea, indicating a strong impact of glacioisostatic activity on the coastal region through the Late Glacial and Holocene, was compiled (Gudelis 1979, Gudelis 1989–1990; Gudelis, Michaliukaitė 1976; Gudelis, Klimavičienė 1993).

M. Kabailienė not only investigated the development patterns of the Curonian Spit (Kabailienė 1959b, 1997b; Кабайлене 1967; Kabailienė, Rimantienė 1996) but also the history of Lithuanian coastal region in general. She presented one of the first studies of pollen assemblages from the sediments of Lithuanian and South Latvian coasts and Russian coasts of Curonian Lagoon and Curonian Spit as well as of vegetation in the eastern coast of the Baltic Sea in Late Glacial and Holocene in 1959 (Kabailienė 1959a). This pioneering study contains a detailed description of pollen assemblages of the sediments of Svencelė, Tyrai and Pajūris bogs in the Lithuanian coastal region and Nida and Kirbė bogs and Papė Lake in the southern part of the Latvian coastal region. In addition, M. Kabailienė analysed sediment sections of the boreholes drilled in the Danė River valley in Klaipėda, at different points of Curonian Spit (Nida and Juodkrantė settlements), on the Russian coast (Morskoje and Rybačij settlements) and in the southern part of the Curonian Spit. She also investigated sediment sections in the outcrops on the banks of Rąžė River and Ventės Ragas Cape. She used the pollen analytical data for dating sediment sequences and determining the development patterns of coastal vegetation. In the same year, M. Kabailienė (1959b) published the first results of diatom analysis of sediments from the Baltic palaeobasins. She also distinguished and described the diatom complexes in the sediments of the Baltic Ice Lake and Ancylus Lake and Litorina and Post-Litorina seas.

The archaeological excavations in the Pajūris bog (in the environs of Šventoji settlement), that were initiated by R. Rimantienė in the 1970s and lasted for more than 20 years, also provided an impetus for palaeobotanical investigations of the Lithuanian coastal region. As many as 42 settlements containing abundant in middle and late Neolithic artefacts were investigated. The pollen from the cultural layers of these settlements were analysed by V. Dvareckas, M. Kabailienė, G. Kleimenova, R. Kunskas, N. Savukynienė and others (Rimantienė 1979; Клейменова и др. 1992). The finds were dated for the first time using the radiocarbon method (Rimantienė 1996, 1999, 2005).

During the geological mapping (in 1997–2000) at a scale 1:50,000, many new boreholes were drilled in the Lithuanian coastal region. Their sediments were analysed for their pollen content by M. Kabailienė, O. Kondratienė, M. Stančikaitė and D. Ūsaitytė and for diatoms by M. Kabailienė and G. Vaikutienė. The results of these investigations are given in geological reports (Bitinas ir kt. 1997, 2000a; Geological Foundation of the Lithuanian Geological Survey); some of which are included in scientific articles (Kabailienė, Stančikaitė 1998; Stančikaitė, Kabailienė 1998; Šinkūnas e*t al.* 1999; Bitinas *et al.* 2000b, 2002; and others).

In spite of these detailed investigations, fossil molluscs in the coastal sediments had not received much attention from researchers. Only in 1960, did P. Šivickis characterise in detail the molluscs found in Lithuania. In his book ’Lietuvos moliuskai ir jų apibūdinimas’ (1960), he not only described the mollusc taxa found in country but also characterised their modern habitats. He pointed out that ’many mollusc shells are found in geological strata, in Quaternary strata in particular’. Noticing that ’the data about these molluscs are lacking in the Republic’, he expressed a hope that ’they will undoubtedly appear in the length of time’ (Šivickis 1960). In his book published in 1973, V. Gudelis (Гуделис 1973) he included a stratigraphical scheme of Estonian post-glacial deposits compiled by H. Kessel and A. Raukas (Кессел, Раукас 1967) which contained a list of dominant mollusc species in different Baltic Sea basins. In his 1998 monograph, Gudelis (1998) suggested that fossil molluscs should be linked to the Baltic palaeobasins. At the end of the 20th to the beginning of the 21st century, biologists from Klaipėda University thoroughly investigated the invasive species (and malacofauna) inhabiting the present Baltic Sea and Curonian Lagoonal waters (Daunys *et al.* 2006; Olenin 2005; Zaiko *et al.* 2009). Nevertheless, the molluscs that inhabited the Baltic palaeobasins had not yet received the attention they deserved. In other words, fossil molluscs in the Lithuanian coastal region had not been investigated.

Aeolian processes in the Lithuanian sea coast and in the Curonian Spit were actively investigated at the end of the 20th century (Kazakevičius 1989–1990; Morkūnaitė, Česnulevičius 1998; Žilinskas *et al.* 2001; and others).

A palaeogeographical reconstruction of the southern part of the Lithuanian coastal region is presented by V. Gudelis and V. Klimavičienė (1990b) and a reconstruction of the northern part is given by R. Kunskas (Rimantienė 2005). Many studies were devoted to the Ventės Ragas outcrop and its environs (Gudelis ir kt. 1989–1990). Yet these authors only confined themselves to palaeoreconstructions of discrete parts of the coast. A general scheme of palaeogeographical reconstructions of the Lithuanian coastal region was still lacking.

The curves of Baltic Sea water-level fluctuations in the Baltic Sea basins in Late Glacial and Holocene were made by V. Gudelis (1979), M. Kabailienė (1999, 2006) (Kabailienė, Rimantienė 1996), Ž. Gelumbauskaitė (2009; and others). To date the most detailed development scenario presented for the Curonian Spit and Lagoon was suggested by M. Kabailienė (Kabailienė 1997a, 1999, 2006; Кабайлене 1967).

There are numerous studies of the history of Nemunas Delta (Басаликас 1961; Kunskas 1974, 1996; Кунскас 1970; Červinskas, Kunskas 1982; Žaromskis 1999; and others). V. Gudelis and V. Klimavičienė have investigated the geomorphological and palaeogeographical features of Nemunas Delta especially thoroughly (Gudelis, Klimavičienė 1993; Gudelis ir kt. 1989–1990).

A detailed history of geological investigations of the South-East Baltic region during the Late Glacial and Holocene is given by J. Šečkus in his doctoral dissertation ’*Analysis of South-East Baltic Sea development by the methods of geological modelling*' (Šečkus 2009).

The Latvian coastal region is the least investigated section of the Baltic coastal regions. Although the first geological investigations of the Latvian coastal region were begun long ago and were associated with P. Rēvel‘ (1938), M. Galeniece‘ (1955), V. Ulst‘ (1957), E. Grinbergs‘ (1957), detailed studies were only carried out during the large-scale (1:50,000) geological mapping of the coastal zone and area of the Gulf of Riga in the 1970-80s. Based on the results obtained, a map of the Quaternary deposits in the Gulf of Riga was compiled and published in cooperation with Estonian researchers at the end of the 20th century (Segliņš, Kajak 1997). The investigation of fossil molluscs formed one of the interesting works from the early research period in the Latvian coastal region; the results were published in 1963. This article describes possibly the oldest fossil *Dreissena polymorpha* found in the sediments of the Baltic Ice Lake (Страуме 1963). In later years, spores and pollen in the Late Glacial and Holocene marine sediments in the Latvian coastal region were investigated by (Стелле и др. 1976), I. Jakubovska, L. Kalniņa, L. Kovaļenko (Segliņš 2001), whereas the majority of investigations of recent coastal geological processes were carried out by G. Eberhards and his collaborators (Eberhards *et al.* 2009). After surveying the research works on the Latvian coastal region one miss's detailed palaeogeographical reconstructions of the coastal zone and summary curves of water-level fluctuations in palaeobasins through the Late Glacial and Holocene.

The geological investigations of Baltic coastal area in the Kaliningrad Region of the Russian Federation, as in Lithuania, started with the studies by H. von Wichdorff (1919), Ch. Brockmann (1954) and others carried out at the end of the 19th to the beginning of the 20th century. This work only gained momentum in the second half of the 20th century. The results of these long-term investigations were synthesised in 1998 by A. Blazhchishin (Блажчишин 1998). The investigations of the Baltic coastal area in the Kaliningrad Region have become particularly active in the last ten years. Researchers from the Atlantic Branch of the Shirshov Institute of Oceanology (Russian Academy of Sciences), together with their colleagues from the All-Russian Institute of Geological Research, have focused their attention on recent coastal area geological processes. The results of these investigations have been presented in a few publications (Boldyrev 1981; Emelyanov 2002; Zhamoida *et al.* 2009), including the *Atlas of the Baltic Sea* (Atlas... 2010). Recently the researchers from the Lomonosov Moscow State University have also been engaged in investigations of the south-eastern Baltic lagoons and spits (Бадюкова и др. 2005, 2007, 2008).

The Estonian Baltic coastal region has been the most intensively investigated among the countries of the East Baltic Region. Here the works of H. Kessel and A. Raukas (Kessel 1958; Кессел 1985; Kessel, Raukas 1982; Кессел, Раукас 1984) devoted to the problems of development stages of the Baltic Sea can be mentioned. These studies contain reconstructions of palaeocoasts together with the results of investigations of fossil molluscs. These Estonian researchers emphasise dating of sediments and fossil molluscs by the methods of absolute geochronology. Many publications on the history of palaeobasins are based on dating carried out by G. Hütt (Königsonn *et al.* 1995; and others) and A. Molodkov (Raukas *et al.* 1996; and others). Among the recent publications on the issues of the Baltic Sea history can be mentioned the studies carried out under the supervision of A. Rosentau (Rosentau *et al.* 2009, 2010) and L. Saarse (Saarse *et al.* 2009). They contain the latest information on the water-level fluctuations in the Baltic Sea as well as reconstructions of the shorelines and the bathymetry of palaeobasins.

The Polish Baltic coastal region has most intensively investigated in the south-eastern Baltic region (Łęczyński *et al.* 2007; Miotk-Szpiganowicz *et al.* 2010; and others). In contrast to the Lithuanian and northern Baltic coastal territories, the Polish coastal region subsided during the Holocene. For this reason, the curves of water-level fluctuations from the Polish coastal region can hardly be correlated with those of Lithuanian coastal region. For this reason, the scale of neotectonic movements must be taken into consideration when comparing palaeoreconstructions.

2. METHODS

2.1. Field investigations

During field investigations, 79 boreholes were drilled (Figure 1, Table 1), 4 outcrops examined (Figure 1, Table 2) and samples for laboratory analysis collected from the water area of the Baltic Sea (Table 3). Based on the rich results of lithological

Table 1 Numbers and coordinates of investigated boreholes.

Serial number	**Number of borehole**	**Coordinates LKS 94**		**Serial number**	**Number of borehole**	**Coordinates LKS 94**	
		X	**Y**			**X**	**Y**
1	Nida-V	6133664	309201	41	26254	6168751	323375
2	3	6194965	315912	42	26259	6165156	329734
3	4	6218433	317839	43	26264	6152359	335741
4	49	6206924	316992	44	26265	6147549	326410
5	52	6205829	316749	45	26266	6147568	326692
6	70	6202747	310658	46	26267	6147618	327011
7	173	6133855	308050	47	26268	6148476	327238
8	177	6130770	499575	48	26269	6147158	329281
9	248	6153633	506171	49	26270	6131869	334093
10	294	6168472	506673	50	26271	6134295	335455
11	305	6173160	506333	51	26395	6195153	316068
12	917	6194753	317111	52	26396	6218078	320905
13	24799	6216991	318780	53	26433	6129726	328606
14	24802	6212625	318041	54	35256	6180687	317911
15	24816	6217664	317509	55	35257	6180054	317681
16	24840	6217551	322407	56	35259	6180826	318103
17	24847	6194814	316750	57	35261	6179959	317784
18	24893	6184083	317204	58	35261c	6179678	317660
19	24896	6183966	317025	59	35263	6179824	317891
20	24966	6200301	324826	60	36856	6174880	319760
21	24969	6174330	317932	61	36858	6174622	319676
22	26217	6154225	327446	62	36859	6174348	319555
23	26219	6154419	328807	63	36860	6174138	319465
24	26221	6135959	318258	64	36864	6173958	319469
25	26222	6134925	323123	65	36865	6173816	319477
26	26225	6135538	320977	66	36884	6171776	320672
27	26226	6153468	320825	67	36896	6171674	322245
28	26227	6153529	323921	68	36903	6174469	319772
29	26235	6160285	327632	69	36904	6174545	319960
30	26236	6159010	325422	70	36927	6171859	321090
31	26238	6158511	330266	71	39637	6174299	319473
32	26239	6139846	328645	72	36938	6174239	319333
33	26241	6142165	336893	73	39648	6171879	321001
34	26243	6134076	328192	74	45476	6171854	320862
35	26244	6138575	322423	75	46776	6214855	317538
36	26245	6136544	309510	76	46810	6214576	317554
37	26246	6132930	309301	77	46823	6214447	317526
38	26248	6153822	316022	78	46829	6214408	317750
39	26249	6145980	315500	79	46842	6214139	317708
40	26253	6168864	329896				

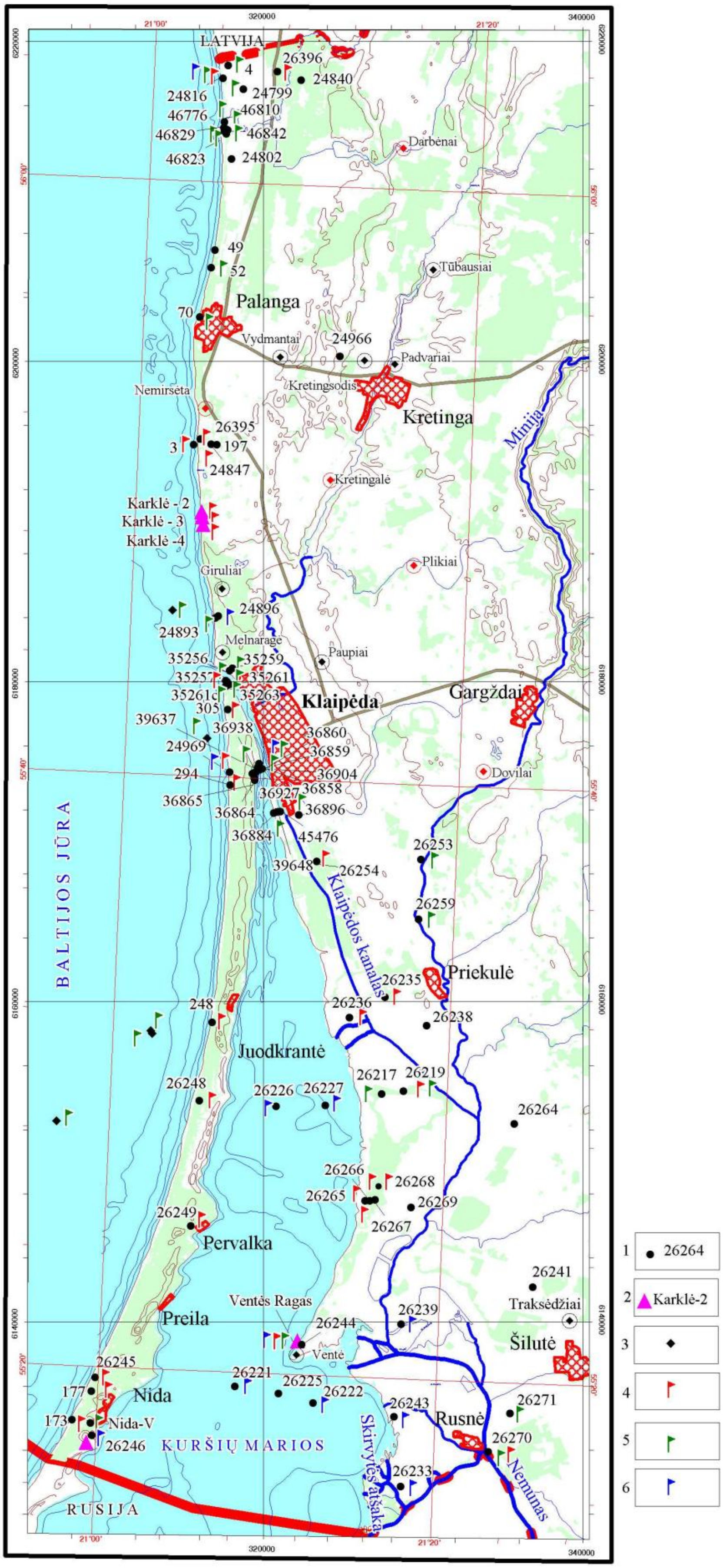


Figure 1 Map of factual data. 1 – borehole and its number, 2 – outcrop, 3 – sampling points in the Baltic Sea water area, 4 – dating by optically stimulated luminescence (OSL) method, 5 – dating by radiocarbon (^{14}C) method, 6 – investigation of fossil molluscs.

Table 2 Names and coordinates of investigated outcrops.

Serial number	Outcrop	Coordinates LKS 94	
		X	Y
1	Karklė-2	6190476	316145
2	Karklė-3	6190201	316166
3	Karklė-4	6189677	316216
4	Ventės Ragas	6140777	323597

Table 3 Coordinates of find points of tree stumps and gyttja on the bottom of Baltic Sea water area.

Serial number	Find point	Coordinates LKS 94	
		X	Y
1	Melnragė	6184467	314988
2	Juodkrantė/1	6158040	313057
3	Juodkrantė/2	6158193	312961
4	Smiltynė	6176475	316482
5	J46	6152559	307072

investigations, the sediments from the boreholes and outcrops were described following the legends of geological and geomorphological maps (1:50,000) developed at the Lithuanian Geological Survey (Lietuvos kvartero ... 2007).

2.2. Fossil molluscs investigations

Well preserved fossil molluscs were found in Būtingė, Melnragė and Nida environs, in Smiltynė, Ventės Ragas Cape and the Nemunas Delta.

Sediment samples for isolation of fossil molluscs were taken directly during the process of drilling. Helical drilling of boreholes 168 mm in diameter, a limited amount of fossil molluscs in the vertical section of sediments determined that one sample of fossil molluscs included the whole sediment interval containing them (except in a few cases). In the laboratory, fossil molluscs were selected in two ways: by sieving (using a mesh diameter up to 1 mm) or by exposing sediments to 10% sodium pyrophosphate ($Na_5P_3O_{10}$) solution for isolation of water insoluble mollusc shells and valves. The volume of sediments taken from the drill cores was calculated using formula $V = \pi r^2 h$, where *r* is the radius of the borehole (m) and *h* is sampling interval (m). Fossil mollusc-bearing samples from the outcrops were weighed.

Molluscs of the class Bivalvia have shells composed of two valves. Therefore, in order to avoid over-estimation of the results (comparing with snails – molluscs of the class Gastropoda) the number of the uncovered valves was divided by two, i.e. the diagrams are based on the number of individuals. Fine (up to 2–3 mm in diameter) or uninformative (for determining species) fragments of valves and shells were not included in calculations of the number (total or of discrete species) of fossil individuals.

As the number of individuals of different species was rather variable (from a few to a few hundred), logarithmic diagrams were used to provide a more vivid demonstration of the specific features of species composition. The logarithmic diagrams show the number of all detected mollusc individuals ('total number') and the number of individuals of different species.

Fossil molluscs were identified using the naked eye and a binocular microscope. The identification reliability was verified by comparing fossil molluscs against H. Kessel's collection of the Baltic Sea molluscs stored at the Institute of Geology, Tallinn University of Technology and using malacofauna atlases (descriptions, drawings and photographs).

2.3. Geochronological and lithological investigations

The fossil molluscs were dated using electroparamagnetic resonance (EPR, performed by G. Hütt, Institute of Geology, Tallinn University of Technology, Research Laboratory for Quaternary Geochronology) and the radiocarbon (^{14}C) method (by R. Rajame at the Research Laboratory for Quaternary Geochronology). The content of isotopes $\sigma^{13}C$ and $\sigma^{18}O$ also was determined in fossil molluscs for specification of the hydrochemical and hydrophysical parameters of the Holocene palaeobasins (determined by T. Martma, Institute of Geology, Tallinn University of Technology, Research Laboratory for Quaternary Geochronology). Based on the values of $\sigma^{18}O$ (ratio of stable oxygen isotopes ^{18}O:^{16}O) in sedimentary carbonaceous formations, it is possible to determine the temperature at the time of sedimentation. Determination of the values of $\delta^{13}C$ (ratio of stable carbon isotopes ^{13}C:^{12}C) allow the reconstruction of the conditions in palaeobasins (productivity, organic carbon burial and type of vegetation) at the time of deposition. For this purpose, valves of the molluscs *Cerastoderma* (boreholes 24893 and 24969), *Macoma* and *Mytilus edulis* (boreholes 24816, 24893 and 24969) were selected. It should be emphasised that the absolute age of the molluscs obtained by the radiocarbon dating did not coincide with the age of sediments dated by the same method though mollusc and sediment samples collected from the same sections and depths. The so-called reservoir effect (Mangerud, Gulliksen 1975; Stuiver, Braziunas 1993) may be the cause of this discrepancy. The absolute age of organic sediments was determined by radiocarbon assay at the Radioisotope Research Laboratory (Nature Research Centre, Institute of Geology and Geography, Vilnius), the Research Laboratory for Quaternary Geochronology (Tallinn University of Technology), the Radiological Dating Laboratory (Trondheim), and at Woods Hole Oceanographic Institution. The data obtained was calibrated using the program *CalPal Online Radiocarbon Calibration* (http://www.calpal-online.de/).

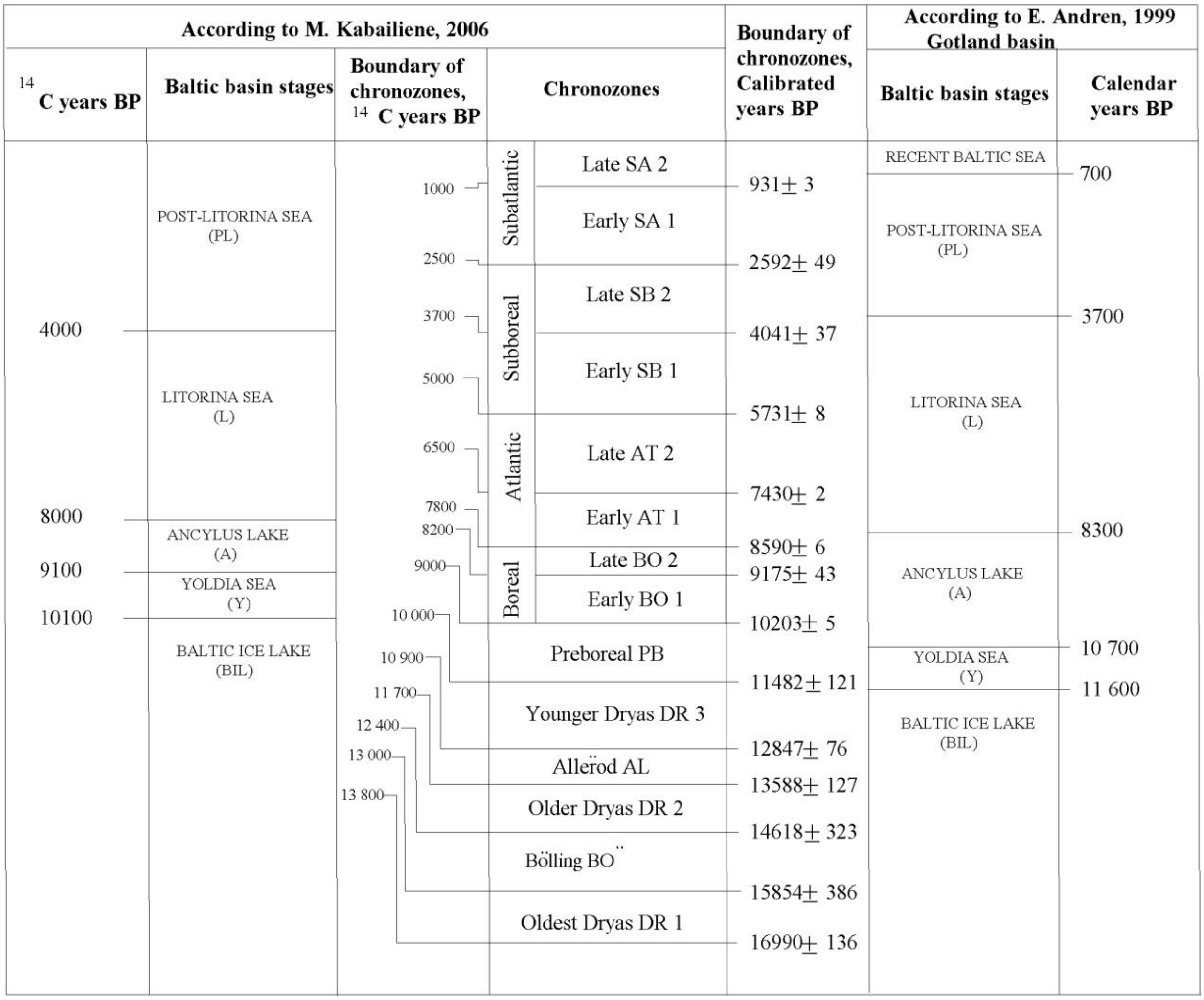
The sandy sediments were dated by the OSL method (by G. Hütt and A. Molodkov, Institute of Geology, Tallinn University of Technology, Research Laboratory for Quaternary Geochronology).

The complex of analytical investigations for absolute dating of sediments was implemented together with determination of the organic carbon content of the sediments and the lithological, chemical and mineralogical investigations the results of which were used for identification and characterisation of the sediments (the results of the investigations are available from: the Geological Archive, Lithuanian Geological Survey, Bitinas ir kt. 1997, 2004; Kanopienė ir kt. 2009).

2.4. Stratigraphical distribution of Late Glacial and Holocene deposits

Two variants of stratigraphical distribution of the Late Glacial and Holocene deposits can be found in different publications and maps: the stratigraphical distribution based on biostratigraphical criteria and the stratigraphical distribution based on palaeogeographical criteria. The stratigraphical distribution of Late Glacial and Holocene deposits of the present study is based on M. Kabailienė' (2006) stratigraphical scheme for the Late Glacial and Holocene. For reconstruction of the palaeohistory of the basins, a correlation stratigraphical scheme of the Gotland basin, published by E. Andrén (1999) was used (Table 4). In the latter scheme, the age of palaeobasins is dated to calendar years before present (BP), whereas in the M. Kabailienė' scheme uncalibrated dates absolute radiocarbon ages are used. Juxtaposing the stratigraphical scheme for the Lithuanian Late Glacial and Holocene with the Baltic Sea development stages for Gotland Basin (Table 4) and attempting to avoid possible confusion, the present author has recalculated the absolute radiocarbon age of the chronozones using the program *CalPal Online Radiocarbon Calibration* (http://www.calpal-online.de/). During the recalculations, one year error was added to the uncalibrated radiocarbon ages (e.g. 1000 ± 1).

Table 4 Juxtaposition of Late Glacial and Holocene stratigraphic scheme (Kabailienė 2006) and the scheme of the Baltic Sea development stages (Andrén 1999).



* The data of bondaries of chronozones are shown at the same scale. The data of radiocarbon (^{14}C) age are calibrated by program *CalPal Online Radiocarbon Calibration* (http://www.calpal-online.de/).

2.5. Analysis of sediment successions

For precise determination of the water-level fluctuations in different Baltic Sea development stages and relevant palaeoreconstructions, the analysis of sediment successions has been used as a tool for objective interpretation of the results obtained and the reconstruction of sedimentary environments. The analysis of sediment successions allowed the differentiation of transgression and regression phases in the basin development.

E. Trimonis (2005) defined sedimentary environment as a stage for erosion and accumulation and sedimentation distinguished by certain physical, chemical and biological conditions and geomorphological features which predetermine the sedimentation patterns and types of sediments. According to this author, the Lithuanian coastal region is a large sedimentary environment in the land and sea interface zone generalised as coastal sedimentary environment with the verging sub-littoral sedimentary environment. Analysis of sediment successions contained in this dissertation is based on the work of R. Žaromskis (1989–1990), E. Trimonis (2005) and O. Pustelnikovas (1998). The author has adapted the sedimentary environments identified by the authors mentioned to the individual reference area. The key-area selected for analysis of sedimentary palaeoenvironments is represented by the central part of the Baltic Sea Lithuanian Coast: Smiltynė–Smeltė Peninsula–Curonian Lagoon (Fig. 2), the geological material from boreholes put down by the State Seaport of Klaipėda was used. The whole spectrum of sedimentary palaeoenvironments – from the beach and barrier ridges to glaciation (Figs 3, 4 and 5) – are represented in this key-area. The analysis of the palaeoenvironments is based on thorough investigation of borehole sections (Fig. 1), sedimentary structures, lithological features and the age of sediments, the latter determined by numerical dating methods.

2.6. Reconstruction of the Baltic Sea stage water-level fluctuations and the of compilation of palaeogeographical schemes

For the compilation of palaeogeographical schemes and reconstruction of the Baltic Sea water-level fluctuations, the results of geological investigations, reinterpreted based on analysis of sedimentary palaeoenvironments, geochronological material and individual information collected during different-scale mapping of the Baltic coastal region were used.

The reconstruction of water-level fluctuations in the Baltic Sea palaeobasins was performed bearing in mind that glacioisostatic uplift was irregular in different segments of the Lithuanian coast in Late Glacial and Holocene (Gudelis 1979), it being the influenced by oscillating neotectonic movements of the Earth crustal blocks (Šliaupa *et al.* 2005). For this reason, separate reconstructions were made for the northern (Šventoji–Palanga), central (Giruliai–Klaipėda–Smiltynė) and southern (Kintai–Nemunas Delta–Nida) parts of the Lithuanian coastal region. The results of the radiocarbon dating of sediments served as the main criterion in determining the water level in the stages basins. The dates were grouped according to the sedimentary palaeoenvironments: land, lagoon, lake (isolated basin) and bog. A few dates from archaeological sites (fireplaces, coal) indicating terrestrial conditions at the time dated were also used (Rimantienė 1999). Based on the diatom analysis results, the dated gyttja, fossil molluscs and sedimentary conditions were classified into gyttja accumulated in a fresh lagoon or lake and gyttja accumulated in marine lagoon.

For reconstruction of water-level fluctuations in palaeobasins, the results obtained by OSL were not used because the error in this method is considerably larger than that of radiocarbon dating (potentially over 1 ka), making these determinations too imprecise for determining the water-level fluctuations some of which lasted only a few hundred years.

The reconstruction of water-level fluctuations is also based on the fragments of the old shorelines identified during geological mapping and decoding of aerial photographs of different scale. The ages of these water-level changes was determined using the results of geochronological and palaeobotanical investigations.

In author’s opinion, the evaluation of water-level fluctuations in the Yoldia Sea, Ancylus Lake and the first Litorina Sea transgression based on the data from the Lithuanian coastal region (land) alone is incorrect. For this reason, the part of the curve characterising these stages is doted (Fig. 10) to indicate the presumed water-level fluctuations.

In the palaeogeographical schemes compiled (Figs 11, 14, 15, 16, and 17), the following objects are plotted: the old shoreline, the main old tributaries and small basins and bogs in the coastal zone. The boundaries drawn are based on illustrated fragments of borehole and outcrop sections and on results of geochronological, palaeobotanical and malacofauna investigations. The palaeogeographical schemes are linked with the recent situation, i.e. the modern shoreline, the hydrographical network and the state borders with the Republic of Latvia and Russian Federation.

3. FOSSIL MOLLUSCS IN THE LITHUANIAN COASTAL REGION

Because this type of research has not been carried out previously in Lithuania, the present project of fossil molluscs is based on H. Kessel's investigations (1958, 1985) which summarises the results of long-term investigations of fossil molluscs in Estonia. His 1985 report contains a detailed description of the Holocene fossil molluscs found on the Estonian coasts of the Baltic Sea (mainland and islands), their species composition and their palaeoecological habitats. The main advantage of H. Kessel's work is that, based on the abundance of fossil molluscs of different age, he distinguished typical molluscan communities in each of the different Baltic Sea stages basins: Yoldia Sea, Ancylus Lake and Litorina and Post-Litorina seas.

Molluscs were classified based on the classification scheme CLECOM (*Check List of European Continental Mollusca,* Natural History Museum of Gothenburg; Sweden) adopted by specialists. This list was coordinated with that of Lithuanian molluscs published by CLECOM (Checklist of species-group taxa of continental mollusca living in Lithuania, 14-07-2002) and the computer database '*Fauna Europea*' (FaEu). The Lithuanian names for mollusc families and some species were taken from the Lithuanian mollusc catalogue compiled and published by the Tadas Ivanauskas Zoology Museum. Although all names of mollusc species and taxonomic groups suggested in the catalogue have not been approved, their relevance is obvious. The Lithuanian mollusc names used in this dissertation are suggested by the compiler of the catalogue, A. Gurskas (2010). The Latin equivalents are given in parentheses. The living environment of the molluscs is described based on the works of P. Šivickis (1960), P. Glöer, C. Meier-Brook (1998), H. Kessel (1985), K. S. Petersen (1987), and S. Skompski (1991, 1996), and information published in the Catalogue of Lithuanian Molluscs (2010). Using this scheme, 20,546 fossil molluscs of 2 classes, 15 families, 22 genera and 48 species found in the Lithuanian coastal region are characterised (Table 5).

Table 5 The systematic list of fossil molluscs of the Lithuanian Coastal Region.

Phylum	**Class**	**Order**	**Family**	**Genus**	**Species**
1	**2**	**3**	**4**	**5**	**6**
MOLLUSCA	*BIVALVIA*	*MYTILOIDA*	*Mytilidae*	*Mytilus* Linnaeus, 1798	*Mytilus edulis* (Linnaeus, 1758)
		UNIONOIDA	*Unionidae*	*Unio* Philipsson,1788	*Unio* sp.
		VENEROIDA	*Dreissenidae*	*Dreissena* Beneden, 1835	*Dreissena polymorpha* (Pallas, 1771)
			Cardiidae	*Cerastoderma* Poli, 1795	*Cerastoderma glaucum* (Poiret, 1789)
					Cerastoderma edule (Linnaeus, 1758)
					Cerastoderma crassum (Gmelin, 1791)
			Sphaeriidae	*Musculium* Link, 1807	*Musculium lacustre* (O. F. Müller, 1774)
				Pisidium Pfeiffer, 1821	*Pisidium amnicum* (Müller, 1774)
					Pisidium henslowanum (Sheppard, 1823)
					Pisidium lilljeborgi (Clessin, 1886)
					Pisidium milium (Held, 1836)
					Pisidium moitessierianum (Paladilhe, 1866)
					Pisidium nitidum (Jenyns, 1832)
					Pisidium obtusale (Lamarck, 1818)
					Pisidium obtusale lapponicum (Clessin, 1886)
					Pisidium pulchellum (Jenyns, 1832)
					Pisidium subtruncatum (Malm, 1855)
					Pisidium supinum (Schmidt, 1851)
					Pisidium tenuilineatum (Stelfox, 1918)
				Sphaerium Scopoli, 1777	*Sphaerium lacustre* (Müller, 1774)
					Sphaerium rivicola (Lamarck, 1881)
					Sphaerium solidum (Normand, 1884)
			Tellinidae	*Macoma* Leach, 1819	*Macoma balthica* (Linnaeus, 1758)
					Macoma calcarea (Gmelin, 1790)
	GASTROPODA	*ARCHITAENIOGLOSSA*	*Viviparidae*	*Viviparus* Montfort, 1810	*Viviparus fasciatus* (Müller, 1774)
					Viviparus fluviatilis (Schlesch, 1939)
					Viviparus viviparus (Linnaeus, 1758)
		ECTOBRANCHIA	*Valvatidae*	*Valvata* O. F. Müller, 1773	*Valvata alpestris* (Küster, 1853)
					Valvata naticina (Menke, 1845)
					Valvata piscinalis (Müller, 1774)
					Valvata piscinalis f. *antiqua* (Sowerby, 1838)
					Valvata pulchella (Studer, 1820)
		NEOTAENIOGLOSSA	*Bithyniidae*	*Bithynia* Leach, 1818	*Bithynia tentaculata* (Linnaeus, 1758)

1	**2**	**3**	**4**	**5**	**6**
			Hydrobiidae	*Amnicola* Gould&Haldeman, 1840	*Amnicola steini* (Martens, 1858)
				Hydrobia Hartmann, 1821	*Hydrobia ulvae* (Pennant, 1777)
				Lithoglyphus Hartmann, 1831	*Lithoglyphus naticoides* (C. Pfeiffer, 1828)
				Potamopyrgus Stimpson, 1865	*Potamopyrgus jenkinsi* (Smith, 1889)
			Littorinidae	*Littorina* Ferussac, 1822	*Littorina littorea* (Linnaeus, 1758)
		NERITOPSINA	*Neritidae*	*Theodoxus* Montfort, 1810	*Theodoxus fluviatilis* (Linnaeus, 1758)
		PULMONATA	*Acroloxidae*	*Acroloxus* Beck, 1838	*Acroloxus lacustris* (Linnaeus, 1758)
			Lymnaeidae	*Galba* Schrank, 1803	*Galba truncatula* (O. F. Müller, 1774)
				Lymnaea Lamarck, 1799	*Lymnaea auricularia* (Westerlund, 1885)
					Lymnaea ovata (Westerlund, 1885)
					Lymnaea peregra (Müller, 1774)
					Lymnaea stagnalis (Linnaeus, 1758)
			Planorbidae	*Gyraulus* Charpentier, 1837	*Armiger crista* f. *cristatus* (Draparnaud, 1905)
					Gyraulus albus (Müller, 1774)
					Gyraulus laevis (Alder, 1838)
			Succineidae	*Succinea* Draparnaud, 1801	*Succinea putris* (Linnaeus, 1758)

3.1. Klaipėda–Būtingė environs

Fossil molluscs (Table 6) in the northern part of the Baltic mainland coast were found in the boreholes at Melnragė (Klaipėda) and north of Klaipėda (to the Lithuanian–Latvian border north of Būtingė): sediments from borehole 24816 in the environs of Būtingė and from boreholes 24893 and 24896 (Fig. 1).

The molluscs recovered from borehole 24816 occur in sand (7,000±1,000) (Tln-1188) dated using the OSL method. The age of mollusc valves of *Cerastoderma* species dated by the EPR method is about 6,500–7,200 years.

Table 6 The summary list of molluscs species identified in the sediments of core samples from the Klaipėda–Būtingė environs.

Species	**Number of borehole**		
	24816	**24893**	**24896**
	Investigated interval, meters a.a.sl.		
	-3.5 – -6.6	**-5.9 – -8.1**	**-0.8 – -2.8**
	Amount of individuals		
Gastropoda			
Bithynia tentaculata (Linnaeus, 1758)	106	849	
Galba truncatula (O. F. Müller, 1774)		51	
Hydrobia ulvae (Pennant, 1777)	31	143	2
Littorina littorea (Linnaeus, 1758)		10	
Valvata piscinalis (Müller, 1774)		83	
Valvata piscinalis f. *antiqua* (Sowerby, 1838)		3	
Valvata pulchella (Studer, 1820)		52	
Bivalvia			
Cerastoderma crassum (Gmelin, 1791)		204	10
Cerastoderma edule (Linnaeus, 1758)	23	1454	35
Cerastoderma glaucum (Poiret, 1789)	21	235	3
Macoma balthica (Linnaeus, 1758)	21	39	16
Macoma calcarea (Gmelin, 1790)	1	196	21
Mytilus edulis (Linnaeus, 1758)	6	12	2
Pisidium amnicum (Müller, 1774)		3	
Total amount of individuals:	**195**	**3334**	**89**

Boreholes 24893 and 24896 contained similar fossil molluscs. Mollusc shells and valves from borehole 24893 (Fig. 1) were found in a sand layer overlying gyttja which accumulated 6,138±97 years BP (Tln-2069) on the basis of radiocarbon dating.

Fossil molluscs found on the mainland coast of the Baltic Sea were typical of the Litorina Sea ecosystem. In the boreholes put down south of the Klaipėda (in the Baltic Sea and Curonian Lagoonal coasts and in the Curonian Lagoon itself) fossil molluscs typical of the Litorina Sea have not been found.

The sediments from all mainland boreholes (north of Klaipėda) contained fossil molluscs of very comparable communities*:* *Cerastoderma edule* were found in abundance, valves of fossil molluscs *C. crassum* and *C. glaucum,* as well as *Macoma calcarea* and *M. balthica* were rarer, *Littorina littorea* molluscs inhabiting the stony offshore of tide zone, were very rare and *Hydrobia ulvae* shells, which tolerate saline water and live on algae, were more numerous. These mollusc communities are characteristic of shallow (up to 5–10 m in depth) littoral zones with sandy or silty (many fossil valves of *M. baltica*) or somewhere stony (fossil *Mytilus edulis* and *L. littorea*) bottoms in areas of boulders, gravel or pebbles (*M. baltica* and *M. edulis* community) (Oleninas ir kt. 1996). These mollusc communities, especially fossil *Littorina littorea,* imply that water salinity in the Litorina Sea hardly reached 8–10‰. This is confirmed by isotopic (δ^{13}C and δ^{18}O) analysis of mollusc valves performed for specification of hydrochemical and hydrophysical parameters (temperature and salinity) of the palaeobasin. In the valves of *Mytilus edulis* (borehole 24816) δ^{13}C was -1.4 ‰ and δ^{18}O -5.3 ‰, *Macoma baltica* (24816) δ^{13}C from -1.4 ‰ to -2.4 ‰ and δ^{18}O from -4.0 ‰ to -4.3 ‰, *Cerastoderma glaucum* δ^{13}C from 0.0 ‰ to 0.6 ‰ (borehole 24618), from 1.1 ‰ to 2.1 ‰ (borehole 24893) and from 1.1 ‰ to 1.8 ‰ (borehole 24969) whereas δ^{18}O from -5.1 ‰ to -5.5 ‰ (borehole 24618), from -4.1 ‰ to -5.3 ‰ (borehole 24893) and from -4.2 ‰ to -5.7 ‰ (borehole 24969). Although relatively many valves of freshwater *Bithynia tentaculata,* a few tens of the three *Valvata* species, *Galba truncatula* and a few of *P. amnicum* were found, it can be assumed that these species were not the native inhabitants of the basin but rather their valves were carried from the neighbouring land areas.

3.2. Curonian Spit

Fossil molluscs from the Nida environs (Fig. 1) were found in lacustrine sediments in borehole 26246, from the outcrop of ‘lagoon marl’ at the base of the Parnidis Dune (Table 7) and from Smiltynė (Table 8) in marine sediments recovered in boreholes 24969 and 36859.

The radiocarbon- age (^{14}C) of organic sediments from Nida and the Parnidis Dune, from which fossil molluscs were collected for determining species composition, is from 8,196±118 (Vs-1160) to 3,506±381 (Vs-1831) years BP.

Borehole 24969 was drilled in the northern part of the Curonian Spit (Smiltynė) at the eastern base of a foredune ridge, and borehole 36859 (Fig. 1) in the eastern coast of the Curonian Spit. Fossil molluscs from borehole 24969 (Table 8) were found in sand aged 8,000±1,200 (Tln-1181) according to OSL dating.

In the southern part of the Curonian Spit (Lithuanian sector), fossil molluscs were found only in the outcrop at the base of the Parnidis Dune in Nida.

In the freshwater lagoon of the Litorina Sea basin (on the modern Curonian Spit), clayey sediments rich in plant remains accumulated. These sediments contain many shells and valves of freshwater molluscs alone (Table 7). The molluscan evidence indicates that the basin was small (*Lymnaea peregra* and other) and had a silty bottom (*Pisidium milium, P. henslowanum, P. supinum, Musculium lacustre, Valvata piscinalis* f.

Table 7 The summary list of molluscs species identified in the sediments of the southern part of the Curonian Spit (Lithuanian sector).

Species	**Borehole 26246 Investigated interval, meters a.a.sl.**			**Parnidis dune outcrop**
	-6.4 – -6.8	**-7.1 – -8.1**	**-12.5 – -12.8**	
	Amount of individuals			
Gastropoda				
Amnicola steini (Martens, 1858)		2		73
Bithynia tentaculata (Linnaeus, 1758)		15		349
Lithoglyphus naticoides (C. Pfeiffer, 1828)		1		
Lymnaea ovata (Westerlund, 1885)			1	
Lymnaea peregra (Müller, 1774)	1		1	
Succinea putris (Linnaeus, 1758)	2	1		16
Valvata alpestris (Küster, 1853)		1		1
Valvata naticina (Menke, 1845)	45	24	18	405
Valvata piscinalis f. *antiqua* (Sowerby, 1838)				294
Valvata pulchella (Studer, 1820)	98	69	36	358
Bivalvia				
Dreissena polymorpha (Pallas, 1771)				112
Musculium lacustre (O. F. Müller, 1774)		4		1
Pisidium amnicum (Müller, 1774)	135	16	2	180
Pisidium henslowanum (Sheppard, 1823)		2		71
Pisidium lilljeborgi (Clessin, 1886)	10	2	1	14
Pisidium milium (Held, 1836)				33
Pisidium moitessierianum (Paladilhe, 1866)	78	32		4
Pisidium nitidum (Jenyns, 1832)	3	3		
Pisidium pulchellum (Jenyns, 1832)				8
Pisidium subtruncatum (Malm, 1855)		2		
Pisidium supinum (Schmidt, 1851)	85	26	2	55
Pisidium tenuilineatum (Stelfox, 1918)	6		1	
Unio sp.		1		
Total amount of individuals:	**462**	**180**	**62**	**1977**

antiqua, *V. pulchella*). Presumably the silty peripheral part of this shallow-water basin (the mollusc community with the exception of a few valves of *Pisidium tenuilineatum* preferring deeper water, is typical of a shallow stagnant or slowly flowing freshwater habitat. This is indicated by the shells of *Bithynia tentaculata* and *Valvata naticina* (especially associated with shallow water) and a few shells of *Lymnaea ovata* (inhabits the littoral zones of water basins), as well as by *Pisidium amnicum* (fossil molluscs of this species occur in greatest abundance), *P. pulchellum* (especially preferring the reed belts in the littoral zones) and land snails *Suicinea putris* inhabiting trees and shrubs growing at the margins of the basins. Fossil valves of *Dreissena polymorpha*, found in the 'lagoon marl', are an object of discussion. This is an invasive species which, according to some authors (Гасюнас 1959, Olenin 2005), reached the Baltic coast from the Ponto-Caspian basin only in the middle of the 19th century. These molluscs inhabit rivers and lakes and also low salinity seas. When and how these molluscs reached the Baltic coast can potentially be answered by further investigations.

Table 8 The summary list of molluscs species identified in the sediments of the northern part of the Curonian Spit.

Species	**Number of borehole**		
	24969	**36859**	
	Investigated interval, metres a.a.sl.		
	-7.1 – -7.8	**-4.56 – -4.86**	**-5.96 – -6.26**
	Amount of individuals		
Gastropoda			
Bithynia tentaculata (Linnaeus, 1758)	184	48	4
Galba truncatula (O. F. Müller, 1774)	17		
Hydrobia ulvae (Pennant, 1777)	61	29	
Littorina littorea (Linnaeus, 1758)	1		
Potamopyrgus jenkinsi (Smith, 1889)		21	3
Theodoxus fluviatilis (Linnaeus, 1758)	2	1	
Valvata piscinalis (Müller, 1774)	22	7	2
Valvata pulchella (Studer, 1820)	11	6	1
Bivalvia			
Cerastoderma crassum (Gmelin, 1791)	165	114	27
Cerastoderma edule (Linnaeus, 1758)	784	184	15
Cerastoderma glaucum (Poiret, 1789)	59	49	15
Macoma balthica (Linnaeus, 1758)	16	19	14
Macoma calcarea (Gmelin, 1790)	129	15	15
Mytilus edulis (Linnaeus, 1758)	4	1	1
Pisidium amnicum (Müller, 1774)	3		
Total amount of individuals:	**1458**	**494**	**97**

The fossil molluscs found in the northern part of the Curonian Spit–Smiltynė – (same as the ones found in the mainland coast) (Table 8) area are characteristic of the Litorina Sea biota. The mollusc communities dominated by *Cerastoderma, Macoma* and *Mytilus* are typical of the shallow (up to 5–10 m in depth) littoral zone of saline basins (*C. edulis*) with sandy or silty (*Macoma baltica*) and in places, stony (*Mytilus edulis* colonies, *Littorina littorea*) bottoms with areas of gravel, pebbles and boulders (indicated by a mixed *M. edulis* and *M. baltica* community). The sediments also contained shells of molluscs that tolerate both fresh- and saline-water basins: *Theodoxus fluviatilis*, living on stones in the surf zone and *Hydrobia ulvae*, living on algae in the littoral zone. The small shells of molluscs, colonising freshwater stagnant or slowly flowing water basins (*Valvata* species and *Galba truncatula*) represented in the core sediments, were presumably carried to the sea by stream and melt-water flows from the land.

3.3. Curonian Lagoon

The fine-grained grey, feldspar-quartz sand encountered at 7.0–9.8 m below the present sea level and found in boreholes 26221, 26222, 26226 and 26227, drilled in the Curonian Lagoon water area (Fig. 1), contained fossil molluscs of the same communities (Table 9).

These sediments especially contained many fossil molluscs of the Valvatidae, Sphaeriidae and Dreissenidae families in the upper parts of the sections examined (Table 9). The Valvatidae species inhabit sandy (*V. naticina*) or silty (*V. piscinalis*) bottoms of shallow stagnant or slowly flowing freshwater (*V. piscinalis* f. *antiqua*, *V. pulchella* and others) basins. The accumulation of the sediments at the basins’ margins is indicated by the very abundant mollusc *V. naticina* a taxa that favours the peripheral zones of water basins. The shells of Bithyniidae (*Amnicola steini, Bithynia tentaculata*), Hydrobiidae (*Lithoglyphus naticoides*), Lymnaeidae (*Galba truncatula, Lymnaea peregra*) and Viviparidae (*Viviparus viviparus, V. fasciatus, V. fluviatilis*) families also indicate the occurrence of a shallow stagnant or slowly moving freshwater basin. The species composition of Bivalvia also is typical of shallow (only a few valves of deepwater *P. tenuilineatum* were found) stagnant or slowly flowing (fragments of the valves of *Unio* mollusc species) freshwater (*P. nitidum, P. moitessierianum,* etc.) lagoon or lake with a silty or sandy bottom or of the littoral zone of this basin. Since only freshwater molluscs were found, it is possible to conclude that at the time of deposition of the sediments described the water in the present Curonian Lagoon was already fresh.

Table 9 The summary list of molluscs species identified in the sediments of the Curonian Lagoon.

Species	**Number of borehole**				
	26221	**26222**		**26226**	**26227**
	Investigated interval, metres a.a.sl.				
	-8.75 – -9.45	**-7.0 – -7.5**	**-9.1 – -9.8**	**-1.9 – -2.7**	**-1.4 – -2.5**
	Amount of individuals				
Gastropoda					
Amnicola steini (Martens, 1858)					2
Bithynia tentaculata (Linnaeus, 1758)	7	3	1	2	9
Galba truncatula (O. F. Müller, 1774)				2	1
Lithoglyphus naticoides (C. Pfeiffer, 1828)	4				
Lymnaea peregra (Müller, 1774)	2				
Valvata naticina (Menke, 1845)	925	60	39	101	1201
Valvata piscinalis (Müller, 1774)	254				
Valvata piscinalis f. *antiqua* (Sowerby, 1838)	1033	91	38	150	605
Valvata pulchella (Studer, 1820)	356	76	31	114	1334
Viviparus fasciatus (Müller, 1774)		6	6		
Viviparus fluviatilis (Schlesch, 1939)		4	1		
Viviparus viviparus (Linnaeus, 1758)		17	6		
Bivalvia					
Dreissena polymorpha (Pallas, 1771)	179	215	102	4	8
Musculium lacustre (O. F. Müller, 1774)	1	2	1		
Pisidium amnicum (Müller, 1774)		2	1	1	1
Pisidium henslowanum (Sheppard, 1823)		2	2		4
Pisidium milium (Held, 1836)	31	6	4	1	1
Pisidium moitessierianum (Paladilhe, 1866)		4	3	2	2
Pisidium nitidum (Jenyns, 1832)	32	2			
Pisidium pulchellum (Jenyns, 1832)			3		
Pisidium subtruncatum (Malm, 1855)	1				
Pisidium supinum (Schmidt, 1851)		18	7	2	3
Pisidium tenuilineatum (Stelfox, 1918)	10				
Sphaerium solidum (Normand, 1884)	1	1	1		
Unio sp.	1	1	1		
Total amount of individuals:	**2838**	**510**	**247**	**379**	**3163**

Therefore the mollusc community in these sequences inhabited a small and shallow water basin or semi-enclosed lagoon of a larger water basin where the silty bottom was overgrown with water plants.

3.4. Ventės Ragas Cape

The sediment cores from the eastern coast of the Curonian Lagoon contained no fossil molluscs. Molluscs (Table 10) were only found in the Ventės Ragas outcrop at a depth of 2.68–2.73 m from the ground surface (3.12–3.07 m a.s.l.) in peat and gyttja-containing silt radiocarbon-dated to 13,603±224 years BP (Vs-1161).

Table 10 The summary list of molluscs species identified in the sediments of the Ventės Ragas outcrop.

Species	**Investigated interval, 3.12–3.07 m a.a.sl.**
	Amount of individuals
Gastropoda	
Armiger crista f. *cristatus* (Draparnaud, 1905)	37
Gyraulus albus (Müller, 1774)	86
Gyraulus laevis (Alder, 1838)	234
Lymnaea peregra (Müller, 1774)	2
Lymnaea stagnalis (Linnaeus, 1758)	3
Bivalvia	
Musculium lacustre (O. F. Müller, 1774)	18
Pisidium amnicum (Müller, 1774)	369
Pisidium henslowanum (Sheppard, 1823)	94
Pisidium lilljeborgi (Clessin, 1886)	1
Pisidium milium (Held, 1836)	174
Pisidium moitessierianum (Paladilhe, 1866)	52
Pisidium nitidum (Jenyns, 1832)	68
Pisidium obtusale lapponicum (Clessin, 1886)	3
Pisidium supinum (Schmidt, 1851)	159
Sphaerium lacustre (Müller, 1774)	10
Sphaerium rivicola (Lamarck, 1881)	11
Sphaerium solidum (Normand, 1884)	20
Total amount of individuals:	**1341**

Summarising the results obtained from the geochronological analysis and the molluscan investigation, it should be emphasised that fossil molluscs so far found in the mentioned Ventės Ragas outcrop are the oldest on the Lithuanian coast. It can be concluded that the molluscs inhabited a small enclosed freshwater basin during Late Glacial when the coast of the Baltic Ice Lake was situated in the environs of Ventės Ragas Cape farther to the west. Whereas the present land area apparently included small lakes which survived after subsidence of this cold freshwater basin. The existence of the littoral zone of a small water basin (including the molluscs *Lymnaea peregra* and *Pisidium obtusale lapponicum*) is indicated by many assemblages of *Pisidium amnicum* valves. Though the water in the basin was still cold at this time (as indicated by the valves of *P. obtusale lapponicum*), it had a silty (judging from the occurrence of *Musculium lacustre*, *Pisidium amnicum, P. henslowanum, P. milium, P. supinum* and *Sphaerium solidum*) and occasionally sandy (*Sphaerium rivicola* and *S. solidum*) bottom which was overgrown with water plants. The finds of the shells of

Armiger crista f. *cristatus, Gyraulus laevis, Lymnaea stagnalis,* and *Sphaerium lacustre* imply that this closed basin was gradually shallowing and overgrowing.

3.5. The Nemunas Delta

Molluscs of similar communities to those noted above were found (Table 11) in boreholes 26233, 26239, 26243 in the Nemunas Delta (Fig. 1).

The particularly large numbers of *Valvata pulchella, V. naticina, V. piscinalis* f. *antiqua* found suggests that the mollusc-bearing sediments accumulated in sandy (especially many fossil *V. naticina*) and slightly silty (*Pisidium amnicum* situations and not only river banks but also in river overflow zones. Of these, *P. milium* inhabits silt of various water basins, *P. supinum* colonises the silty bottoms of large rivers and small

Table 11 The summary list of molluscs species identified in the sediments of the Nemunas Delta.

Species	**Number of borehole**		
	26233	**26239**	**26243**
	Investigated interval, metres a.a.sl.		
	-1.6 – -3.1	**-2.5 – 2.8**	**-3.0 – -3.5**
	Amount of individuals		
Gastropoda			
Acroloxus lacustris (Linnaeus, 1758)			2
Amnicola steini (Martens, 1858)	5		1
Bithynia tentaculata (Linnaeus, 1758)	4	4	1
Valvata naticina (Menke, 1845)	651	114	237
Valvata piscinalis f. *antiqua* (Sowerby, 1838)	51	41	97
Valvata pulchella (Studer, 1820)	707	373	782
Bivalvia			
Musculium lacustre (O. F. Müller, 1774)	5		
Pisidium amnicum (Müller, 1774)	205	39	16
Pisidium henslowanum (Sheppard, 1823)	28	12	2
Pisidium lilljeborgi (Clessin, 1886)	2	5	1
Pisidium milium (Held, 1836)	67	24	
Pisidium moitessierianum (Paladilhe, 1866)	105	33	13
Pisidium nitidum (Jenyns, 1832)			1
Pisidium obtusale (C. Pfeiffer, 1821)	2		
Pisidium pulchellum (Jenyns, 1832)	1	1	
Pisidium subtruncatum (Malm, 1855)	12		
Pisidium supinum (Schmidt, 1851)	18	16	9
Pisidium tenuilineatum (Stelfox, 1918)	18		2
Sphaerium solidum (Normand, 1884)	3		
Unio sp.	8		2
Total amount of individuals:	**1892**	**662**	**1166**

streams. This indicates a river backwater, its littoral zone overgrown with reeds (*P. pulchellum, Acroloxus lacustris),* or possibly a river mouth near a larger freshwater basin (*V. piscinalis* f. *antiqua*, *P. lilljeborgi, P. tenuilineatum)*. The existence of a small backwater with slowly flowing water (fragments of *Unio* mollusc valves) is also indicated by the molluscs *Amnicola steini, Acroloxus lacustris, Musculium lacustre* and *Sphaerium solidum* and a rich community of *Pisidium* (*P. amnicum*, *P. henslowanum*, etc.) species.

4. SEDIMENTARY ENVIRONMENTS OF THE LITHUANIAN COASTAL SEDIMENTS

In the key-area (Fig. 2), eight typical sedimentary palaeoenvironments have been distinguished and described using method of E. Trimonis' (2005). Analysis of the sedimentary palaeoenvironments allowed the differentiation of sedimentation sequences conditioned by transgressions and regressions within the basins.

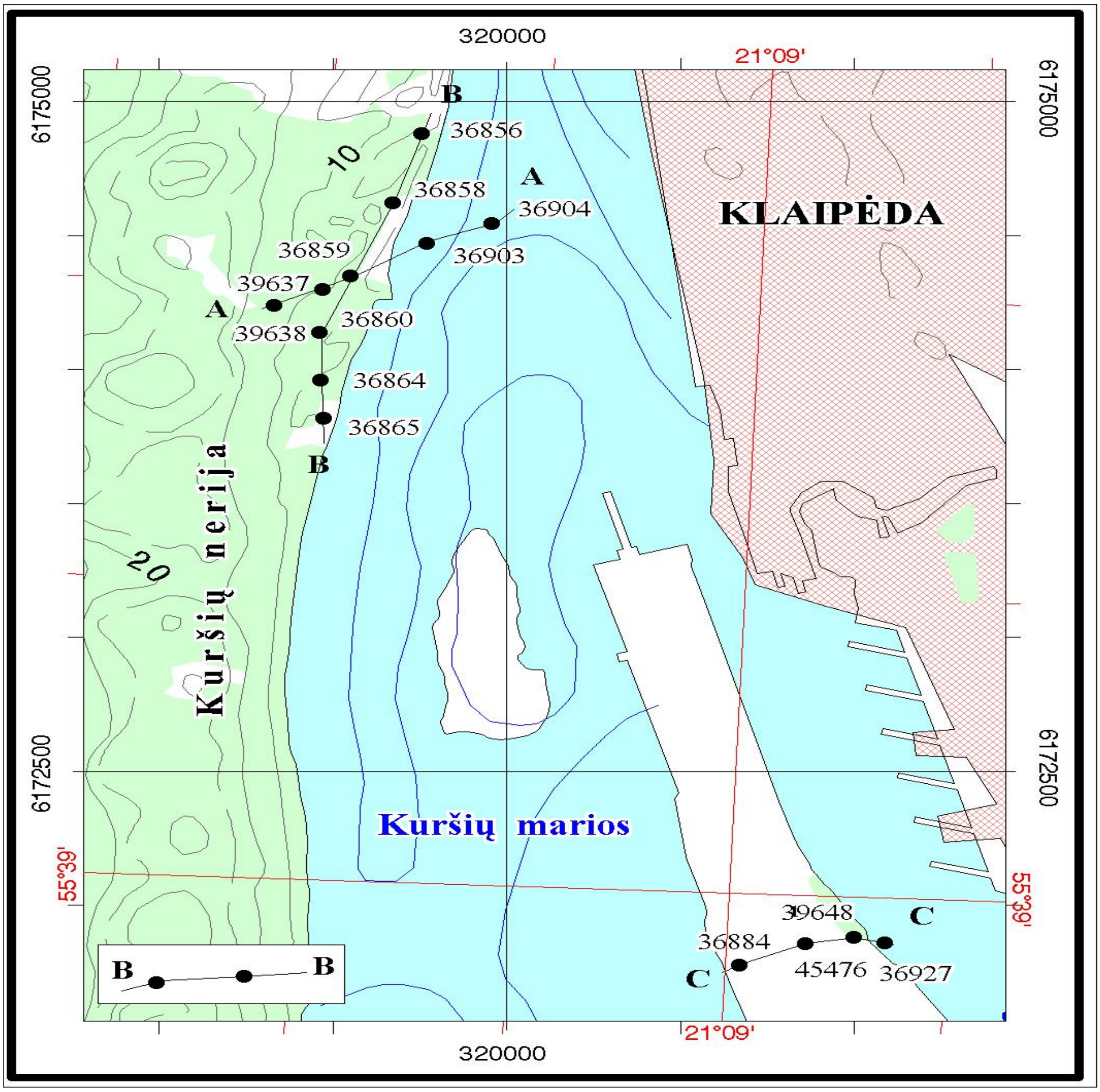


Figure 2 Key-area of analysed sedimentation sequences. (A–A, B–B, C–C – lines of geological--lithological cross-sections, ● 36903 borehole and its number.)

Beach sedimentary environment (PpSA) is situated west of the key-area. The eastern coasts of Smeltė peninsula and Curonian Spit and the western part of the mainland coast are urbanised and not shown in the fragments of the sections.

Barrier-ridge sedimentary environment (BPSA) can be divided into two parts: open sea and lagoon. The reference area of this sedimentary environment includes the upper part of the Curonian Spit and Smeltė peninsula sediments. The BPSA in the upper part of the Curonian Spit sediments has developed under the dominant aeolian processes whereas the $BPSA_1$ of the Smeltė peninsula was formed by sea waves and currents.

Lagoon sedimentary environment (LSA). The number on the right side of the index stands for the succession of sedimentary environment from the oldest (e.g. LSA_1) to the youngest (e.g. LSA_8). In the Post-Litorina Sea sediments of the key-area (Curonian Spit, Figs 3, 5 and 6), three sedimentary lagoon environments can be distinguished: LSA_6 (the oldest of Post-Litorina Sea), LSA_7 and LSA_8. In the sediments of the Litorina Sea from two (Curonian Spit, LSA_3 and LSA_2) to five (Smeltė peninsula, LSA_1, LSA_2, LSA_3, LSA_4, and LSA_5) sedimentary lagoonal palaeoenvironments can be distinguished.

Sub-littoral sedimentary environment (SbSA). Four sub-littoral sedimentary environments of the Litorina Sea have been distinguished in the key-area: $SbSA_1$, $SbSA_2$, $SbSA_3$ and $SbSA_4$.

Lacustrine sedimentary environment (ESA). Two lacustrine sedimentary environments (ESA_1 and ESA_2), separated by a sedimentation break, were identified in the key-area.

Bog sedimentary environment (PSA). Bog sedimentary palaeoenvironments separate: in the Curonian Spit the sedimentary environments of Post-Litorina and Litorina seas (PSA_3) and two lacustrine sedimentary environments (PSA_1) and in the Smeltė peninsula two sedimentary lagoon environments of Litorina Sea (PSA_2) and two lacustrine sedimentary palaeoenvironments (PSA_1).

Glacier sedimentary environment (LpSA, LgSA) was also distinguished in the key-area. The first glacial sedimentary palaeoenvironment ($LgSA_1$) is represented by glacigenic sediments and the second, proglacial palaeoenvironment ($LpSA_2$) is represented by sediments of the Baltic Ice Lake.

Table 12 Integrated table of typical sedimentary environments of the key-area. (Compiled after E. Trimonis (2005), based on the characteristics of lithological composition of core samples from the key-area.)

Name of sedimentary environment and its index	**Lithological composition**	**Sedimentary environment**
Littoral		
Beach sedimentary environment PpSA	Sand, various grained, with black minerals, sometimes – with well and very well flatly rounded gravel and pebbles.	Part of the coastal zone composed of coarse material by swash, waves and currents.
Barrier-ridge sedimentary environment BPSA	Sand, fine grained, very well sorted, with thin interlayers of paleosoil. Sand, various grained, often, at the bottom of layer – well and very well flatly rounded gravel and pebbles.	Formed by waves, currents and wind action. Composed of well-sorted sand with typical beach structures and marine fossils on the side of the open sea and composed of finer sand with plant remains and lagoon fossils on the side of lagoon.
Lagoon sedimentary environment LSA	Sand, fine and very fine grained, with remnants of fine-grained organic matter, with admixture of black minerals, muscovite and glauconite, with thin interlayers of glauconitic sand, sometimes in the upper part of the layer – with gyttja. Silty gyttja with thin interlayers of peaty gyttja. Silt carbonaceous, with thin interlayers of sand, quartz and gyttja.	Sedimentation processes are predetermined by hydrographic conditions and input of sediments into lagoons. Strong drift flows may fill the lagoons with sediments converting them into lakes or bogs.
Sub-littoral (shelfs)		
Sub-littoral sedimentary environment SbSA	Sand various grained with plenty admixture of black minerals, with fine gravel, in some places gravel, with remnants of marine molluscs (*Cerastoderma*, *Macoma*, *Mytilus*), with amber.	The shallow littoral zone of the sea from the shoreline till the depth of 200 m. It is intensively affected by numerous factors (climate changes, water level fluctuations, water strata dynamics, etc.).
Lakes and bogs		
Lacustrine sedimentary environment ESA	Silt with gyttja. Gyttja with remnants of freshwater molluscs. Sand, very fine grained, in some places with gyttja or peat, with admixture of fine-grained organic matter, in the lower part of layer – with peat.	Typical accumulation of drift (river, sea, waves, wind) material. Chemogenic and biogenic sediments form in the course of biological and chemical processes.
Bog sedimentary environment PSA	Peat, in some places with gyttja, with thin interlayers of gyttja and sand.	Sedimentation intensity depends on biological productivity, climate, relief, hydrogeological conditions and soil type.
Glacier (glaciation)		
Proglacial sedimentary environment LpSA	Sand, various grained, in some places – gravel and pebbles.	Related with ice melting and thaw water flows. Sandy sediments accumulate in the periglacial lakes generated by glacier melting.
Glacial sedimentary environment LgSA	Till with gravel and pebbles and interlayers of sand and silt.	Typical exaration and accumulation processes. The most typical form of glacier sediments: basal moraine, deformation moraine and ablation moraine.

Table 13 Integrated chronological chart of sedimentary environment sequences in the key-area.

Index of sedimentary environment	**Prevailing type of sediments**	**Geological index****	**Sequences: regressive/ transgressive**		**Special charcteristic of sediments, their age in calibrated radiocarbon (^{14}C) years BP**
BPSA	Sand, fine grained	v IV	↑		Very well sorted, with thin interlayers of paleosoil.
BPSA$_1$*	Sand, various grained	m IV PL			In some places, at the bottom of layers, with very well flatly rounded gravel and pebbles.
LSA$_8$	Sand, fine grained	ml IV PL		↑	With admixture of black minerals, muscovite and glauconite, fine-grained organic matter, with thin interlayers of glauconitic sand, in the upper part of the layer – with silt and gyttja.
LSA$_7$	Sand, fine-very fine grained	ml IV PL			With big admixture of black minerals, fine grained organic matter, in some places in the upper part of the layer – with gyttja.
LSA$_6$	Gyttja	ml IV PL			With thin interlayers of peaty gyttja. 3364±102
PSA$_3$	Peat with gyttja	b IV	↑		With thin interlayers of peaty gyttja. 1078±106 ?
LSA$_5$	Silt with gyttja, gyttja	ml IV L			With thin interlayers of sand, at the bottom of the layers – sand, fine grained. 4413±226
SbSA$_4$	Sand, various grained	m IV L		↑	With big admixture of black minerals and fine gravel.
LSA$_4$	Sand, very fine grained	ml IV L			With admixture of black minerals and fine grained organic matter.
PSA$_2$	Peat	b IV	↑		With peaces of gyttja and thin interlayers of very fine grained sand.
LSA$_3$	Silt with gyttja, gyttja	ml IV L			With thin interlayers of gyttja and quarzt. 6819±202, 7501±64
LSA$_2$	Sand, very fine grained	ml IV L		↑	With admixture of black minerals, muscovite and glauconite, fine grained organic matter, in the upper part of the layer – silt with thin interlayers of sand with gyttja and peat.
SbSA$_3$	Sand, various grained	m IV L			With fine gravel.
SbSA$_2$	Sand, various grained	m IV L			With big admixture of marine subfossil molluscs, also with amber.
LSA$_1$	Sand, fine grained	ml IV L			With big admixture of black minerals.
			↑		*Pinus* tree stumps on the Baltic Sea offshore at the depth of 14.5 m. 7784±119
SbSA$_1$	Sand, medium grained	m IV L		↑	With big admixture of black minerals.
EAS$_2$	Silt with gyttja, gyttja	l IV			In some places silty and sandy, with remnants of ostracodes and freshwater molluscs. 9281±133, 10375±98
PSA$_1$	Peat	b IV	↑		In some places with gyttja. 9256±151, 9786±160
EAS$_1$	Sand, very fine grained, gyttja	l IV			In some places with gyttja, with admixture of fine grained organic matter, in the upper part of the layer in some places with gyttja and remnants of freshwater molluscs.
LpSA$_2$	Sand, various grained	lg III B			In some places gravel and pebbles, in the bottom of the layer – with bank of gravel and pebbles.
LgSA$_1$	Till	gd III nm$_2$			In some places with lenses of sand and silt.

**The number at the right side of index shows the relative age of sedimentary environment from oldest (eg., 1) untill the youngest one (eg., 8). (For legend see Fig. 4.)

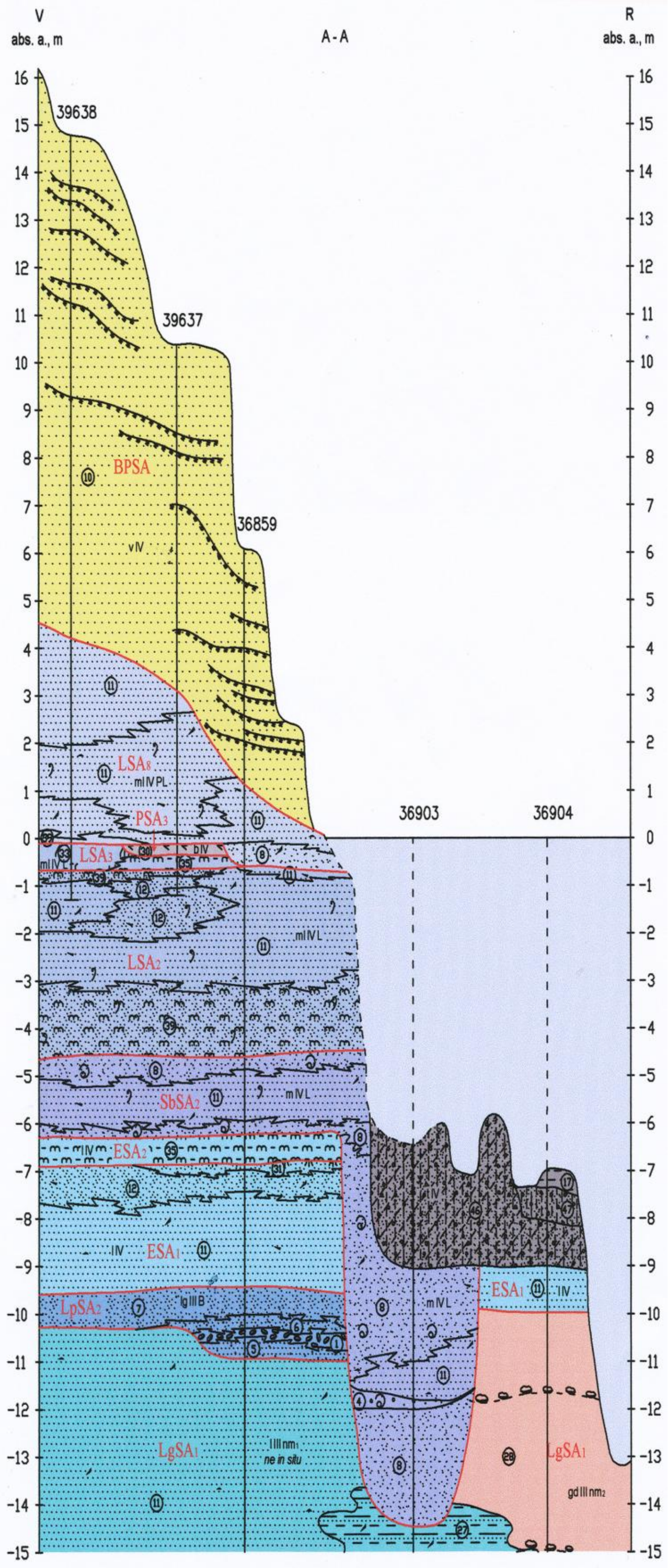


Figure 3 Sedimentary palaeoenvironments in the Curonian Spit and Curonian Spit, cross-section A–A. (For legend see Fig. 4.)

The characteristics of successions and palaeoenvironments distinguished are presented in tables 12 and 13 and the palaeoenvironments are shown in Figs 3, 5, 6 and 4 (legend). Changes of sedimentary environments, depending on the character of successions, show the past dynamic conditions in a basin: transgression, regression and stable state. The grading of sedimentary successions from lacustrine (ESA) sedimentary conditions into bog sedimentary conditions (PSA) records either transgression into the basin or its stable water level, but intensive sedimentation. This pattern of sedimentary successions can be observed in borehole 36860 (e.g. Fig. 5, ESA$_1$ → PSA$_1$). Meanwhile the grading of sedimentary successions from bog conditions to those in a lacustrine sedimentary environment (PSA → ESA), and later into a sub-littoral sedimentary environment (SbSA), indicate

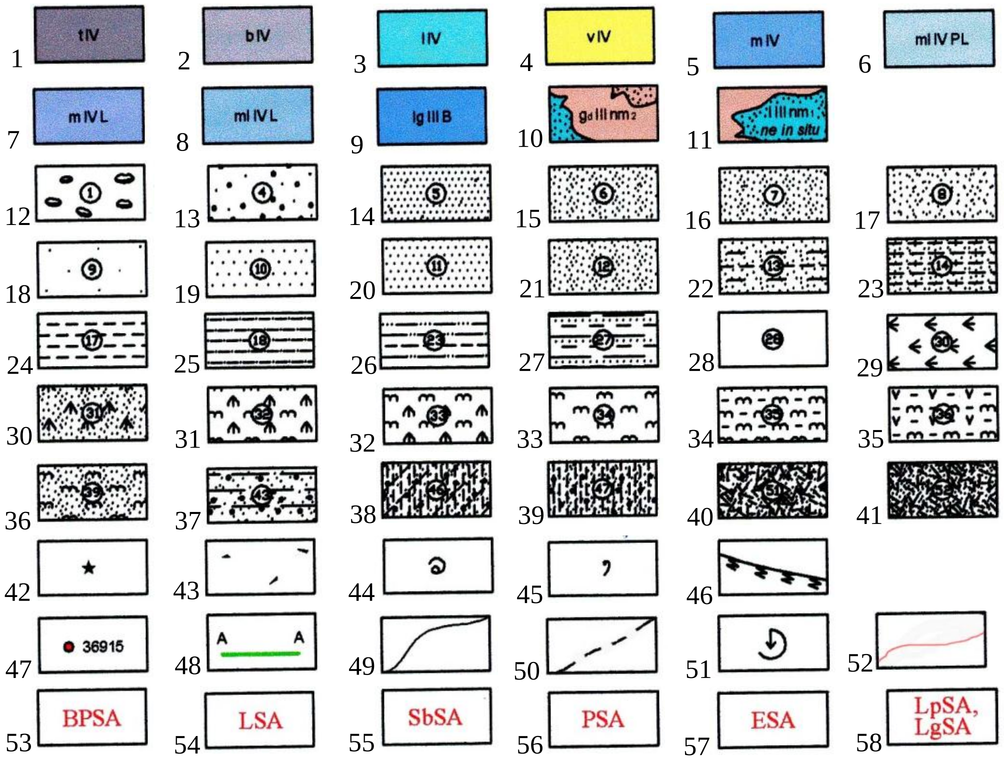


Figure 4 Legend for Figures 3, 5 and 6.
Stratigraphy and genesis: Holocene. 1 – anthropogenic deposits, 2 – biogenic (bogs) sediments, 3 – limnic sediments, 4 – aeolian sediments, 5 – recent marine sediments, 6 – Post-Litorina Sea sediments (lagoonal facies), 7 – Litorina Sea sediments (opean sea facies), 8 – Litorina Sea sediments (lagoonal facies). Late Glacial. 9 – Baltic Ice Lake sediments. Upper Pleistocene. 10 – Upper Nemunas glacial deposits (deformation till), 11 – lenses of Lower Nemunas limnic sediments. *Lithological composition:* 12 – pebbles, 13 – gravel and pebbles, 14 – gravel with sand, 15 – gravel, 16 – sand with gravel, 17 – sand, various grained, 18 – sand, coarse grained, 19 – sand, medium grained, 20 – sand, fine grained, 21 – sand, very fine grained, 22 – sand with silt, 23 – silty sand, 24 – silt, 25 – sandy silt, 26 – silty-sandy clay, 27 – laminated layer of silt, sand and clay, 28 – till, 29 – peat (type not identified), 30 – sand with peat, 31 – peat with gyttja, 32 – peaty gyttja, 33 – gyttja, 34 – silty gyttja, 35 – silt with gyttja, carbonaceous, 36 – sand with gyttja. *Antrophogenic deposits:* 37 – sand, various grained, clayely, with gravel and pebbles, 38 – sand, various grained, muddy, with soil, gravel, pebbles and peaces of till, 39 – sandy mud with gravel and pebbles, 40 – sand with soil, gravel and pebbles, 41 – sand with soil. *Admixtures:* 42 – amber, 43 – fine grained organic matter, 44 – remnants of fossil molluscs, 45 – glauconite, 46 – paleosoil. *Other sings:* 47 – borehole, its number, 48 – line of geological cross-section, 49 – boundary of stratigraphic-genetic and lithologic units, 50 – thrust-folds, 51 – glacio-dislocacions, 52 – boundary of sedimentary environment. *Sedimentary environments:* 53 – Barrier-ridge sedimentary environment, 54 – Lagoon sedimentary environment, 55 – Sub-littoral sedimentary environment, 56 – Bog sedimentary environment, 57 – Lacustrine sedimentary environment, 58 – Glacier sedimentary environment.

the beginning of a transgression. Borehole 36860 is characterised by a sedimentary succession representing a transgression: from an initial bog environment to a lacustrine environment, the latter then being replaced by a sub-littoral environment (PSA_1 → ESA_2 → $SbSA_2$). The transgressive character of the basin also is demonstrated by the patterns

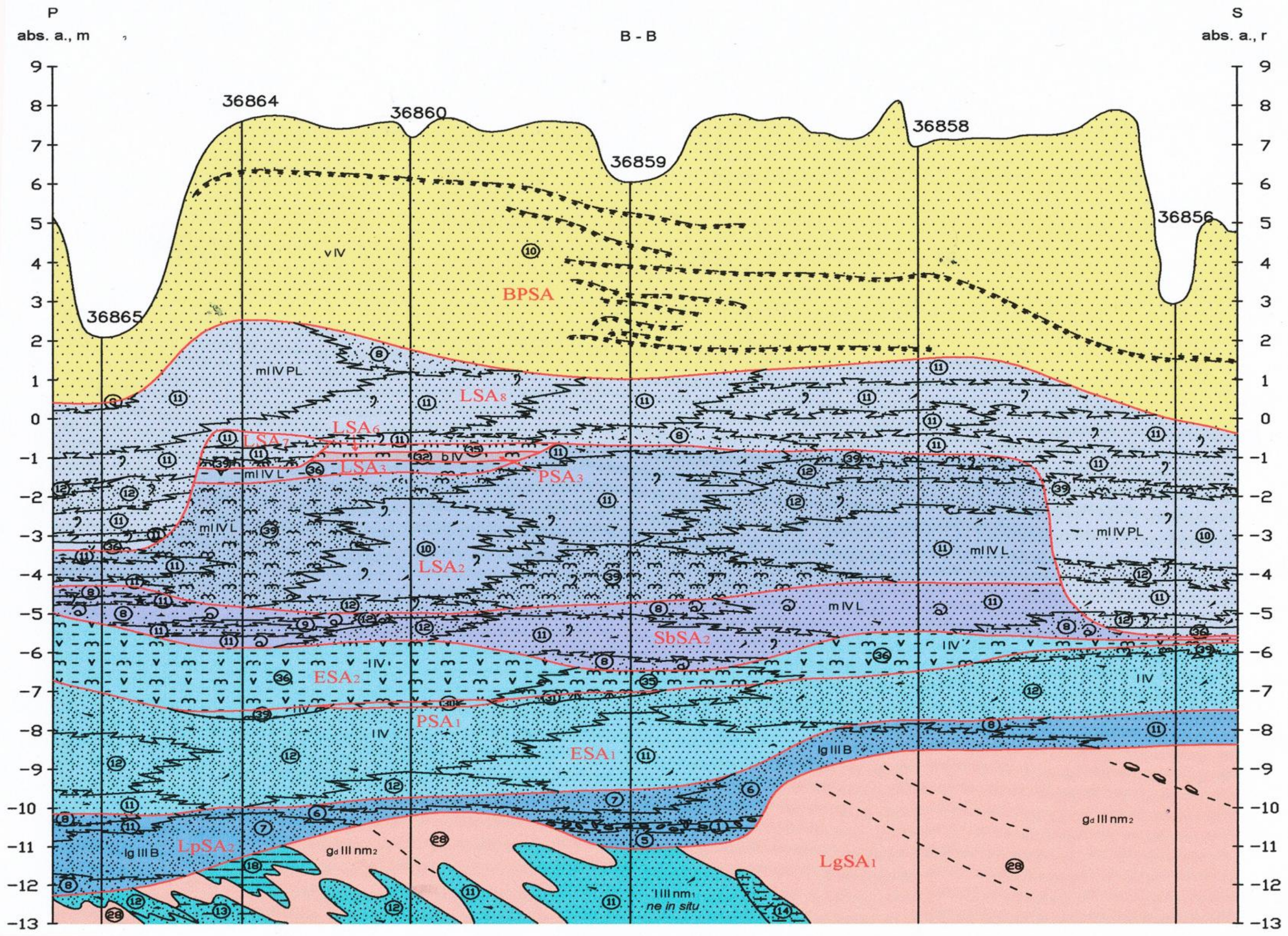


Figure 5 Sedimentary palaeoenvironments in the Curonian Spit, cross-section B–B. (For legend see Fig. 4.)

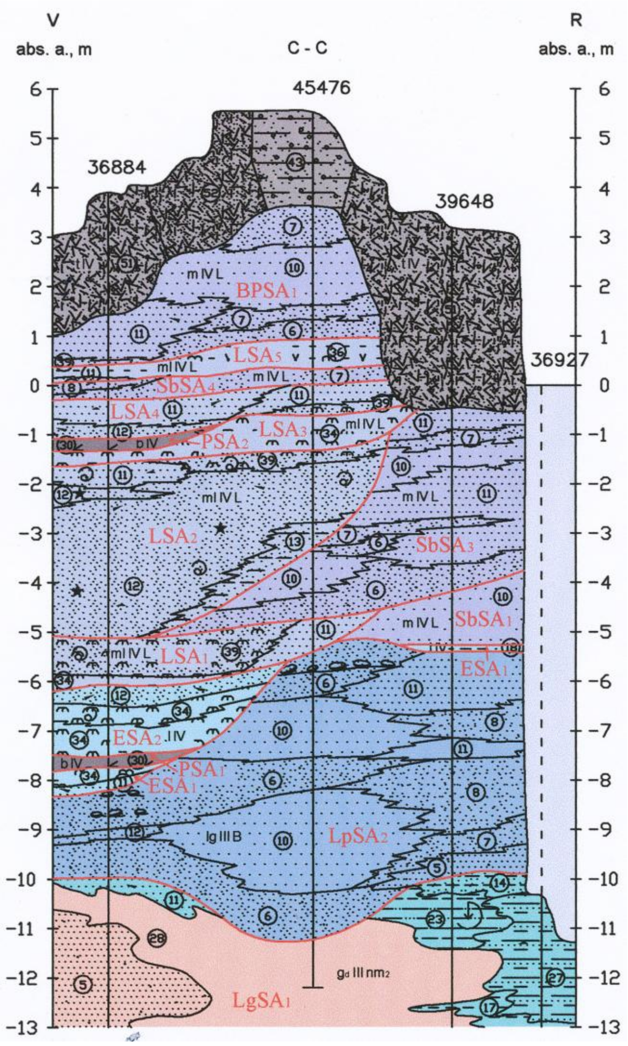


Figure 6 Sedimentary palaeoenvironments in the Smeltė peninsula cross-section C–C. (For legend see Fig. 4.)

of the sedimentary successions: where the lagoonal environment is replaced by a barrier-ridge environment (LSA → BPSA) and then a lagoonal environment is replaced by a sub-littoral environment (LSA → SbSA) (e.g. Fig. 6, section of borehole 45476 where LSA$_5$ → BPSA$_1$ and LSA$_4$ → SbSA$_4$). By contrast, the pattern typical of a regressive system is as follows: a sub-littoral environment is replaced by a lagoonal environment and the latter grades into a bog environment (SbSA → LSA → PSA) (e.g. Fig. 3, boreholes 36859, 36860 and 39637, where SbSA$_2$ → LSA$_2$ → LSA$_3$ → PSA$_3$), etc. Analysis of the patterns of sedimentary sequences in the key-area showed that some sections (e.g. Fig. 6, boreholes 36884 and 45476) of Litorina Sea sediments include deposits of three marine transgressions and three regressions.

The spectrum of palaeoenvironments distinguished in the key-area encompasses all possible environments found on the Lithuanian coastal region. For this reason, the data arising from the sedimentary environment analysis has served as a basis for the interpretation of all the sediment sequences investigated in the Lithuanian coastal region.

5. GENERAL FEATURES OF THE GEOLOGICAL STRUCTURE OF THE LITHUANIAN COASTAL REGION

The Quaternary deposits of the Lithuanian coastal region overlie the Lower Triassic, and Middle and Upper Jurassic rocks, whereas in the environs of Klaipėda, and south of the city, they overlie the Cretaceous rocks. In the palaeo-incision, north of Šventoji, the Quaternary overlies the Upper Permian (Šliaupa 1977). The dominant thickness of Quaternary deposits amounts to 60–80 m in the region, whereas the amplitude thickness fluctuation depends on the character of Quaternary landscape. Because the land surface is most highly uplifted in the southern part of the Lithuanian coastal region (at Rusnė Island), the Quaternary rock mass in this area is thinnest, reaching less than 20 m. Meanwhile, the greatest thickness of Quaternary deposits reaches 80–100 m and in places exceeds 140 m in the Curonian Spit, where the recent aeolian relief is highest, and in the places where deep palaeo-incisions occur. The latter frequently coincide with the alignment of tectonic fault zones, and here the thickness of Quaternary deposits reaches 143 m (in the environs of Palanga).

The Quaternary thickness is predominated by morainic (till) sediments. According to the stratigraphic scheme used by the Lithuanian Geological Survey (Satkūnas, Grigienė 2005; Lietuvos kvartero ... 2007; Žin. 2009, Nr. 74-3055), the Quaternary thickness is composed of Dainava, Žeimena and Upper Nemunas formations generated during glacials or stadials. The distribution of inter-till sediments (except the sediments of Pamarys-Sub-Formation) is fragmentary. They more frequently occur in the lower part of Quaternary thickness: in palaeoincisions and sub-Quaternary relief declensions. Interglacial sediments have not been detected in Western Lithuania. Lacustrine sediments of Lower Nemunas Formation occur locally in the Klaipėda and Šventoji environs whereas up to 20 m thick layer of Late Glacial lacustrine sediments of Medininkai Formation Pamarys Sub-Formation is spread in the greater part of the Lithuanian coastal region.

In the greater part of Lithuanian coast, the Pleistocene formations underlie Late Glacial and Holocene sediments: deluvial formations and alluvial deposits, aeolian sediments, and lacustrine and marine sediments (Figs 7, 8 and 9).

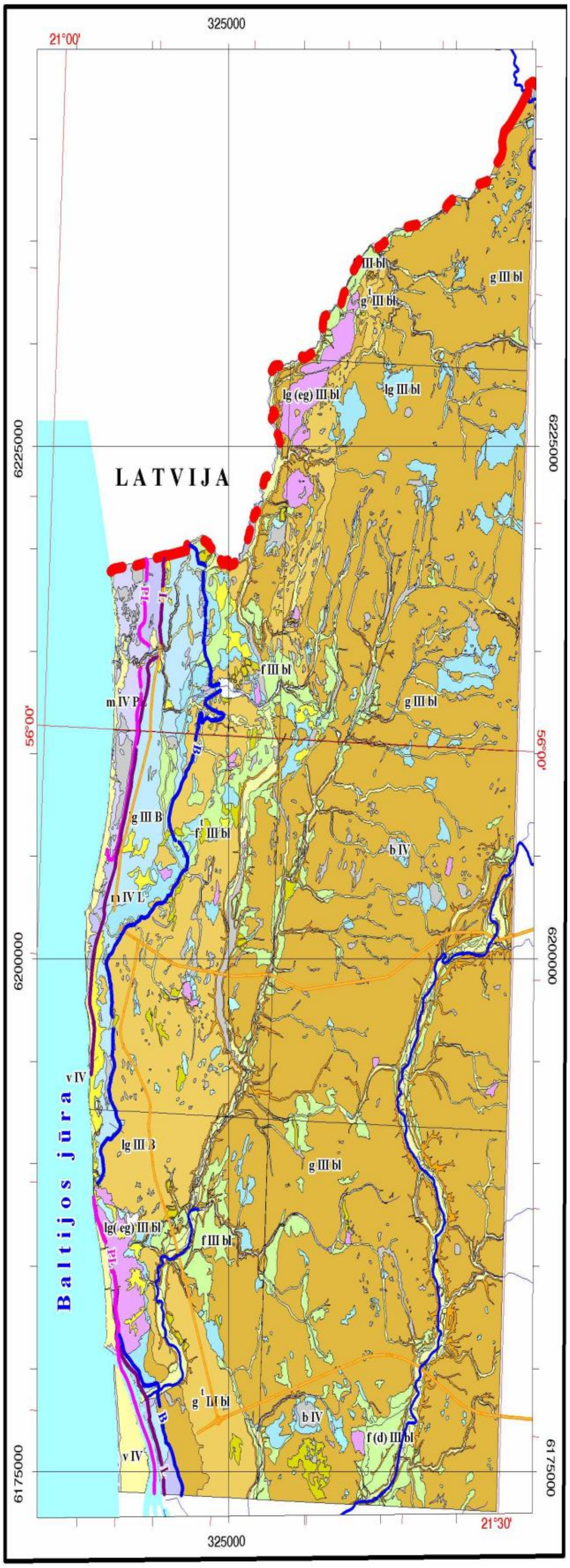


Figure 7 Quaternary geology map of the northen part of the Lithuanian Coastal Region. Schematized. Compiled by author. (For legend see Figure 8.)

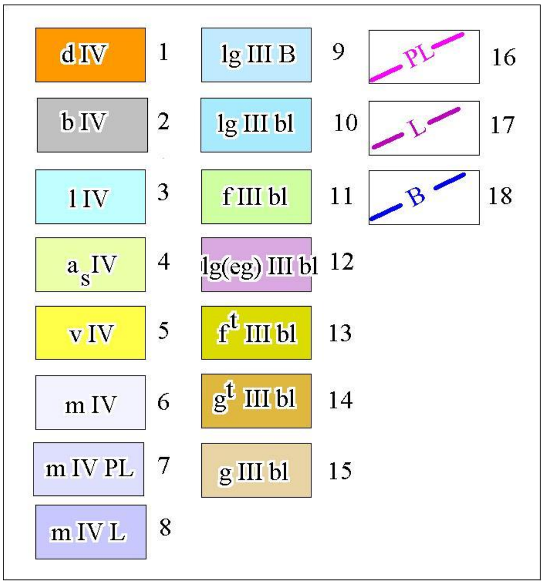


Figure 8 Fragment of legend of the Quaternary geology map. *Stratigraphy and genesis.* Holocene. 1 – deluvial deposits (sand with gravel and pebbles), 2 – biogenic deposits (peat), 3 – limnic sediments (sand, very fine grained, silty gyttja, silt with gyttja), 4 – alluvial (d – deltas, s – flood plane) deposits (sand, fine and medium grained), 5 – aeolian deposits (sand, fine and medium grained), 6 – marine deposits and sediments: m(k) – beach facies, m(l) – lagoonal facies (sand, fine, medium and coars grained, sand with gravel), 7 – Post-Litorina Sea sediments (sand, fine and medium grained), 8 – Litorina Sea sediments (sand, fine and medium grained). Pleistocene. Late Glacial. 9 – Baltic Ice Lake sediments (sand, fine and various grained, clay). Upper Nemunas Formation. Baltija Sub-Formation. 10 – glaciolacustrine sediments (sand, fine grained, silty sand, sandy silt), 11 – glaciofliuvial deposits (f(d) – deltas) (sand, fine, medium and coars grained, sand with gravel, gravel), 12 – englacial glaciolacustrine sediments: lg(k) – kame, lg(kt) – kame terrace (sand, fine grained, silty sand, sandy silt, silt, clay), 13 – marginal glaciofluvial deposits (sand, various grained, sand with gravel), 14 – marginal glacial deposits (till), 15 – basal glacial deposits (till). *Other signs.* Shoreline of Baltic Sea palaeobasins: 16 – Post-Litorina Sea, 17 – Litorina Sea, 18 – Baltic Ice Lake.

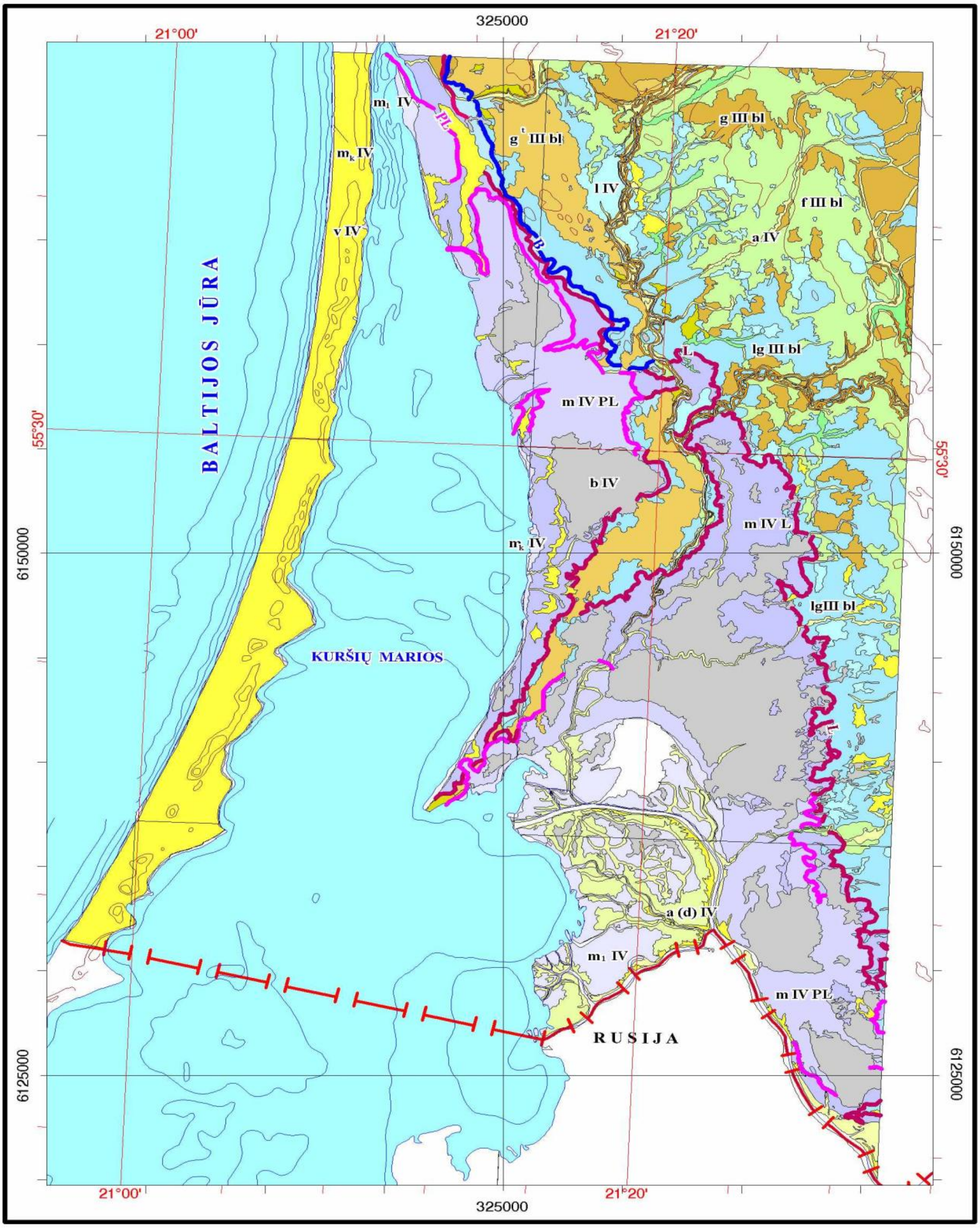


Figure 9 Quaternary geology map of the southern part of Lithuanian Coastal Region. Schematized. Compiled by author. (For legenda see Figure 8.)

The latter are classified as sediments of proglacial lakes, Baltic Ice Lake, Litorina and Post-Litorina seas.

6. WATER-LEVEL FLUCTUATIONS, PALAEOECOLOGICAL AND PALAEOGEOGRAPHICAL CONDITIONS IN THE BALTIC SEA PALAEOBASINS

6.1. Water-level fluctuations in the Baltic Sea stage- basins

The Baltic Sea development dynamics in the Lithuanian coastal region during the post-glacial is best demonstrated by the summary curve of water-level fluctuations in the Baltic Sea palaeobasins (Fig. 10). The proglacial basins formed during the last deglaciation in the Lithuanian coastal region can be regarded as remnants of the Baltic Sea. At that time, approximately 14–13 ka BP, the remains of the last ice sheet still occupied the Baltic Sea depression but organic material and sediments already accumulated in the area of the present coast. A local basin on the Ventės Ragas Cape, accumulating gyttja, formed 13.6 ka BP (Fig. 13) (Bitinas *et al*. 2002). After some time, this lake presumably dried up and 12.5–12.3 ka BP was covered by peat. The shoreline of the Baltic Ice Lake (BIL) at that time in the Lithuanian coastal region presumably did not reach the Ventės Ragas environs (Fig. 11). Thus the shorelines at a higher hypsometric level in the southern part of the Lithuanian coastal region (Fig. 9) have been left by local glacial lake basins rather than BIL. Meanwhile north of Ventės Ragas Cape, the shorelines of the BIL have been noticeably uplifted by glacioisostasy during the Late Glacial: in Klaipėda +7 m, Palanga +10 m and Būtingė +16 m (Fig. 7). The available data are insufficient for determining the precise time of BIL regression. Presumably it took place at 12–11 ka BP. This assumption is supported by the information reported by other researchers: regression on the Polish coast (Uszynowicz 2006) is reported to have taken place at *c*. 12 ka BP, whereas investigations in central Sweden (the drainage area) showed that the BIL regression ended at 11.56 ka BP (Björk *et al*. 2002).

The water level in the Yoldia Sea 11.6–10.7 ka BP was a few tens of metres lower than present and its coasts did not reach the current Lithuanian coastal region. This assumption is supported by the finds of tree stumps on the recent Lithuanian offshore area, near Juodkrantė (the altitudes -27 – -28 m). Here radiocarbon dating gave a date of 10,898±157 – 10,344±76 years BP (Vs-1646, Vs-1372), indicating that this area was

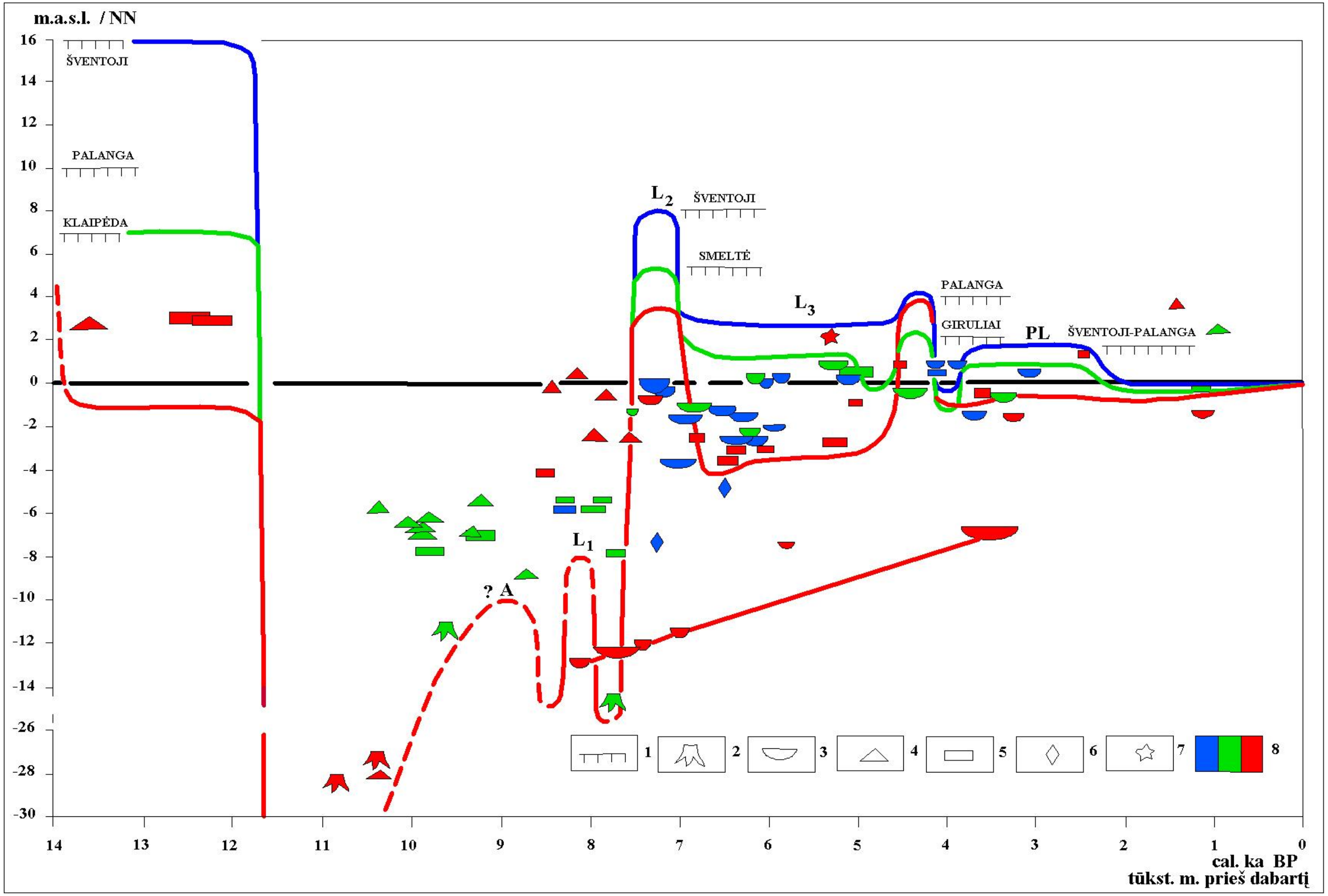


Figure 10 Reconstruction of water level fluctuation (shoreline position) of the Baltic Sea basins during the Late Glacial and Holocene. 1 – terrace, 2 –tree stump, 3 – marine lagoon sediments, 4 – freshwater lagoon sediments, 5 – peat, 6 – molluscs remnants, 7 – archaeological findings, 8 – shoreline position in the different sectors of the Lithuanian Coastal Region: northern – blue, central – green, southern – red.

colonised by pine forests (Bitinas ir kt. 2004) at that time.

Pine forests presumably also continued to grow in this area during the Ancylus Lake phase (i.e. 10.7–8.3 ka BP). This is indicated by the remains of stump dated at 9.6 ka that occur at a depth of 11 m in the offshore area close to Smiltynė. During the maximal transgression, the Ancylus Lake water level could not have exceeded -10 to -8 m (these data do not include the glacioisostic factor) at a higher hypsometric level, the area of the present Klaipėda Strait was occupied by freshwater lakes and bog terrains. The available evidence does not allow the amplitude of the regression to be determined. However, it seems likely that the water level in the present offshore area was no lower than -23 – -25 m. This is demonstrated by the perfectly preserved pine stumps found at Juodkrantė at a depth of -27 m and -28 m. They could only have survived in this condition in reduction environment, i.e. under the water.

The first Litorina Sea transgression (L_1) began at *c.* 8.3 ka BP in coastal region (Fig. 14). At that time, the water level stood at -8 – -7 m, and this account for the fact that a freshwater lagoon (where an 8.2 ka BP ’lagoon marl‘ had been accumulating) had already existed under the area of the present Curonian Spit. The water level could not be higher because, at a higher hypsometric level the central part of the Lithuanian coastal region was occupied by boggy terrain (Fig. 14). This transgression lasted only a relatively short time span and at *c.* 8.0–7.9 ka BP a short regression took place. This is indicated by fossil roots of a tree found at Melnragė at a depth of 14.5 m (7,784±119 years BP) (Vs-1388). The regression was short since by *c.* 7.5 ka BP the maximal Litorina Sea transgression began (L_2). The shorelines left by this transgression were detected at Kintai (+3 m NN), Smeltė (+5 m NN) and Šventoji (+8 m NN) (Fig. 15). The following regression began at 6.9 ka BP. Judging by the freshwater small lakes and bogs in the southern and central parts of the coastal region, the water level must have been a few metres lower than today. Following the regression, the water level remained stable for a relatively long period from 6.4 to 5.1 ka BP). This period was ended by a small regression. The existence of this event can only be judged by a regressive succession of sedimentary palaeoenvironments in the sections at Klaipėda Strait (Figs 3, 5 and 6). Later, at *c.* 4.7 ka BP, one more (the third) small transgression of Litorina Sea (L_3) occurred. During this phase the water level rose once more leaving the shorelines at Giruliai (+2 m NN) and Palanga (+4 m NN) (Fig. 16).

According to the water level fluctuation curve, the beginning of the Litorina Sea transgression in the Lithuanian area corresponds closely with the stratigraphic scheme developed for the Gotland Deep in the Late Glacial and Holocene suggested by E. Andrén (1999). In this scheme the beginning of the Litorina Sea phase is dated at 8.3 ka BP, and reconstructions in South-East Sweden made by other Scandinavian researchers in which the beginning of Litorina Sea to 8.5 ka BP (Yu *et al.* 2005) and the maximal transgression approximately at 8 ka BP when sea level rather rapidly rose by at least 6–7 m. The evidence assembled by Polish workers suggests that a rather rapid rise of sea level with amplitude of 10 m took place between 8 and 7 ka BP (Uscinowicz 2006). Estonian researchers also have reported that the maximal Litorina Sea transgression took place no earlier that 8–7 ka BP and the water level rose 7 m (Veski *et al.* 2005, Rosentau *et al.* 2010). It is worth mentioning here that during the second Litorina Sea transgression (L_2), the water rise was very fast. Presumably in no more than one hundred years, the water level rose 20 m. German scientists: the sea level on the West Pomeranian coast abruptly rose by over 10 m at 7.9 ka BP, (Harff *et al.* 2001). This rapid water rise presumably explains how aeolian formations were able to survive near the Kaliningrad sector of the Curonian Spit (Блажчишин 1998).

The beginning of Post-Litorina Sea in the Lithuanian coastal region can be associated with the final marine transgression at *c.* 3.9 ka BP. The traces of terraces formed by this transgression indicate that the water level at that time was 2 m higher than it is today in the Palanga–Šventoji sector (Fig. 17). Further water-level fluctuations of this sea cannot be judged because of the lack of geochronological information. It is possible only to assume that the Post-Litorina Sea level began falling at *c.* 2.4–2.2 ka BP and gradually reached the present-day level.

It should be emphasised that the reconstruction of water-level fluctuations in the Baltic Sea basins is encumbered by the fact that the ancient shorelines have not only been unequally affected by glacio-isostatic movements of the crust in different parts of the Baltic basin, but they have also deformed by oscillatory movements of the Earth crustal blocks. This is especially obvious in the northern part of the coast where, for example, deformations associated with neotectonically active faults of the Earth’s crust can be seen in the terrace formed by the maximal Litorina Sea transgression (Šliaupa *et al.* 2005).

6.2. Proglacial lakes

On the basis of cosmogenic dating of boulders in Lithuania, the last ice sheet melted by *c.* 13.3 ka BP (Rinterknecht *et al.* 2008). Similar evidence has been obtained during investigation of peat deposits in the environs of Kašučiai where the formation of organic deposits began somewhat before 14.5 ka BP (Šeirienė *et al.* 2006). There is a good ground for assuming that *c.* 14 ka BP, proglacial lakes occupying the Baltic Sea depression began submerging the Lithuanian coastal region. Detailed decoding of black-and-white aerial photographs from different years and at different scales, together with comparison of the information obtained with other available geological material, has allowed a detailed description of marks of palaeobasins in the recent landscape and their plotting on geological–geomorphological maps of the coastal region (Figs 7 and 9).

The lake which submerged the northern present offshore of the country reached the western slope of the marginal ridges where at an absolute altitude of +37 m, a flat ice-marginal terrace was formed, the surface of which was later reworked by aeolian processes (Fig. 7). The basin occupying the western edge of the present land between the blocks of dead ice formed a large ice-marginal plateau. A fragment of its eastern part (the western part has been abraded during the following Baltic Sea stages) can be seen in the neighbourhood of Giruliai. The sediments of these proglacial basins are spread on the both sides of the marginal Rimkai–Ventės Ragas Cape ridge, the left bank of the Minija River, and the south of Šilutė, in the Rusnė Island, the Curonian Spit and under the Curonian Lagoon (Fig. 9). In the Kintai area, the glaciolacustrine sediments overlie glacial Middle Pleistocene formations at the eastern bottom of marginal ridge. The absolute altitude of the top of the glacial sediments on the Curonian Lagoon coast and under the lagoon ranges from -19 – -20 m (beneath the spit and the lagoon) to -7 – -9 m (on the Rusnė Island). In the Coastal Plain and Nemunas Delta region, the traces of proglacial lakes can be seen at a absolute altitudes of 40, 16–20 and 6–8 m above present sea level. The proglacial sediments consist of fine-grained to very fine sand with silt, silt and silty clay. The thickness of the layer is 0.6–4.0 m.

6.3. Baltic Ice Lake

During the end of the Oldest Dryas Stadial (DR2) – Allerød Interstadial (Al) – Younger Dryas Stadial (DR1) (the time of existence of the Baltic Ice Lake; about 13.7–11.6 ka BP), the present Lithuanian coastal region was submerged by the waters of the Baltic Ice Lake (BIL). The BIL formed in the southern part of the Baltic Sea depression when local basins joined into one large proglacial body of water.

At the beginning of its existence, the BIL waters reached the western slope of the marginal formations' sector (Figs 7 and 9), occupying the present coastal region, and remodelling the area by abrading and smoothing it. Active accumulation processes formed the BIL terrace observed in the coastal sector between Karklė and Šventoji and in Klaipėda (Figs 7, 11 and 12).

In the environs of Palanga–Šventoji, the BIL formed a largely undulating plain with a flat and wide ridge stretching in the centre of the area. Near Palanga, this terrace surface reaches 9.5–10 m in height, whilst north of Būtingė it occurs at 12–16 m above the present sea level. In places, single dunes and even large dune complexes can be seen. The ridge at the centre of the terrace is flat (relative altitude 1.5–2.0 m) and wide (200–300 m). The second, slightly narrower ridge can be seen on the northern part of the terrace. The eastern (northern central area) part of the terrace is dissected by a wide, flat valley. To the east, the BIL terrace plain merges into a region covered by glaciolacustrine sediments which abut the marginal morainic formations (Fig. 7).

In the Palanga–Karklė coastal sector, the BIL terrace plain occurs at an absolute altitude of up to +16 m (Palanga). Towards the south, it gradually declines to an absolute altitude of +6 m (at Karklė). The flat surface of the terrace is covered by dunes towering to a height of 16 m above present sea level. The eastern margin of the terrace is represented by a washed-out, wide valley cut into the surface, whilst the western margin is marked by an abrasion slope. In the Klaipėda city area, the planar BIL surface reaches absolute altitude of +7 m. In the east, this terrace plain merges into the ground moraine till plain, whereas a terrace plain of Litorina Sea abuts its western edge.

In many places south of Klaipėda, the top of the BIL sediments occurs below the present sea level, between the absolute altitude at marks -2 – -3 and -12 – -13 m. The only exception is between Klaipėda and Priekulė where the sediments are exposed at the

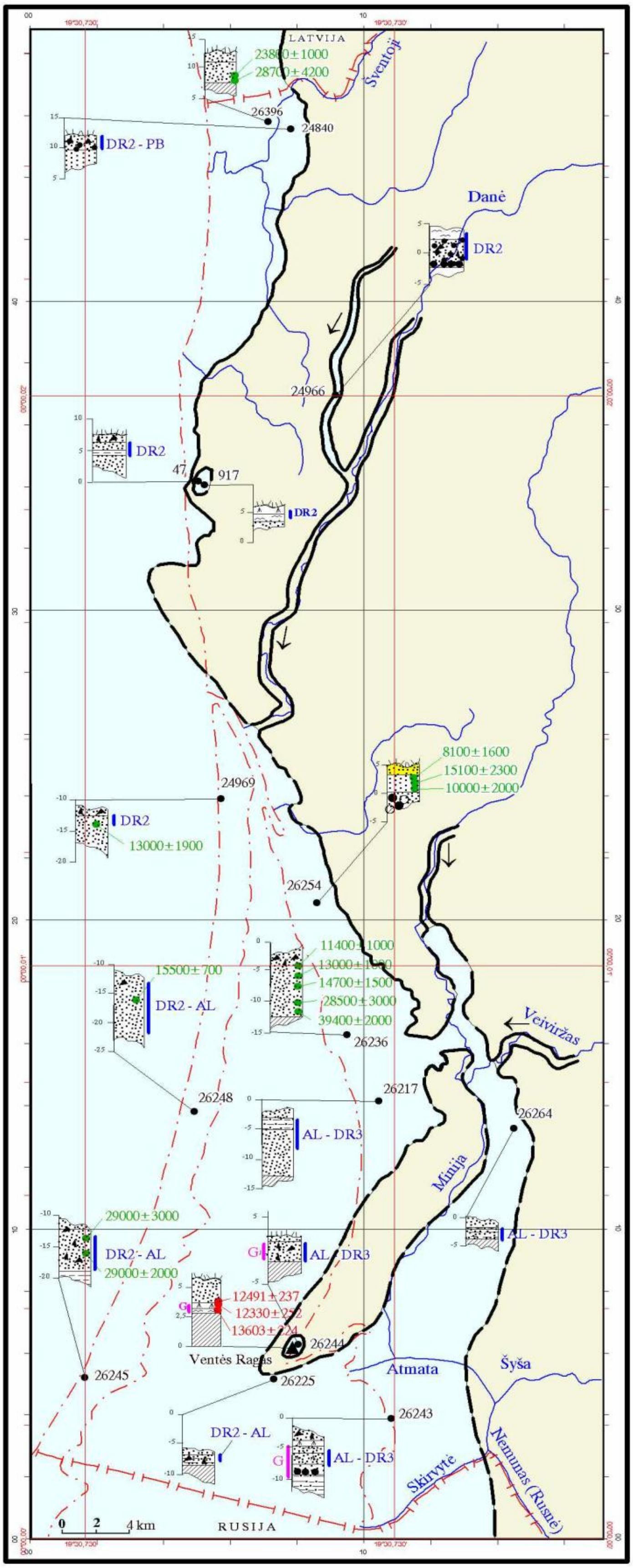


Figure 11 Palaeogeographic scheme of the Baltic Ice Lake (about 13.0–11.7 ka BP). (For legend see Fig. 12.)

land surface as a narrow terrace (Fig. 9). South of Klaipėda, the BIL waters washed the western slope of the marginal ridge in the Rimkai–Priekulė area leaving a plain 6 m above present sea level and shoreline features at an absolute altitude of 7 m (Fig. 9). In the sediments on the western margin of the Svencelė bog, M. Kabailienė found very well preserved diatoms typical of the BIL: planktonic *Aulacoseira islandica morph. helvetica* and benthic *Campylodiscus noricus var hibernicus*, *Cymatopleura elliptica*, *Opephora martyi* and *Paralia arenaria* (Kabailienė 1959a, 1959b, 1960; Stančikaitė, Kabailienė 1998). This author, who also analysed diatoms from borehole 26244 sediments, ‘the entire sector is dominated by freshwater diatoms typical of oligotrophic basins, including *Opephora martyi*, *Navicula scutelloides*, *Fragilaria inflata* et var. *istvanfyi* and *Achnanthes lanceolata* et var. *elliptica* (Kabailienė 1959a, 1959b, 1960; Stančikaitė, Kabailienė

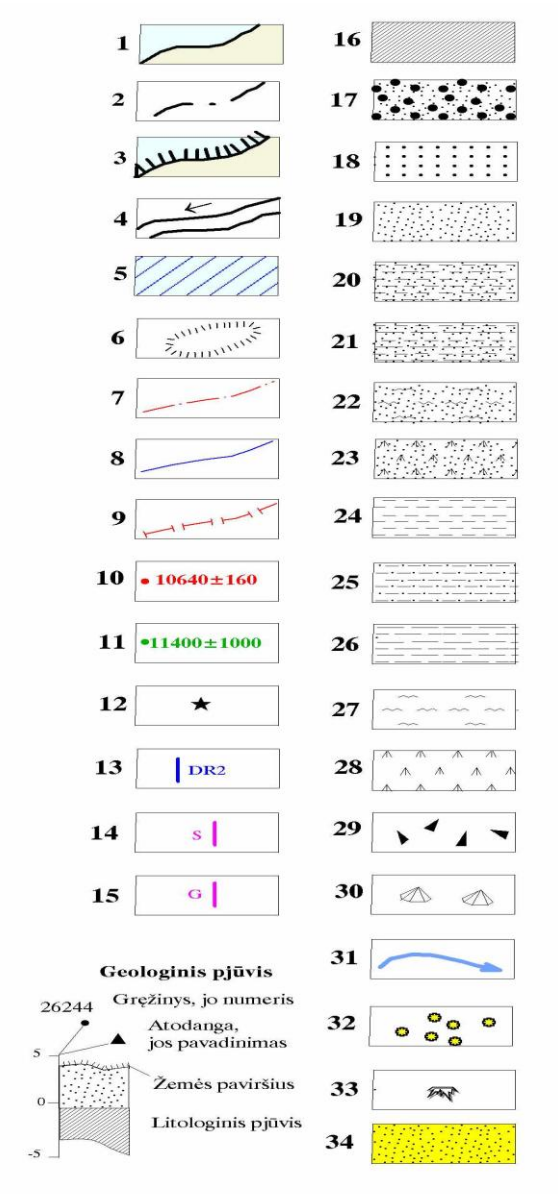


Figure 12 Legend for Figures 11, 14, 15, 16 and 17. *Shoreline of palaeobasin:* 1 – determined by geomorhologic criteria and ir aero-photoimages, number on the line – age of palaeocoast (years BP), 2 – supposed position of shoreline, 3 – shoreline of residual basin, 4 – palaeoriver, 5 – range of 'lagoon marl', 6 – bog, 7 – recent shoreline, 8 – recent river, 9 – state boundary. *Absolute age of sediments (years BP), determinated by:* 10 – radiocarbon (^{14}C) method, 11 – optically stimulated liuminescence (OSL) method, 12 – archaeological findings, 13 – chronozones according to pollen data (DR1 – Oldest Dryas, DR2 – Older Dryas, AL – Alleröd, DR3 – Younger Dryas, PB – Preboreal, BO – Boreal, AT1 – Early Atlantic, AT2 – Late Atlantic, SB1 – Early Subboreal, SB2 – Late Subboreal, SA1 – Early Subaltantic, SA2 – Late Subaltantic). *Palaeoecological condition (salinity) of the basin according:* 14 – diatoms, 15 – molluscs (G – freshwater basin, S – brackish basin, G(S) – freshwater basin with influence of brackish water *Lithology:* 16 – till, 17 – gravel, 18 – sand, various grained, 19 – sand, fine grained, 20 – silty sand, 21 – silty and clayely sand, 22 – sand with gyttja, 23 – sand with peat, 24 – silt, 25 – sandy silt, 26 – clay, 27 – gyttja, 28 – peat. *Other sings:* 29 – remnants of fine grained organic matter, 30 – remnants of molluscs, 31 – direction of amber transportation, 32 – area of amber accumulation, 33 – tree strump, 34 – aeolian deposits.

1998). Presumably the sediment she examined formed in the littoral zone of a bay of the BIL'. In the present author's opinion, the area of the Ventės Ragas Cape outcrop and that of borehole 26244 (Fig. 13) cannot be identified although they are spaced only 200 m apart. They are absolutely not related to each other. The related disputable questions (a small lake on the shore of the BIL or a bay?) could be answered after detailed complex investigations.

The BIL sediments in the coastal zone between Šventoji and Karklė are composed of sand of varying grain-sizes (sometimes including gravel and silt), or in rare cases of silt or clay, comprising a stratum 0.7–7.8 m thick. The thickness of this BIL sand bed south of Melnragė ranges from 4 to 5 m and in the Curonian Spit area, where it is buried beneath thick Holocene formations (up to 15–20 m), its thickness is 0.2–4.7 m.

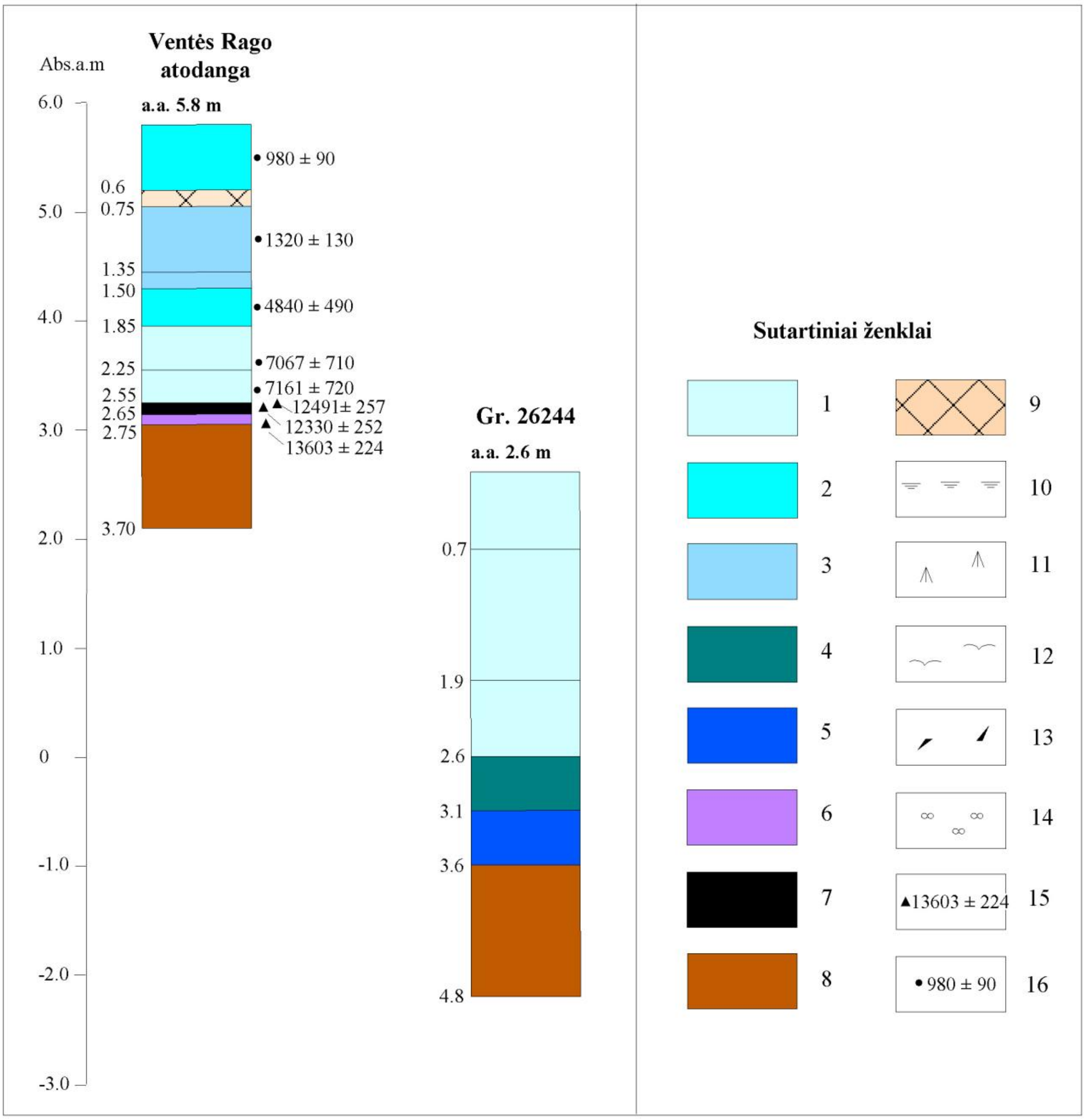


Figure 13 Sections of Ventės Ragas Cape outcrop and borehole 26244.
1 – sand, fine grained, 2 – sand, very fine-fine grained, 3 – sand, fine-very fine grained, 4 – silty sand, 5 – sandy silt, 6 – gyttja, 7 – peat, 8 – till, 9 – athropogenic deposits, 10 – soil, 11 – admixture of peat, 12 – admixture of gyttja, 13 – remnants of fine grained organic matter, 14 – remnants of molluscs, Absolute age of sediments (years BP), determinated by: 15 – radiocarbon (^{14}C) method, 16 – optically stimulated liuminescence (OSL) method.

6.4. Yoldia Sea

In the Preboreal (PB) (about 11.6–10.7 ka BP), the water of the BIL drained through a strait in central Sweden into the Atlantic Ocean where the water level was considerably lower than that of the BIL. The succeeding Yoldia Sea basin – therefore in contact with the ocean, the water level being low and the shoreline situated further to the west than that previously. Its shoreline should be occurr in the region of the -40 – -50 m isobaths beneath the present Baltic Sea (Gudelis 1955; Kabailienė 1967; Kabailienė *et al.* 1996; Raukas 1995; Schoning 2001).

6.5 Ancylus Lake

The Ancylus Lake existed in the area of the present Baltic Sea from the second half of Preboreal (PB), throughout the Boreal (BO) until the beginning of the early Atlantic (AT1) period, i.e. 10.7–8.3 ka BP (Andrén 1999). Yet the occurrence of this lake’s shoreline in the Lithuanian area is still a matter of debate. According to M. Kabailienė (1959b), Ancylus Lake diatom assemblages have been found in the sediments – clay and sand with silt – of the Danė River valley at a depth of 5–6 m. These sediments contained a rich freshwater diatom flora dominated by forms typical of oligotrophic ’transparent water‘ of the Ancylus Lake. They included *Campylodiscus noricus var hibernicus, Epithemia hyndmanii* and *Opephora martyi*. Some of the dominant diatoms were represented by species flourishing in organic-rich, eutrophic basins, such as *Gyrosigma attenuatum, Cymatopleura elliptica, C. Solea, Surirella caprioni, Rhopalodia gibba* and *Anomoeoneis sphaerophora*. However, these samples did not contain *Melosira arenaria*, a species which favours sandy bottomed water bodies and has been habitually occurred with the Ancylus Lake diatoms. Summarising the results obtained from the diatom assemblages of Danė River valley, M. Kabailienė concludes that the mixed composition of the diatom flora, including a large number of eurihalyne species, implies that the sediments accumulated in an eutrophic environment in the silty and overgrown littoral zone of the Ancylus Lake (Kabailienė 1959b). In addition, sediments containing a few freshwater diatoms, which could have inhabited the Ancylus Lake, were found at a depth of 8.8–11.1 m below sea level in a borehole drilled 2.4 km north of the Nida lighthouse (the diatom analysis from borehole 26245 was carried out by M. Kabailienė), in Smiltynė (Kabailienė *et al.* 2009) (borehole 36859; sediment -8.8 – -9.5 m. According to G. Vaikutienė this represents the ’littoral zone of the Ancylus Lake during the end of Boreal regression’), the Nida area at a depth of 12–24 m NN (Kabailienė 1959), and at Juodkrantė (Kabailienė 1969). Based on reconstructions of the water-level fluctuations in the Baltic Sea basins, suggested by Ž. Gelumbauskaitė (2000, 2002, 2003), the water level of Ancylus Lake near the Lithuanian coasts must have been 4 m below that of the present sea level. Thus, the shore of the Ancylus Lake presumably occurs beneath the present Curonian Lagoon. However, molluscs typical of the Ancylus Lake have not been recovered from the sections examined.

Presumably, the terrestrial regime established following the Baltic Ice Lake regression, at the end of the Younger Dryas Stadial (DR3), persisted throughout Boreal time (BO) until the early Atlantic (AT1) in the Lithuanian coastal region, i.e. this area was land and the Ancylus Lake water level during the maximal regression was 8–10 m below present sea level. It is possible that the first rudiments of the Curonian Spit emerged during that time. The available evidence indicates that small freshwater lakes and peat bogs occurred in the Klaipėda Strait area from 10.7–9.0 ka BP. No evidence is known to indicate whether or not these sediments were submerged at the end of Ancylus Lake transgression 9.0–8.3 ka BP. Moreover, at that time, the coastal area of the Baltic Sea was overgrown by pine forests indicated by a pine stump dated at 9.6 ka BP found at a depth of 11 m in the submerged area off- Smiltynė.

The data about the existence of the Ancylus Lake in the Lithuanian coastal region are comparatively scantier in comparison with the data about other Baltic Sea stages. Often also they are contradictory. For this reason, reliable identification of the shoreline of Ancylus Lake and reconstruction of the palaeogeographical conditions of those times are impossible. The reconstruction of palaeogeographical conditions is possible only on the basis of the data obtained during bottom investigation what was not the goal of the present work.

6.6. Litorina Sea

With the rising level of the global sea-level at the beginning of the early Atlantic period (AT1), the first wave of the Litorina Sea transgression reached the Lithuanian coastal region. The Litorina-Sea stage lasted until the late sub-Boreal period (SB2), i.e. from *c.* 8.3 to *c.* 3.7 ka BP (Andrén 1999). The Litorina-Sea sediments are found over the whole coastal region of Lithuania. The thickness of the sediment unit is from 1–2 m in the southern part of the Curonian Spit to 8–14 m beneath the Spit and the Curonian Lagoon. The present coastal region bears features inherited from three Litorina-Sea transgressions: 8.3–8.0 (L_1), 7.5–7.0 (L_2) and 4.7–4.1 (L_3) ka before present.

The first of these transgressions (L_1) was not intensive: the water level in the basin was 7–8 m below the present Baltic-Sea level (Fig. 14). No marks of the first transgression occur in the present terrestrial area. Sandy and clayey sediments accumulated 8.3–8.0 ka ago, and containing a few typical marine and mesohalobe diatoms, were only detected as a 0.7–3.0 m thick stratum in boreholes (24799) (Kabailienė 1998). In the middle of the early Atlantic (AT1), almost the whole Curonian Lagoon (borehole 26225), the Nemunas Delta (boreholes 26243, 26271) and the present Baltic Sea offshore area (approximately to the -8 m isobath) north of the Olando Kepurė Cape was a terrestrial area that supported, river channels and bogs (917, 24816, 24966, 35256, etc.). By that time, a continuous narrow spit had formed in the sea. The ’nose‘ of this feature might have reached the latitude of Olando Kepurė. This ancient spit isolated the already existing embayment from the open sea forming a lagoon, limiting the inflow of saline water into the basin. The oldest radiocarbon-date ’lagoon marl‘ recovered in this study is 8.3–8.2 ka which implies that the ancient spit might have emerged even before the beginning of the first Litorina-Sea transgression, i.e. already when the Ancylus Lake was present. The ancient spit began forming west of the present spit as a sand bar (the eroded shore of Sembian peninsula were the source of the sand). Through the course of time this bar developed into a sand shoal separating the lagoonal embayment from the open sea. The existence of the ancient spit as well as its location and boundaries are indicated by the distribution of the ‘lagoon marl‘ deposit underlying

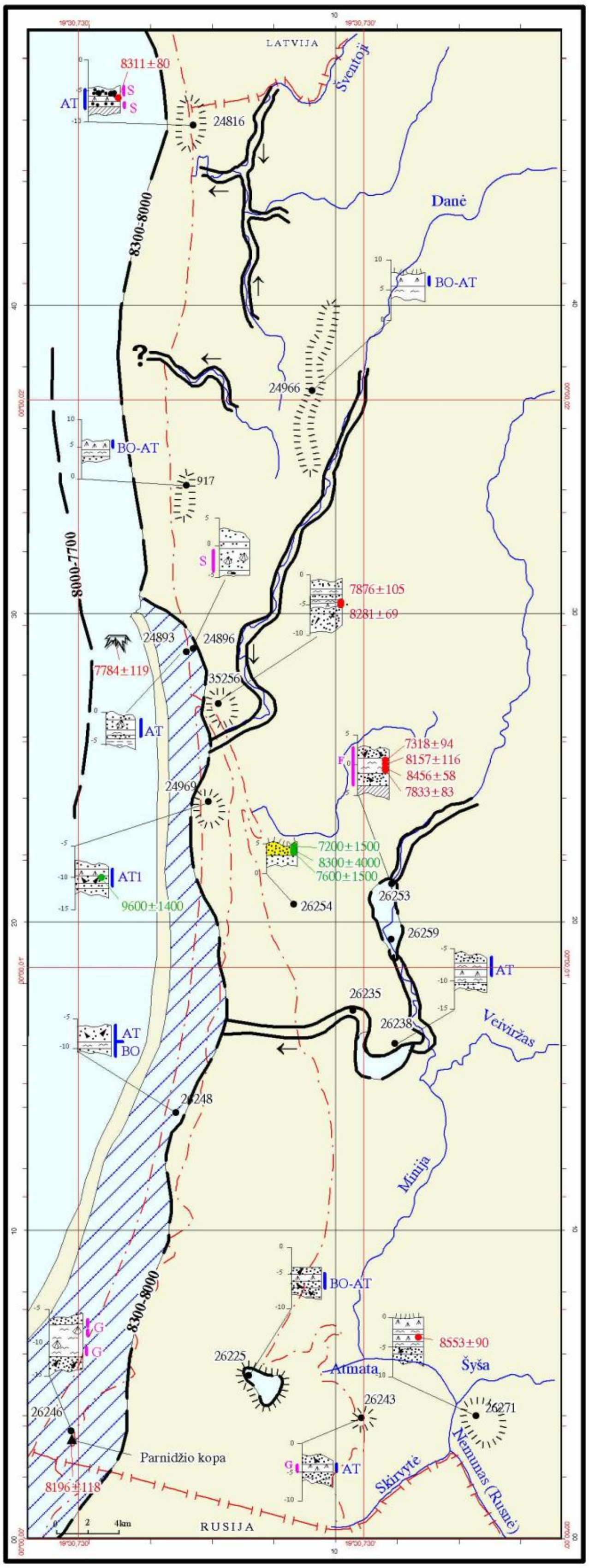


Figure 14 Palaeogeographic scheme of the first Litorina Sea transgression (8.3–8.0 ka BP). (For legend see Fig. 12.)

the present Curonian Lagoon and Spit (this unit has been detected in a few tens of boreholes; the data is available in the Geological Archive, Lithuanian Geological Survey) and in Melnragė (24893; an absolute altitude -3.2 – -4.3 m). The distribution of the lagoonal sediments (Fig. 14) shows that the ancient spit (as reported by V. Gudelis in 1955 and 1979) was situated about one kilometre or more to the west than the present Curonian Spit. Thus there is sufficient evidence to support the existence of the ancient spit. However, the causes of its emergence are uncertain: whether it was inherited from the Ancylus Lake or formed as a sand bar during the Litorina Sea and during later transgression events, and migrated to a higher hypsometric level. It is not clear whether the flat, perfectly polished of crystalline rock pebbles are alone a product of abrasion of hypsometrically lower-bedding till exposed in the underwater slope at Juodkrantė. Gyttja-bearing sandy silt with impurities of organics (up to 11–16%) and containing fossil wood, together with molluscs and fish bones dated to 5.3 ka, accumulated on the lagoon bottom that emerged during the first Litorina-Sea transgression (Buynevich *et al.* 2009). During this phase, the water in the lagoon was fresh, as indicated by a rich community of freshwater molluscs preserved within the ’lagoon marl‘ (Table 7). Judging from the freshwater diatom assemblage recovered from these sediments, the deposits accumulated under the eutrophic conditions in the littoral zone of the freshwater basin during the Atlantic (AT) – Subboreal periods (SB) (Kabailienė 1959b, 1967, 1996, 1997a; among others). By contrast, analysis of fossil molluscs (Table 7) serves as a basis for the assumption that a shallow closed freshwater basin existed here at this time (Damušytė 2006, 2009).

In the author’s opinion, this lagoon should be regarded as the predecessor of the Curonian Lagoon because throughout its further history, the basin always remained to a greater or smaller extent isolated from the open sea. Therefore, the first Litorina-Sea transgression should be regarded as a generator of the ancient lagoon and spit which, though slightly deformed, eventually attained their present form.

In many sections, the sediments of the first Litorina Sea transgression (L_1) underlie a peat and sand layer with abundant fossil plants, up to 1.2 m thick, deposited at the end of early Atlantic. This proves the assumption that the first Litorina-Sea transgression lasted for a relatively short time and already in the early Atlantic (AT1) (8.0–7.6 ka BP), pine forests grew on the coast of the dried-up basin (at a depth of 14.5 m in the Baltic Sea at Melnragė, pine stumps aged 7,784±119 years BP (Vs-1388) were found; Fig. 14), peat deposited in landscape depressions, and gyttja containing very small fragments of freshwater mollusc shells accumulated in small lakes (borehole 26238).

A new Litorina Sea transgression (L_2) is associated with the end of the early Atlantic (AT1) to the beginning of the late Atlantic (AT2). This second Litorina-Sea transgression (L_2), which took place 7.5–7.0 ka BP, though short, was the most intense one (Fig. 15). The water level of this phase rose above present sea level, submerging the whole present coastal region. In its northern part, the shoreline traces occur at left 8 m above present sea-level, whilst in the central part they occur at 5 m and in the southern area, they are at 3 m above the present water level. The second Litorina-Sea transgression submerged the northern part of the narrow but continuous ancient spit, leaving a few isolated islands. Through the breach between the islands, the sea currents transported amber from the Sembian peninsula into the ancient lagoon. Today amber deposits are found in the Kiaulės Nugara shoal and at Juodkrantė (Tamkutonis 1960, Valiukevičienė, Gasiūnienė 1995). Thus amber assemblages in the Lithuanian offshore should be related to the beginning of the second Litorina-Sea transgression when with the rising water the zone of intensive coastal erosion on the Sembian peninsula reached the amber-bearing Palaeogene strata.

The inflow of brackish marine water to the lagoon was limited, allowing the water mass of the ancient lagoon to remain fresh. Although the pauses in the sedimentation process (Fig. 15) were long, ’lagoon marl‘ continued accumulating on the lagoon bottom. The molluscan analytical evidence indicates that the basin contained freshwater, it was closed and shallow. According to other authors, this could have been a shallow, almost closed embayment or lagoon of the Litorina Sea. This assumption is based on the fact that the sediments from the basin yield diatoms typical of the Litorina Sea itself (Kabailienė 1967, 1999). In spite of this it is also possible that these diatoms were swept from the open sea across the then narrow spit by marine water during storms.

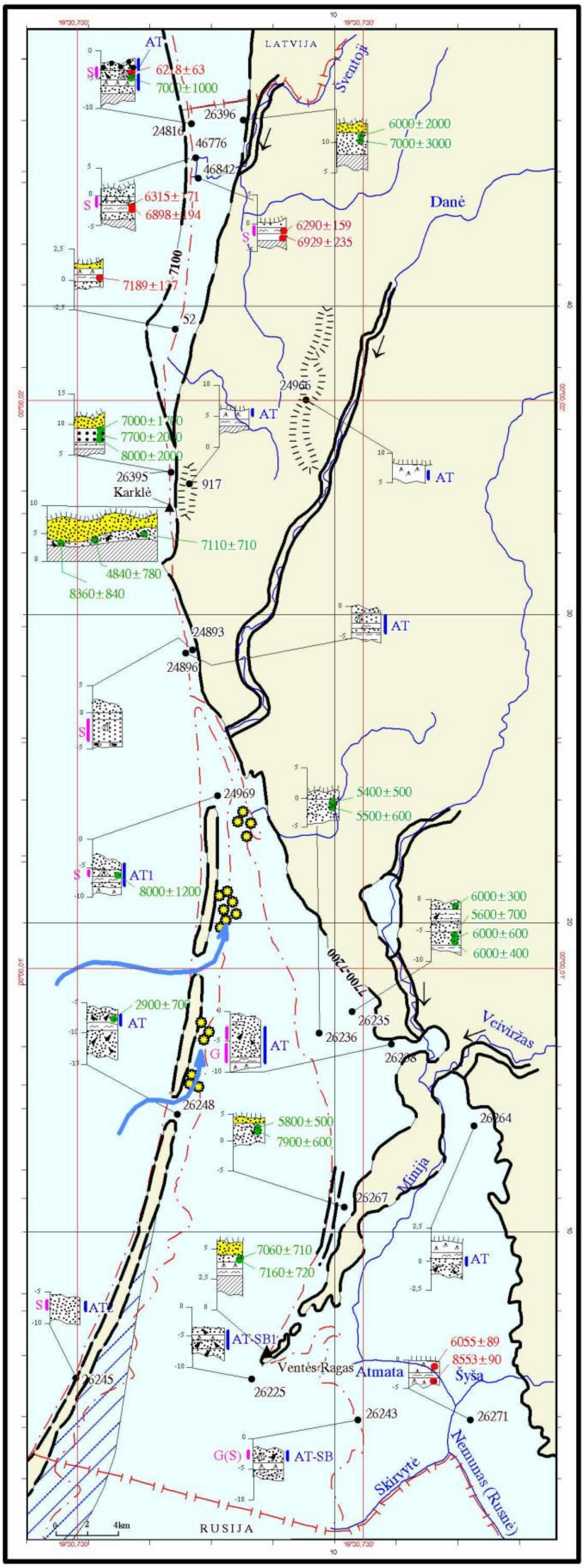


Figure 15 Palaeogeographic scheme of the second (maximal; 7.5–7.0 ka BP) Litorina Sea transgression. (For legend see Fig. 12.)

Thus the second or maximal Litorina-Sea transgression, which took place in the early Atlantic period, transformed the ancient landscape. The Baltic Ice Lake terrace in the northern part of the present Lithuanian coastal region in many places was degraded and a new, lower terrace emerged.

As a consequence of the coastal erosion, a rather high marine cliff, in places exceeding 20 m in relative height, developed in the sector between the Palanga and Klaipėda. The Litorina-Sea level fluctuations conditioned deposition of sediment layers either characteristic of the offshore or of the lagoon. Both in the northern and southern parts of the present coastal region, a series of recession coastal terraces and ridges survived. The humid and warm climate of the first half of Altantic, and the elevated groundwater level, caused the increased bog-formation processes. In the region of the present Nemunas Delta, these processes began by 7.5–6.0 ka BP (Bitinas *et al.* 2002). Frequent and intensive rainfall, water-level fluctuations in the Litorina Sea and neotectonic movements of the Earth's crust periodically activated fluvial erosion processes. At that time, sectors of the present Šventoji, Darba and Žiba erosion river valleys began being incised across the Baltic Ice Lake terrace. There also emerged a widespread erosion hollow extending across the terrace south of Palanga.

With the rising water level in the ocean, during the second Litorina-Sea transgression, the greater part of marine mollusc species (still inhabiting the basin) reached the ancient basin (Boyden 1971). During the climate optimum in the Atlantic time (AT), littoral molluscs, especially a Bivalvia fauna of brackish and saline water, flourished. The sediments of Litorina Sea sampled from the boreholes in the coastal region in particular contain many valves of fossil *Cerastoderma glaucum, C. edule* and *C. crassum* were identified (Tables 6 and 8).

Analysis of malacofauna showed that sandy, sometimes silty, bottom sediments containing molluscs that accumulated in the littoral and coastal zones (basin depth up to 5–10 m) of a saline basin (salinity about 5–8‰), i.e. the palaeogeographical conditions and species composition of the molluscs were typical of the Litorina-Sea basin (Boyden 1971, Kessel 1985, Damušytė 2009).

Meanwhile, the characteristics of the fossil molluscs (shells and valves) found in the Curonian spit (Nida environs, Table 7), the Curonian Lagoon (Table 9) and Nemunas Delta (Rusnė Island, Table 11) boreholes imply that in the Atlantic period, the water of the lagoon occupying the present area of Curonian Lagoon and Nemunas Delta was fresh, judging from the detected freshwater fossil *Gastropoda* and *Bivalvia*.

At the end of the second Litorina-Sea transgression, the shoreline of the then sea was almost the same as it is now. North of the present Palanga, a semi-enclosed lagoon developed (boreholes 46776, 46829 and others) separated by a narrow spit from the open sea. A lagoon still occupied the area of the present Rusnė Island at this time. The position of the spit was close to the present one: presumably, its formation was completed by no later than 6.0 ka BP and it was populated by *c*. 5.3 ka BP (Rimantienė 1999).

By *c*. 6.6 ka BP (Fig. 14), the Litorina-Sea level in the Nemunas Delta area fell to -4 – -5 m. The previous bays evolved into shallow lagoons in which bog-formation processes intensified, generating some of the largest bogs of the region: Aukštumala, Svencelė and Rupkalviai. Presumably at the same time, following the Litorina-Sea level fall, the Minija River changed its course, turning southwards from Priekulė. This transformation of the hydrographic network was probably also influenced by oscillating neotectonic movements of the underlying crustal blocks.

The Curonian Spit development continued. On the basis of radiocarbon dating of buried soils, the first generation of parabolic dunes had already emerged in the Subboreal period. At the same time, the aeolian processes slowed and the first soils began to form.

The oldest palaeosoil identified in the sequence is dated to 5,301±190 years BP (Гаигалас и др. 1989). However, it seems likely that soil formation began considerably earlier, bearing in mind that radiocarbon dates from deposits in the aeration zones (here soil layers in the sand stratum) often resulted in rejuvenation of the soil profiles (Arslanov 1987).

The third, and final Litorina-Sea transgression (L3) was considerably weaker. It began during the second half of the early Subboreal time (SB1) *c*. 4.7 ka BP and ended at the end of the early Subboreal period (SB1) *c*. 4.1 ka BP. The shoreline left by the Litorina Sea occurs at: 4 m in the northern part of the present coastal region, and at 2 m in the central part above the present sea level. In the southern area, the shoreline is presumably 3–4 m below the present sea level. The terraces generated by this third transgression are visible at Palanga and Giruliai (Fig. 16).

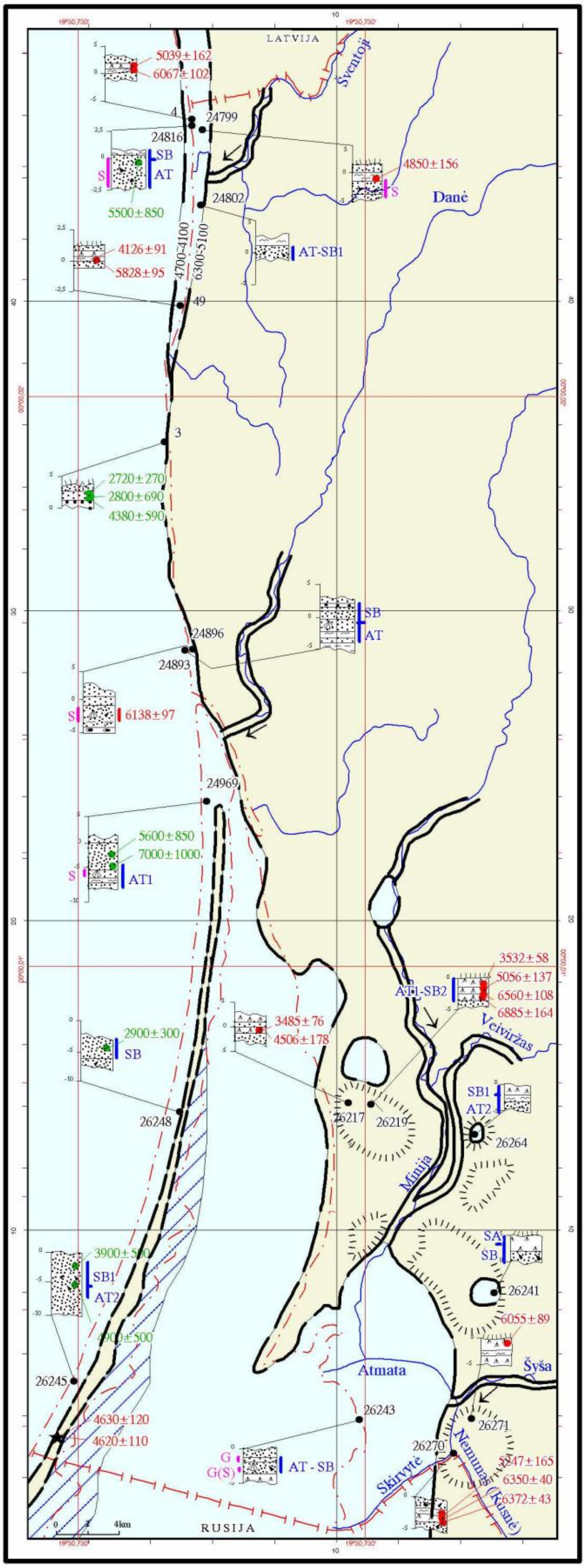


Figure 16 Palaeogeographic scheme of the third Litorina Sea transgression (4.7–4.1 ka BP). (For legend see Fig. 12)

The marine (offshore, lagoonal and coastal) Litorina-Sea sediments are distributed along the whole Lithuanian coast, except in a small section between Olando Kepurė Cape and Nemirseta. In places, the sediments underlie the Post-Litorina Sea marine, alluvial (Nemunas Delta) and aeolian sediments, and antrophogenic formations (in Klaipėda city). The top of the sediment unit is exposed on the mainland coast (e.g. an absolute altitude in the Būtingė area at 7–8 m). Beneath the Curonian Spit and Lagoon it dips to 10–12 m below the present sea level. The variation in the thickness pattern of this stratum is similar, beginning at tens of centimetres in the former offshore of the Litorina Sea, and increasing to 7–10 m in the western periphery of the present coastal region. Based on their lithological composition and sedimentary environment, the Litorina-Sea sediments can be classified into offshore and lagoonal deposits. The offshore sediments are most widespread, yet in the central and southern parts of the reference area, the upper part of sediments were probably deposited under lagoonal conditions. The offshore sediments are mainly represented by fine-grained sand, in places intermixed with silt, and in fewer cases with silt, sandy silt, sand and silt or even sand with pebbles. The sandy sediments often contain organic materials and even fossil molluscs. The lagoonal sediments are represented by silt mixed with gyttja or sand with gyttja and peat (e.g. Šventoji area, borehole 46810, and others, Fig. 1).

6.7. Post-Litorina Sea

In the course of its’ shoaling and freshening, the Baltic Sea entered the subsequent, Post-Litorina, development stage. This period lasted from the beginning of the late Subboreal (SB2) till the beginning of the late Subatlantic time (SA2), i.e. from 3.7 to 0.7 ka BP. The Post-Litorina water level was slightly lower than that of Litorina Sea, in the northern part of the region the shoreline can be traced at 2 m and in the central part 1 m above the present sea level, whilst in the southern part it occurs at 1 m below the sea level. The position and form of Post-Litorina Sea shoreline is comparable to the present shoreline, except that there were more embayments and lagoons. One of these features persisted in the environs of Šventoji (Fig. 17). This already populated, shallow, freshwater lagoon, was separated from the open sea by a sand spit (Rimantienė 2005). Shallow bays also existed at Dreverna and in the present Nemunas Delta area. The landscape generated by Post-Litorina Sea transgression 3.7–2.4 ka BP (Fig. 17) can be seen in the Vanagupė–Šventoji and Olando Kepurė–Melnragė districts (Fig. 17). Here the surface of Post-Litorina Sea terrace is elevated in the southerly direction from 0.3 m (north of Būtingė) – 1.8 m (at Šventoji), to 4.0 m in the Vanagupė area. Low bogs (the present Coastal Bog and Šventoji Meadow) occupied large areas on the waterlogged and, in places, bogged up Post-Litorina Sea terrace. Lagoonal sediments accumulated in the Palanga–Šventoji area. A low (0.5–1.0 m above the terrace surface), flat and wide Post-Litorina coastal ridge occurs in the Būtingė area where it abuts the Litorina-Sea terrace plain.

The surface of Post-Litorina terrace south of Olando Kepurė rises from 2.0 m to 6.0 m (at Melnragė) above sea level. South of Klaipėda, the Post-Litorina Sea waters submerged only part of coastal land north of the Svencelė bog where an open-sea plain (formed by abrasion–accumulation coastal formation processes) emerged at 2.5 m above the present sea level, north of Dreverna and a lagoon plain formed between Pempiai and Svencelė (dominated by accumulation processes).

In the southern part of the region, the Post-Litorina Sea lagoon reached the south-western to western margin of Aukštumala, submerging the entire southern edge of the present lagoon and the present Nemunas Delta as far as Paleičiai. The surface of the Post-Litorina Sea lagoonal plain that was formed occurrs *c*. 0.2–0.8 m above present sea level (Fig. 9). At the time of Post-Litorina Sea, the Curonian Spit gradually attained its’ present form. During the Post-Litorina Sea transgression *c*. 3.7 ka BP, the sea level in the Nemunas Delta region rose by 1–2 m above the present sea level (indicated by a sand interlayer in the peat of Svencelė bog and a layer of buried peat in the zone of the Atmata and Skirvytė branches, Fig. 17, borehole 26270). Judging from the age of sediments, the water in the former lagoonal bay, near the modern Rusnė Island, persisted until the end of the first millennium (borehole 26270). The formation of the Nemunas Delta (at least that part in Lithuania) began

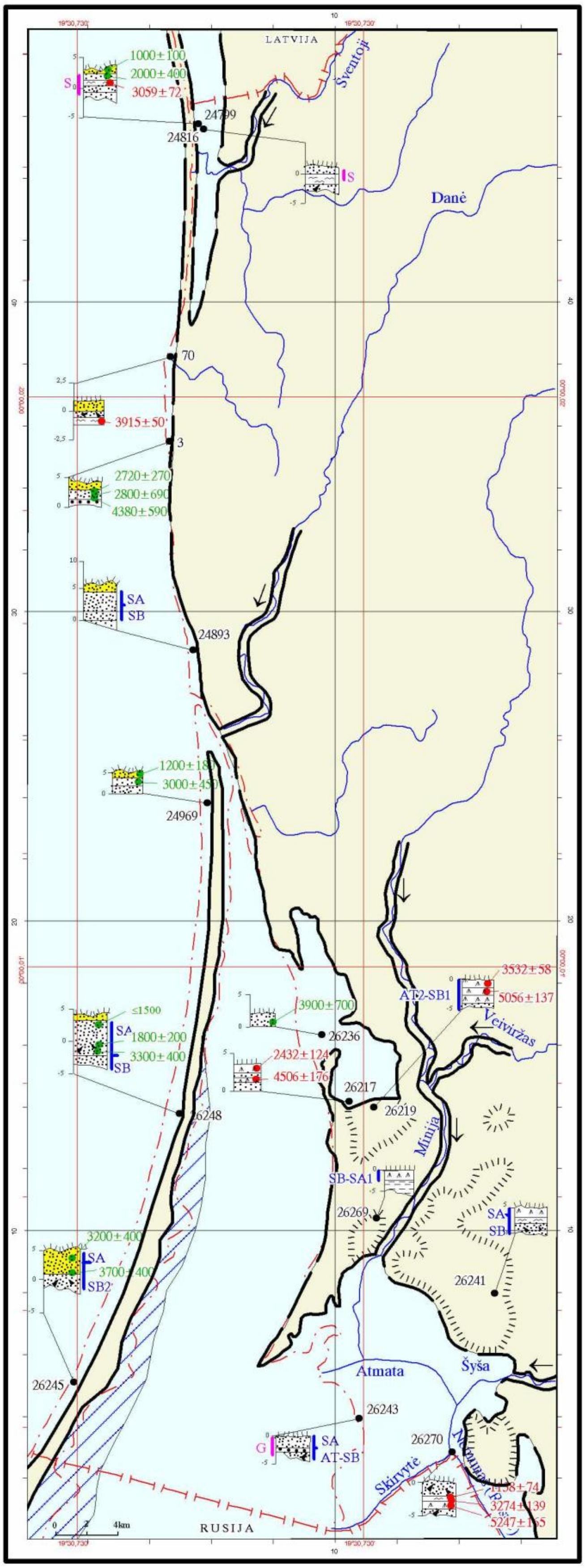


Figure 17 Palaeogeographic scheme of the Post-Litorina Sea (3.7–2.3 ka BP). (For legend see Fig. 12)

forming by *c*. 1.2 ka BP. At 1,158±74 years BP (Vs-1171) (based on sediments from borehole 26270), the present Rusnė Island and Krokų Lanka and its surrounding area was submerged by the waters of Post-Litorina Sea bay (the Curonian Lagoon) (Fig. 17). This bay was surrounded by lagoons, with the emerging Aukštumala, Rupkalviai (Žalgiriai) and Strazdapolis bogs. Therefore the present Nemunas distributary (Rusnė) cut its way between the Rupkalviai and Strazdapolis bogs and surged into the bay very recently from a geological point of view of, i.e. no earlier than 1.0–1.2 ka BP. This dating is based on palaeobotanical and geochronological evidence that indicates that lagoonal sediments continued to accumulate in the area of the present Nemunas Delta until this time. The sediment cores contain solitary species of halophylous and indifferent freshwater diatoms typical of the Post-Litorina sedimentary basin.

Only freshwater molluscs (especially of the Valvatidae and Sphaeriidae families) were identified from the sediments of this time in the southern part of the coastal region (Tables 7, 9 and 11). This supports the assumption that, freshwater basin existed in the southern part of the present Lithuanian coastal region during the period from Subboreal – Subatlantic and confirm that the sediments accumulated in a shallow freshwater basin.

Marine (offshore and lagoonal) Post-Litorina Sea sediments deposits were have been identified in the following coastal sectors: the Būtingė–Šventoji–Vanagupė area, south of the Olando Kepurė Cape, the Nemunas Delta, the Curonian Lagoon, the coast north of Kintai, underlying the greater part of the Curonian Lagoon and beneath the Curonian Spit. The Post-Litorina Sea sediments overlie those of the Litorina Sea and are themselves overlain mainly by modern marine or bog and aeolian deposits. The top of the sediment stratum underlying the youngest deposits extends no deeper than 3 m below the present sea level. The dominant thickness of this stratum is 2–3 m. The greater part of the landscape is occupied by offshore sediments: fine-grained or infrequently variously grain-sized sand or sand with pebbles. In places, the sand contains thinly dispersed organic matter and fossil mollusc shells or their fragments.

CONCLUSIONS

- In the Lithuanian coastal region the stratigraphical subdivision of the Weichselian Late Glacial and Litorina Sea marine and lagoonal sediments is based on the available results from fossil molluscs. Molluscs in the sediments from other palaeobasins have not been found. The results of stratigraphical subdivision of the sediments obtained are in good correlation with the evidence derived from geochronological and palaeobotanical investigations.
- The basins of the proglacial lakes, the Baltic Ice Lake, and the Litorina and Post-Litorina Seas have played a dominant role in the geological development of Lithuanian coastal region. The coast of the Yoldia Sea did not reach the present Lithuanian coast. The nature and the reconstruction of palaeogeographical conditions in the coastal region at the time of Ancylus Lake remains an unsolved problem.
- A curve of water levels in the Baltic Sea palaeobasins has been compiled based on the results of the palaeosedimentary analysis of borehole sections, and on the results of complex geochronological and palaeontological investigations. Based on the results obtained, the sediments and landforms from three Litorina Sea transgressions – at *c*. 8.3–8.0 ka BP (L_1), 7.5–7.0 ka BP (L_2) and 4.7–4.1 ka BP (L_3), and one Post-Litorina Sea transgression at 3.7–2.4 ka BP, have been investigated.
- The second, maximal, and indeed most intense Litorina-Sea transgression (L_2) produced the greatest impact on the Lithuanian coastal region. It most markedly transformed the landscape and deposited the thickest layer of marine sediments.
- The formation of the Curonian Spit began earlier than 8.5 to 8.3 ka BP, i.e. during the Ancylus Lake or the first Litorina Sea transgression (L_1) periods. The main geological–geomorphological features of the present spit developed during the Litorina-Sea regression that followed the second Litorina-Sea transgression (L_2) at 6.9–6.3 ka BP.
- The formation of the Lithuanian segment of the Nemunas Delta, including Rusnė Island and the adjacent area's began in the latest Holocene, i.e. in historical times at *c*. 1.1 ka BP.

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SANTRAUKA

Baltijos jūros pietrytinis pakraštys – Lietuvos pajūris – yra specifinis šalies regionas, turintis didelę ekonominę ir rekreacinę svarbą ir labai jautriai reaguojantis tiek į natūralių gamtinių reiškinių sukeliamus pokyčius, tiek ir į žmogaus invaziją. Todėl šio regiono geologinės sandaros pažinimas, jo geologinės raidos žinojimas, čia vykstančių geologinių procesų suvokimas neabejotinai buvo, yra ir bus ypač aktualūs. Lietuvos pajūris pasižymi sudėtingu reljefu, kurio formavimuisi didelę reikšmę turėjo ne tik paskutinysis (Viršutinio Nemuno) kontinentinis ledynas, bet ir Baltijos jūra. Pastarosios įtaka Lietuvos pakrantei pradėjo reikštis jau vėlyvajame ledynmetyje, kuomet didėjant kritulių kiekiui bei tirpstant ledynams kito Pasaulinio vandenyno vandens lygis, tuo pačiu sąlygodamas globalius pokyčius ir jo periferijos vandens telkiniuose.

Tyrimų objektas apėmė kelių dešimčių kilometrų pločio Baltijos jūros pakrantės ruožą žemyniniame krante, Lietuvai priklausančias šiaurines Kuršių nerijos ir Kuršių marių akvatorijos dalis. Pagrindinis darbo tikslas buvo atkurti, pasinaudojant naujausiais tyrimų duomenimis, Lietuvos pajūrio geologinę raidą poledynmečiu. Darbe pateiktoms išvadoms pagrįsti naudojamasi 81 kalibruoto radiokarboninio amžiaus (^{14}C) data ir 104 absoliutaus amžiaus datomis, nustatytomis optiškai stimuliuotos liuminescencijos metodu (OSL), 4 atodangų ir 79 gręžinių nuosėdų pjūviais.

Atkuriant Lietuvos pajūryje buvusių Baltijos jūros raidos stadijų baseinų paleoekologines sąlygas svarbus vaidmuo tenka nuosėdose randamų augalų ir gyvūnų makro- bei mikroliekanų tyrimams. Baseino paleoekologinių sąlygų įvertinimui ypač svarbios yra moliuskų ir diatomėjų liekanos, o paleoklimatinių sąlygų įvertinimui – žiedadulkės bei sporos. Todėl šiame darbe vandens moliuskų, kaip patikimų paleobaseinų ekologinių sąlygų indikatorių, fosilinių liekanų tyrimams skiriama daug dėmesio.

Iškastinių moliuskų tyrimų duomenys Lietuvos pajūrio zonoje leido stratigrafiškai suskirstyti tik vėlyvojo ledynmečio ir Litorinos jūros jūrines bei lagūnines nuosėdas: Lietuvos pajūryje kol kas aptikti ir apibūdinti tik fosiliniai moliuskai, vėlyvuoju ledynmečiu gyvenę tik lokaliuose gėlo vandens telkinuose, o holoceno metu – tik Litorinos ir Postlitorinos jūrose bei jų lagūnose (kitais laikotarpiais čia buvusių baseinų nuosėdose iškastinių moliuskų neaptikta). Moliuskų liekanų tyrimų pagrindu

atlikto nuosėdų stratigrafinio suskirstymo rezultatai gerai dera su geochronologinių bei paleobotaninių tyrimų duomenimis.

Absoliutaus datavimo metodų taikymas nuosėdų amžiui nustatyti, iškastinių moliuskų liekanų apibūdinimas, nauji paleobotaninių tyrimų rezultatai bei kita gausi geologinė informacija leido patikslinti Baltijos paleobaseinų vandens lygio (kranto linijos) kaitą vėlyvajame ledynmetyje ir holocene, sudaryti seriją paleogeografinių rekonstrukcijų – kartoschemų skirtingų Baltijos jūros raidos stadijų baseinams.

Apibendrinus naujausių, tame tarpe ir autorės atliktų, tyrimų rezultatus galima teigti, kad Lietuvos pajūrio geologinei raidai poledynmečiu esminę įtaką turėjo prieledyninių ežerų, Baltijos ledyninio ežero bei Litorinos ir Postlitorinos jūriniai baseinai. Joldijos jūros krantai nesiekė dabartinės Lietuvos pajūrio zonos. Probleminiu tebelieka Anciliaus ežero metu Lietuvos pajūrio zonoje buvusių paleogeografinių sąlygų rekonstravimas. Pagal atliktos gręžinių pjūvių paleosedimentacinės analizės duomenis ir kompleksinių geochronologinių-paleontologinių tyrimų rezultatus sudaryta Baltijos jūros baseinų vandens lygio kaitos kreivė. Šių tyrimų pagrindu Lietuvos kranto zonoje ištirtos trijų Litorinos jūros transgresijų, vykusių apytikriai prieš 8300–8000 metų (L_1), 7500–7000 metų (L_2) ir 4700–4100 metų (L_3), taip pat dar vienos transgresijos, vykusios Postlitorinos jūros laikotarpiu prieš 3700–2400 metų, nuosėdos bei reljefo formos. Didžiausią poveikį Lietuvos pajūrio kranto zonai turėjo antroji, maksimali ir pati intensyviausia, Litorinos jūros transgresija (L_2), kurios metu žymiausiai buvo performuotas reljefas bei suklota didžiausia jūrinių nuosėdų storymė. Kuršių nerijos formavimasis prasidėjo anksčiau kaip prieš 8500–8300 metų. Esminiai geologiniai-geomorfologiniai dabartinės nerijos bruožai susiformavo apytikriai prieš 6900–6300 metų, t.y. po maksimalios Litorinos jūros transgresijos (L_2) sekusios regresijos metu. Dabartinė Nemuno deltos Lietuvos dalis, apimanti Rusnės salą bei greta esančias teritorijas, pradėjo formuotis holoceno pabaigoje, jau istoriniais laikais, apytikriai prieš 1100 metų.

Darbas iliustruotas 17 lentelių ir 41 paveikslu.