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On the Eastern Baltic environment changes: a case study of the Curonian Lagoon area

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Sea level fluctuation, neotectonic movement, variation of sedimentation conditions, human impact play an important role in sea development. Water level fluctuation and vertical movements determine the rates of the long-term sedimentation process. The sea level rises (sinking of coasts south of 56° N), and its amplitude increases from 1.5 mm y^{-1} (in the beginning of the 20th century) to 3–4 mm y^{-1} (predicted for the 22nd century). The rise of coasts (sinking of sea level) and uplift is evident in the central and especially northern Baltic (1–9 mm y^{-1}). These factors speed up the erosion of shallow areas, eutrophication and rapid accumulation of sedimentary matter in local lagoons. The latter processes complicate the ecological situation in the shallow (mouth) areas. Human activity takes place in the river areas, lagoons and geochemical barriers. The mentioned factors modifity the rates of sedimentation (0.6–15 mm y^{-1}) in the Baltic Sea basin, which reach their maximum in the shallow lagoons of the Eastern Baltic (2.5–15.0 mm y^{-1}). A synthesis of the data obtained by the author and information contained in references made it possible to make a many-sided forecast regarding a more than a thousand-year development of the Curonian Lagoon and the Eastern Baltic. A rapid transformation of coasts will take place, the nearshore basins – Viainameri (Estonia), the Gulf of Riga, the Curonian and Vistula lagoons, the Puck Bay – will shallow. Nearby new shallow lagoons will appear in the place of these basins. The Eastern Baltic lagoons (Curonian and Vistula) in future will become similar to the present state of the Polish Pomeranian coastal zone where the Leba, Gardno and other lakes which used to be vast lagoons are in the final stage of degradation.

The predicted development of the Eastern Baltic will take place if the range of tectonic movements and sea level changes remains the same and there will be no human invasion with supermodern technologies into the natural processes.

Key words: sedimentation rates, vertical movements, sea level changes, the Curonian Lagoon, Eastern Baltic Sea basin

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INTRODUCTION

The problems of the natural Baltic Sea development under the possible human impact and increasing life necessity for the sea require complex investigations. The shallow water zones of the Eastern Baltic Sea and areas of semi-closed bays (lagoons) as areas of high bioproductivity, recreation potential or perspective for the mass development of tourism in this case are most important. The sedimentation processes, eustatic rise of sea level (subsidence of coasts) and land uplift (rising of coasts or bottom) are very important for development of the sea. And what about the human factor? It is the best investigated phenomenon at present.

The presumption is very important in connection with the problem and research hotly debated nowadays about the rise of the World Ocean due to the global climate warning caused by human activities. However, with no account for Earth crust movements, the research is directed towards high expenses but low results. These movements affect the Baltic Sea and the adjacent region from the very beginning of its formation (>13 thousand years). They apparently changed the sea areas, hydrological regime, saline maritime basin, changed freshwater lakes; sea bays turned into lagoons or later into lakes. During the period of the latest 3–4 thousand years, the lakes turned into swamps and peat-bogs of different productivity. The pit deposits are now exploited in the areas of the eastern and southern Baltic coast. The mentioned changes continue. Therefore, due to glacial isostatic processes, the northern part of the sea, the Baltic shield and the western part of the Eastern European plate rise from 0–0.1 mm y^{-1} north of Liepaja environs to 3–9 mm y^{-1} in the Gulf of Bothnia area. And otherwise, the eastern and southern areas south of Liepaja are subsiding at a speed of 0.1–0.2 mm y^{-1} (Table). The depression of −1.8 m (Raczki Elbląskie) in the Vistula Lowland (valley) is related to this subsidence.

Table. **Changes of eustatic sea level, land uplift and sedimentation rates in various basins of the Baltic Sea (according to the published data)**
Lentelė. **Eustatinio jūros lygio, žemės plutos kilimo ir sedimentacijos greičio pokyčiai įvairiose Baltijos jūros dalyse (pagal literatūros duomenis)**

Basin, location	Factors						
	Global					Sedimentation rate	
	Observation periods (prediction)	Rise of sea level		Land uplift		Unit, mm y^{-1}	References
		Unit, mm y^{-1}	References	Unit, mm y^{-1}	References		
North and Baltic Sea areas	20th century	1.5	Sterr, 1992				
	21st century	6–10					
Baltic Sea area (South)	1970–1990	2	Sterr, 1992				
Baltic Sea area		0.,8–1.1	Lisitzin, 1964				
		1.1–1.4	Malkki, 1987				
Finland		0.8	Eronen, 1987				
NW Europe	1850–1940 1970–2005	1.1	Morner, 2005				
Gulf of Bothnia basin				9–3	Современные…, 1975, Voipio, 1981, Kuusisto, Lemella, 1987		
				8–9	Bjork 2005		
Gulf of Finland						0,6–2.2 0,63–1.12	Купцов и др., 1982 Pustelnikovas, 1992
Gulf of Finland (at Chanko)		–3	Lisitzin, 1964				
NW Gulf of Finland				4–3	Kuusisto, Lemella, 1987		
Finland, Sweden, Estonia				3–1	Kakkuri, 1987		
Baltic Proper, Sweden	1774–1984	–1.01	Ekman, 1986	4.93	Ekman, 1986	0.6–2.5	Voipio, 1981, Купцов и др., 1984
Baltic Proper, Sweden (at Stockholm)	1885–1984			3.92	Ekman, 1986		
Riga Bay, Latvia, Sweden				2–1	Recent…, 1975; Voipio, 1981		
				1–0	Kakkuri, 1987		
Latvia (Liepaja) – Baltyisk (Kaliningrad region)				(–0.5–1.2)	Современные…, 1975		
Curonian Lagoon				(–<1)	Современные…, 1975	2.5–3.6	Pustelnikovas, 1994, 1995
				(–0–4.9)	Šliaupa et al., 2005	5–15	Emelyanov et al., 1998
Lithuania, Kaliningrad region				(–<0)	Kakkuri, 1987		
Vistula lagoon				(–1.5–2.5)	Harff et al., 2001	5.3–7.5	Блажчишин,1995;
				(–<0.5)	Современные…, 1975	1.15	Емельянов, Выпых, 1987
Poland, Germany				(–1–2)	Современные…, 1975		
Gdańsk Bay						1.4	Емельянов, Выпых, 1987
Southern Baltic				(–1)	Bjorck, 2005	0.13–2.92	Pempkoviak, 1992
Port of Gdańsk						70	Szwernowski, 1957
Port of Klaipėda						300	Результаты …, 1989

The extent of neotectonic movements and their direction, together with the intensity of hydrometeorological factors (wind, waving, tide) accelerate the erosion of the sea bottom and shore, as well as enhance the sedimentation of terrigenous matter. The changes in the basin apparently affect the organic world which is often thought to decline or flourish depending only on human impact.

The human impact on sedimentation is evident (Erlenkeuser et al., 1974; Hallberg, 1991, etc.), but its scale and influence on the marine ecosystem, however, are recently dabated (Pustelnikovas, 1992, 1994, 1996, 1998, etc.). On what scale will they influence the Baltic Sea development in the future? Also, it should be remembered that the marine environment contains different objects – plants, hydrobionts, soil, peat, genetic deposits and rocks, etc., affected by submarine discharge of groundwater from aquifers of different age, long-term fluctuations in space and time and other insufficiently investigated phenomena. They represent the elements of natural processes of the Baltic Sea development with different palaeo- and recent-ecological variations. Different stages of analysis of relations between natural and human factors are reflected by some authors (Гершанович, 1984; Емельянов, Лукашин, 1986; Pustelnikovas, 1998).

SEDIMENTATION CONDITIONS, GEOLOGICAL STRUCTURE AND VERTICAL MOVEMENTS IN THE BALTIC SEA BASIN

Different sedimentation conditions and the geological structure of basins determine the formation of a variable composition of sediments. Their different types in most cases reflect dependence of their formation on the natural regime – changes of hydrological conditions, the character of bedrocks of denudation basins or changes of climatic conditions.

The scale of long-term sedimentary processes is changing. These changes are related to variations in sea level and vertical crustal movements. The mean data on these changes in the Baltic and surrounding area are given in Table.

The tendency of land uplift in the Northern and Central Baltic is evident. The sea level, on the contrary, is rising southwards from Sweden, Latvia and Lithuania. J. Kakkuri (1987) drew the zero isoline of land uplift at about 56°N. The rise of the World Ocean level during the 20th century is approximately 1.4–1.5 mm y^{-1} (Eronen, 1987; Sterr, 1992) and it has speeded up in the Baltic during the last 50 years (Eronen, 1987; Mallki, 1987). At the beginning of the 22nd century the rate of rising, according to these data, could be about 3–4 mm y^{-1}.

Lisitzin (1964) and Ekman (1986) showed that the eustatic sea level in the Finnish and Swedish coasts (during the 18th–20th centuries) decreased by 1–3 mm y^{-1} (Table 1). The local decrease of this level is a compensation to land uplift in the Scandinavian area. At the same time, many of scientists fixed the land uplift to 9–1 mm y^{-1} in Sweden, Finland, Estonia and partly in Latvia (Table). The latitude 56°N is a limit between the land uplift in the North and the land subsidence in the South. All the mentioned countries (coasts) are under the influence of the uplift. On the contrary, the coasts of Lithuania, Kaliningrad region, Poland and Germany are in the stage of land subsidence (sinking of the Earth crust). In this case, we identified the sea level rise. The decline of the sea level in relation to the land uplift is indicated by the fact that the ports of Vaasa and Puri moved from their first locations to the present ones by 10–40 km from land to the shoreline starting with the 13th–14th centuries (Palomaki, 1987). This uplift is reflected by Finland's bedrock fractures (Niini, 1987) and by changes of floods in the Aland Archipelago (Munsterhjelm, 1978). Land uplift and eustatic changes of sea level accelerate the erosion of shallow areas and, later on, the accumulation of sedimentary matter in the local basins. This process complicates the ecological situation, particularly in the shallow (mouth) area.

THE CURONIAN LAGOON AS A MEDIUM OF SEDIMENTATION AND AN AREA OF NEOTECTONIC MOVEMENTS

The Curonian Lagoon (Kuršių marios) represents a freshwater shallow basin separated by the Curonian Spit (Kuršių nerija) from the Baltic Sea (Fig. 1). It is a transitory running water basin of sedimentation collecting the runoff water from the Nemunas and other minor rivers. Sedimentary matter undergoes considerable differentiation here. Some incoming sedimentary matter settles mostly in its southern part, whereas the rest is carried out through the narrow Klaipėda Strait into the Baltic Sea.

At present, the surface area of the lagoon makes 1584 km^2 and its basin contains about 6 km^3 of water. The annual output of water into the sea makes about 26.5 km^3. Therefore, the coefficient of annual exchange of water masses of the lagoon is rather high (4.4). The process of water exchange is especially intensive in its whole northern part. The mean annual input of saline marine water into the lagoon reaches 5.8 km^3 (cited from Pustelnikovas, 1998).

The main water mass as a narrow strip moves to the north towards the Klaipėda Strait. The second one, a less powerful surface flow from the Nemunas mouth, is directed southwards. This is confirmed by zones of the highest content of chemical elements (in our case Pb) in the bottom sediments in the southeastern part of the lagoon (Fig. 2, according to Pustelnikovas, 1998).

The bottom of the Curonian Lagoon is shallow with depressions the mean depth of which is 3.8 m, maximum 5.8 m (in the open southern part) and 13–14 m in the artificially deepened part (the Klaipėda Strait). The bottom relief of the northern part of the lagoon is represented by two main morphological forms: (1) a wide plateau in the east with the depths to 2 m and the width ranging between 2 and 8–10 km, and (2) a near-spit channel which stands out in the bottom relief along the Curonian Spit (Kuršių nerija). The development of this channel is a result of bottom fracturing during the squeezing out of plastic Quaternary deposits – sapropel, silt and gyttja. This channel is the main artery in the process of water exchange between the Curonian Lagoon and the Baltic Sea (Гуделис, 1959). The differences of sedimentation enable to distinguish the following zones: the southern one with sedimentation predetermined mainly by abrasive processes, bioproduction of organic matter and secondary inflow of thin dispersed fluvial sedimentary matter; the central and northern zones where the crucial role is played by the fluvial material from the Nemunas River, the hydrological regime of the water body itself and the intensity of water exchange. The sedimentation in the Curonian Lagoon has an obviously terrigenous character. Sedimentation in these areas and changes of the coasts and surface areas are going at various rates. The topical importance of these rates becomes evident while attempting to solve the practical problems of fish productivity, the increasing industrialization of the Klaipėda port, many transnational issues, etc. The problem of the geographical evolution of the lagoon has been in the focus of attention for almost 50 years. However, during the last 20–25 years, analyses of its development yielded fast only to the ecological-anthropogenic factor. In this topic, we followed the chronological analysis of stages of development of the idea about the natural cause of evolution.

V. Gudelis (1955), on the ground of repeated levelling, proved that the coastal plain during the 1000–500 years has elevated by 40–70 cm and the Earth crust in the lagoon area rises by 0.5–1.2 mm y^{-1}. Later this author (Гуделис, 1959) specified that "the elevation of the Earth crust is characterized by the rises behind the southern part of the lagoon". Thus, its northern part during the last 50 years has been rising at the rate of 0.12 cm y^{-1}. But the

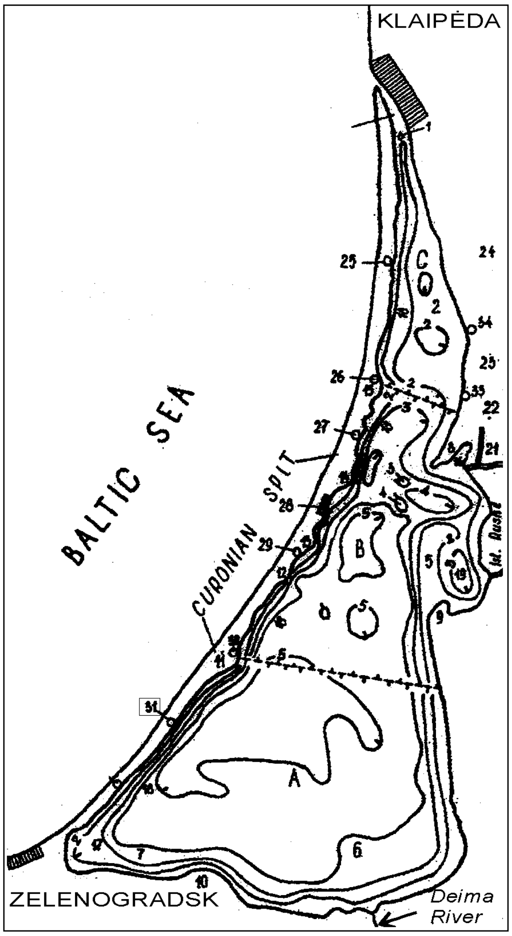


Fig. 1. Relief scheme of the Curonian Lagoon.
Dotted line – boundaries of the southern (A), central (B) and northern (C) sedimentation zones. Isobaths in m.
Geographical names of the Curonian Lagoon and adjoining areas:
Islands and shoals: 1 – Kiaulės Nugara island, *2* – Ventė-Klaipėda plateau (littoral), *3* – Akmena, *4* – Kalva, *5* – Ežia, *6* – Labgaršva, *7* – Kivelis. *Capes: 8* – Ventės, *9* – Liekų, *10* – Ostry, *11* – Rybatchy, *12* – Kaspalėjos, *13* – Grobšto, *14* – Bulvikio, *15* – Arklių. *Caves: 16* – Kniaupas, *17* – Brukis. *Depressions: 18* – Panerijos duburys, *19* – Skirvytės, *20* – Klaipėda strait.
Bogs and lakes in the coastal area: 21 – Krokų Lanka, *22* – Aukštumalės, *23* – Tyrų, *24* – Šventelės. *Settlements: 25* – Juodkrantė, *26* – Pervalka, *27* – Preila, *28* – Nida, *29* – Morskoe, *30* – Rybatchy, *31* – Diuny, *32* – Lesnoye, *33* – Kintai, *34* – Dreverna

1 pav. Kuršių marių dugno reljefo schema.
Punktyrinės linijos – ribos tarp pietinės (A), vidurio (B) ir šiaurinės (C) sedimentacijos zonų, izobatės m.
Kuršių marių ir jas ribojančių plotų geografiniai pavadinimai:
Salos ir seklumos: 1 – Kiaulės nugara, *2* – Ventės-Klaipėdos plynaukštė (litoralė), *3* – Akmena, *4* – Kalva, *5* – Ežia, *6* – Labgaršva, *7* – Kivelis. *Ragai: 8* – Ventės, *9* – Liekų, *10* – Ostryj, *11* – Rybačij, *12* – Kaspalėjos, *13* – Grobšto, *14* – Bulvikio, *15* – Arklių. *Užutėkiai: 16* – Kniaupas, *17* – Brukis. *Įdubos: 18* – Panerijos duburys, *19* – Skirvytės, *20* – Klaipėdos sąsiauris. *Pelkės ir ežerai priekrantėje: 21* – Krokų lanka, *22* – Aukštumalės, *23* – Tyrų, *24* – Šventelės. *Gyvenvietės: 25* – Juodkrantė, *26* – Pervalka, *27* – Preila, *28* – Nida, *29* – Morskoje, *30* – Rybačij, *31* – Diuny, *32* – Lesnoje, *33* – Kintai, *34* – Dreverna

peat of the Litorina Sea (4500–4000 years ago) in the southern part of the Curonian Lagoon is presently lying at a depth of 4–5 m below the water level.

The other authors (Современные движения..., 1975) showed that the Earth's crust within the lagoon has been subsiding. O. Jakubovsky, from 85-year mareographical observations (1886–1970), obtained the following values of subsidence: 0.6 ± 0.3 mm y^{-1} in the environs of Liepaja, 0.8 ± 0.3 near Klaipėda and 1.2 ± 0.3 mm y^{-1} near the port of Baltiysk. S. Pobedonostsev in the same sources shows this subsidence in the region of the Curonian Lagoon to be 1–2 mm y^{-1} (Современные движения..., 1975). S. Šliaupa et al. (2005) identified a stabile regime of the Curonian Lagoon in the surroundings of the Klaipėda strait, but in the vicinity of Nida the coasts evidently subside to 4.9 mm y^{-1}.

The hydrodynamic regime, the reconstruction and deepening of the port are the major factors in the formation of geochemical anomalies in the sediments of the Klaipėda Strait. The periodic and stable high input (sediment fluxes) of marine water into the strait contains much sedimentary matter thus causing extreme sedimentation rates in the strait (300 mm y^{-1}, see Table). One of the resons of such extreme rates can be the constantly increasing influence of this subsidence (sinking) in the south direction.

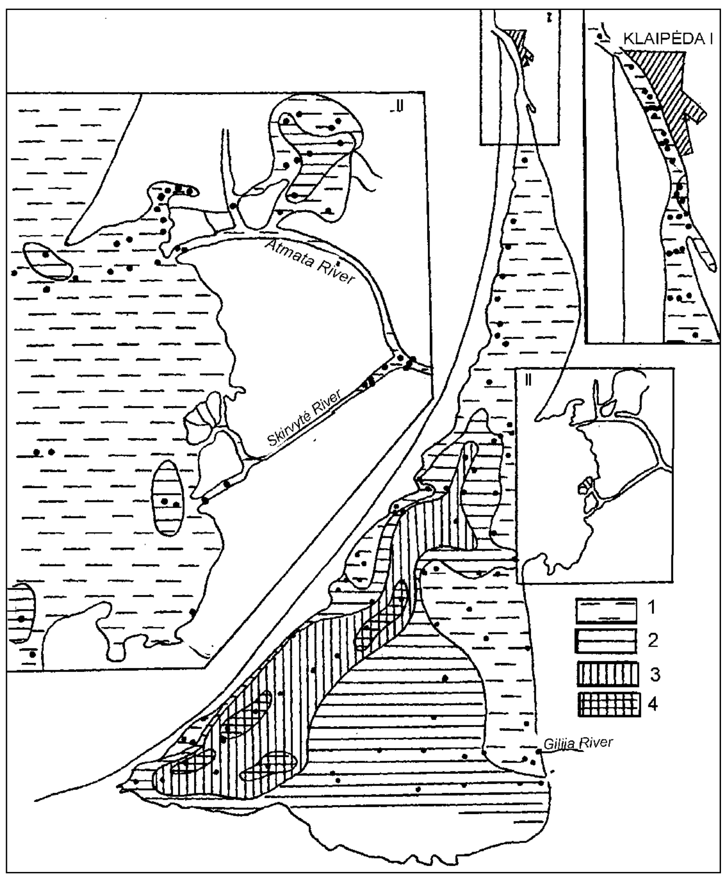


Fig. 2. Pb distribution in the bottom sediment surface layer of the Curonian Lagoon. Content, ppm: *1* – <20, *2* – 20–100, *3* – 100–200, *4* – >200

2 pav. Pb pasiskirstymas Kuršių marių dugno nuosėdų paviršiuje, kiekis ppm: *1* – <20, *2* – 20–100, *3* – 100–200, *4* – >200

A slow subsidence of Kaliningrad region and the lower one in the course of the Nemunas at the rate of 2 mm y^{-1} by Meshcheriakov and Siniagina (1956) had been pointed out. The recent slow subsidence of the Gdansk Basin area was indentified by J. Harff et al., (2001), but this subsidence of the Vistula lagoon coasts reaches 1.5–2.5 mm y^{-1}. In the Southern Baltic (Poland, Germany), the subsidence of coasts reaches 1–2 mm y^{-1} (Современные движения, 1975; Harff et al., 2001). E. Červinskas (cited from Basalykas, 1965) established that during the period of 125 years (1800–1925), according to the analysis of cartographic materials, the Nemunas delta extended into the lagoon by 2.5 km (annual movement about 20 m). He also calculated that moving forward at this rate the Nemunas will fill the widest part of the lagoon with sediments during a period of 2500 years and will form a vast, fertile, coastal plain.

The transformation of the Curonian Lagoon is not going to be a simple process. Sedimentation and eutrophication superimpose the most recent shifts of the Earth crust. And really, the subsidence of the Baltic Sea and the Curonian Lagoon coast is obvious even at a distance of 100–200 km. The rate of subsidence of the northern part is twice as slow as in the southern one. It will result in the future shifting of the Nemunas course southwards and the cessation of the river runoff in the northern direction. But it may happen only in the case if the modern "epoch" of slow subsidence is not replaced by a period of slight elevation (Гуделис, 1982). Besides, data are lacking on the role of changes of the level of the World Ocean. The comprehensive data on the changes of the sea level, isostatic elevation and rates of sedimentation in the Baltic Sea region have been summarized by O. Pustelnikovas (2000). A slow and uneven isostatic elevation of the Earth crust leads to a simultaneous relative subsidence of the lagoon shores, increasing towards its southern part. It favours the shrinking of the area and shortens the lagoon's existence.

The water surface of the lagoon diminished during 50 years from 1610 to 1574 km^2, i. e. by 36 km^2 (0.7 km^2 y^{-1}) (Červinskas, 1972). The eastern coast of the lagoon is mostly low, boggy, and peaty. The thickness of the peat layer often reaches 11 m. The deltaic lake Krokų Lanka at present is a decaying coastal water body. A similar fate in the nearest several hundred years awaits the Kniaupas cove.

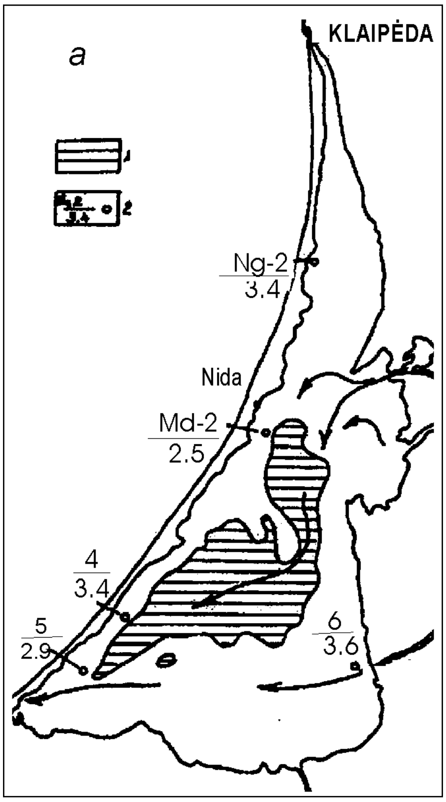
The shores of the Curonian Spit have been transforming during 1910–1980 (Kazakevičius, 1989–1990). Their contours straightened and became shorter. The shores lost on the avarage 0.003% of their primary length. The straightening of the shoreline takes place as a result of abrasion of capes and filling of coves with sediments. Thus, during these 70 years the spit shores shortened by 1941 m (1347 m in the northern Lithuanian part and 594 m in the southern Kaliningrad region part). And yet, the northern and central parts of the lagoon have diminished, whereas the southern part increased. The abrasion of the spit shores increases with shrinking of the dunes uncovered with forests. This is the cause of the extreme erosion of shores at the rate of 1.7 m y^{-1} in the environs of Morskoye as a result of the influence of the Nemunas stream, currents and hydrometeorological conditions.

Are changes in the lagoon area affected by sedimentation? The terrigenous character of sedimentation is predetermined by the input of sedimentary matter mainly with the Nemunas load (as the main artery of its transport). E. Červinskas (1972) calculated the yearly load of the Nemunas to contain at least 0.4–0.5 million tonnes of solid particles. If this drift distributes uniformly over the entire bottom of the lagoon, the sand and mud layer would be 0.15 mm. The author assumes that in this case the lagoon would turn into land in less than 4000 years. As the sediments later deposited since the time of emergence of the lagoon (ca 5000 BP) are several tens of meters thick, the process of sedimentation in the past was by far more intensive than in the present days. This assumption is to a certain degree confirmed by the quantitative distribution of chemical elements in the layer of 0–115 cm, which developed during the last 300 years (Pustelnikovas, 1998). V. Gudelis (Гуделис, 1959) assumes that the time interval of the Curonian Lagoon-ceasing to be a lagoon is measured in thousands of years. According to the scale of geological calculations, this time is not far away.

The first sedimentological investigation of suspension (Гуделис, Пустельников, 1983) gives the range of sedimentation rates from 1.39 to 2.70 mm y^{-1}. It is several times higher than the rates in the Baltic Sea. From these data a conclusion is drawn that the depression of the lagoon will be filled up with sediments in 3 thousands years. A more precise determination of the sedimentation rate by the ^{210}Pb method made it possible to update the dating (Pustelnikovas et al., 1991). Thus, in the zone of accumulation of muddy sediments the rate varies within 2.5–3.6 mm y^{-1}, or 3.2 mm y^{-1} on the avarage. At such rates of sedimentation (without accounting for the differentation of material in geological history) the basin will be filled up in no more than 1.5–2 thousand of years. The newest investigations (Emelyanov et al., 1998) give the rates of 5–15 mm y^{-1}. In this case, the basin will be filled up within approximately 700–800 years! The process of differentation of sediments, while being buried for geological chronicle of the lagoon history, and submergence of the lagoon shores (during 1902–1970 it reached 1–2 m 1000 y^{-1} (Современные движения, 1975) compensate to a certain extent for the elevation of the bottom due to accumulation of sediments and squeezing of the older plastic soils.

In author's opinion, there is no real ground to assert that water bodies eutrophicated because of the washing out of agricultural activity products (Razinkovas, 1994, etc.). Undoubtedly, the eutrophication is the main result of natural processes, which is proved by the chemical composition of sediments and the distribution of the forms of green algae *Pediastrum* in a sediment thickness aged several hundreds of years. The rapid formation and increase of the Nemunas delta front and Lake Krokų Lanka as well as other natural changes of the delta area are usually accounted for eutrophication as a result of intensification of agriculture in the delta area, which increased accumulation in this area (Seibutis 1960, etc.). But... The mentioned events are dated to the beginning of the 18th century when intensive agriculture did not exist. The negligible sea transgression could not have exerted a more or less significant effect on the course of the mentioned changes.

Hight rates of sedimentation in the delta front and the northern part of the lagoon and neotectonical movements could have been the main cause of the increase of the delta front and shrinking of the area of the lagoon. It speeded up the processes of natural eutrophication. It also stabilized the shore, favoured the development of peat in the eastern shore south of the Liekų Ragas cape and the overgrowth of many branches of the



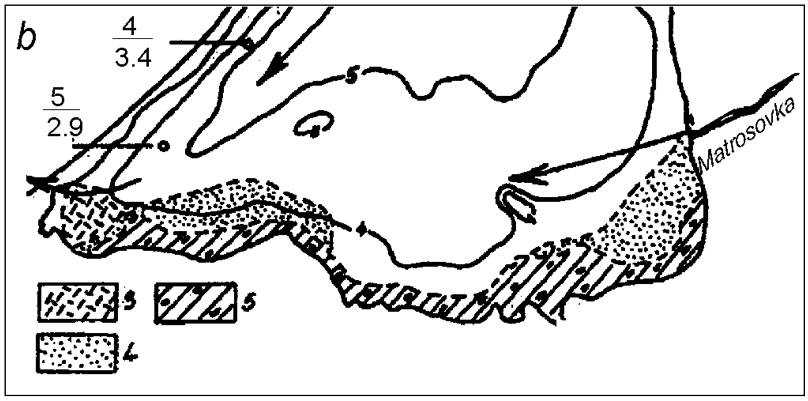


Fig. 3. The Curonian Lagoon area in the 30th century. Bottom topography
(*a*): *1* – 5 m isobath, *2* – stations in which the rates of sedimentation were determined (nominator – station number, denominator – sedimentation rates, mm y^{-1}). Geological structure of the southern part of the Curonian Lagoon
(*b*): *3* – Holocene peat, *4* – boulder-gravel-sandy residual deposits, *5* – morainic (Pleistocene) till. In both (*a, b*) parts: arrows show the direction of the Nemunas River stream in to the Baltic Sea
3 pav. Kuršių marios XXX a.
(*a*): *1* – 5 m izobatė, *2* – stotys, kuriose buvo nustatytas sedimentacijos greitis (skaitiklyje – stoties Nr., vardiklyje – sedimentacijos greitis mm · $metus^{-1}$). Pietinės Kuršių marių dalies geologinė sandara
(*b*): *3* – holoceno durpės, *4* – likę dariniai (rieduliai, žvyras, smėlis), *5* – moreninis (pleistocenas) molis. Abiejose dalyse (*a, b*) strėlėmis pavaizduota Nemuno upės tėkmės kryptis į Baltijos jūrą

Nemunas as early as in Atlantis stage. The latter factors prove a reduction of sediment transport through the northern branches of the Nemunas. Maximum sedimentation rates in front of the Matrosovka branch (3.6 mm y^{-1}, Fig. 3a) indicate an increased amount of solid sediments transported by this branch and the shifting of decisive sedimentation factors to the southern part of the lagoon. This was not strongly stimulated by the subsidence of the southern part of the lagoon, which in turn favoured the regression of the southern shore including the mouth zone of the Deima River. The most intensive erosion of shores is observed in the Brukis cove situated in the southwestern part of the lagoon near Zelenogradsk. As a result, the Curonian Spit base near Lesnoye grew considerably narrower. The stable zone of the spit begins north of the Lesnoye settlement. Based on the data of the Quartenary structure, author assumes that in the nearest geological future (about 28–30 years) the spit will be broken through by the Nemunas River and the Sea near Lesnoye (Fig. 3b).

CONCLUSIONS

Prediction of the development of the Eastern Baltic
From the position of the dominance of natural sedimentation in the present stage of geological history and taking into consideration the vertical movements and amplitude of sea level oscillation, we have made an attempt to predict the development of the Eastern Baltic Sea in the nearest thousand of years.

The land uplift is connected also with the slowing down of the runoff of the Baltic rivers flowing westward and northwestward. The joint influence of the three mentioned factors cardinally changes the ecological situation. The tidal currents become more frequent in the eastern part of the Gulf of Finland, flooding Saint Petersburg and the neighbouring cities. The solid and liquid drift of the Neva River as well as industrial wastes accumulate in the near-mouth parts of the river. The accumulation speeds up as does also the rapid natural eutrophication (especially in the mouth areas). The latter will be more active in the southern part of the Riga Bay (the lower course of the Daugava and the Lielupe), Curonian and Vistula lagoons. The land rise will decrease slowly, and the northern runoff of the Nemunas River water into the Baltic through Klaipėda will shift the river bed south-westwards. The delta will shift in the same direction. The Curonian Lagoon and the Curonian Spit will turn, correspondingly, into a bog and continental dunes. The morainic background as a durable barrier will occur on the Nemunas River way towards the south. Then the river water and extreme storm surge from the sea will break the basement of the spit where the upper 10-m layer of Litorina and more ancient peat and soils are deposited. The lagoon water will spout into the Baltic Sea. The new Nemunas bed will be similar to the old river branch at the Yoldia time (10–9.5 Ka BP) – from the end of the Early Holocene and the beginning of the Late Holocene. The development of the new branch of the Nemunas and its water draining into the Baltic Sea will take their course on a higher transgressional level and at a considerable distance to the east from the Early Holocene bed.

Neotectonic movements will speed up the abrasion of the South-Eastern coasts and the erosion of the bottom in the western shallow-water areas. It will change the Estonian coasts, speed up the shallowing of Viainameri (Estonian Archipelago Sea) and the decrease of the Riga Bay area. On the other hand, an underwater shallow will occur near the spit, to the east from which it will form a new lagoon in the Riga Bay of the type of the Puck lagoon in the Gdańsk Bay. The abrasion of Sambia

Peninsula will speed up. The Vistula and Puck lagoons will pass the natural eutrophication processes and a decrease of the areas, their development will be slower than in the Curonian Lagoon. Therefore, the future of the Eastern Baltic coastal zone will be similar to the present state of the Pomeranian coast of Poland where lakes Leba, Gardno and some other, which used to be wide lagoons, are separated from the sea by wide dune belts and are in the stage of full degradation.

The prognosticated course of development in the 21st–30st centuries will happen if (1) there are no changes in the scale of tectonic phenomena, (2) there are no human impact with super-high technologies on the natural processes. The natural processes will predominate, however, locally they will be complicated by human activity. Its scale will be small.

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RYTŲ BALTIJOS APLINKOS POKYČIAI REMIANTIS KURŠIŲ MARIŲ BASEINO TYRIMAIS

Santrauka

Jūros lygio svyravimai, neotektoniniai judesiai, sedimentacijos sąlygų kaita ir žmogaus poveikis yra svarbūs veiksniai jūros raidai.

Vandens lygio pokyčiai ir vertikalūs judesiai nulemia ilgalaikės sedimentacijos greitį. Jūros lygis kyla (krantai grimsta) į pietus nuo 56° š. pl. ir jo amplitudė didėja nuo 1,5 mm · metus^{-1} XX a. pradžioje iki prognozuojamo 3–4 mm · metus^{-1} greičio XXII a. pradžioje. Krantų kilimas (jūros regresija) akivaizdus vidurio ir ypač šiaurinėje Baltijoje (1–9 mm · metus^{-1}). Šie veiksniai spartina seklių plotų eroziją, eutrofizaciją ir nuosėdinės medžiagos akumuliaciją atskirose lagūnose, o tai apsunkina ekologinę padėtį sekliose srityse. Žmogaus veikla pasireiškia upių žiočių, lagūnų, geocheminių barjerų zonose. Minėti veiksniai sąlygoja įvairų (0,6–15,0 mm · metus^{-1}) sedimentacijos greitį Baltijos jūros baseine, kurio maksimumas fiksuojamas Rytų Baltijos lagūnose (2,5–15,0 mm · metus^{-1}).

Apibendrinti autoriaus ir literatūros duomenys leidžia prognozuoti Kuršių marių ir Rytų Baltijos raidą per 1000 metų. Ženkliai keisis krantai, priekrantės baseinai (Viainameri (Estija), Rygos įlanka, Kuršių ir Aisčių marios, Pucko įlanka) seklės. Šių baseinų vietoje netrukus atsiras naujos seklios lagūnos. Rytų Baltijos lagūnų (Kuršių ir Aisčių marios) ateitis bus panaši į dabartinį Lenkijos Pamario kranto zonos būvį; čia Lebos, Gardno ir kt. ežerai, buvę didžiulėmis lagūnomis, pasiekė baigiamąją degradacijos stadiją.

Prognozuojama Rytų Baltijos raida vyks, jei nesikeis tektoninių judesių ir jūros lygio pokyčių kryptys ir tęsis supermodernių technologijų invazija į gamtos procesus.

Олегас Пустельниковас

ИЗМЕНЕНИЯ ОКРУЖАЮЩЕЙ СРЕДЫ ВОСТОЧНОЙ БАЛТИКИ НА ПРИМЕРЕ ИССЛЕДОВАНИЙ БАССЕЙНА КУРШСКОГО ЗАЛИВА

Резюме

Колебания уровня моря, неотектонические движения, изменения условий седиментации и влияние деятельности человека весьма важные факторы развития моря.

Изменения уровня воды и вертикальные движения обусловливают скорости долговременного процесса седиментации. Уровень моря поднимается (берега опускаются) к югу от 56° с. ш., а его амплитуда увеличивается от 1,5 мм · год$^{-1}$ в начале XX в. до 3–4 мм · год$^{-1}$, прогнозируемых к началу XXII в. Поднятие берегов (регрессия моря) очевидно в Центральной и, особенно, в Северной Балтике (1–9 мм · год$^{-1}$). Эти факторы ускоряют эрозию мелководья, эвтрофикацию и аккумуляцию осадочного материала в отдельных лагунах. Последние процессы усложняют экологическое состояние на мелководных участках. Антропогенный фактор проявляется в устьях рек, в лагунах, в зонах геохимических барьеров. Вышеупомянутые факторы обусловливают различные (0,6–15,0 мм · год$^{-1}$) скорости осадконакопления в бассейне Балтийского моря, которые максимальных значений достигают в лагунах Восточной Балтики (2,5–15,0 мм · год$^{-1}$).

Обобщение данных автора и литературных публикаций позволило прогнозировать развитие Куршского залива и Восточной Балтики на более, чем 1000 лет вперед. Заметно изменятся берега; прибрежные бассейны (Вяйнамери в Эстонии, Рижский залив, Куршский, Вислинский, а также Пуцкий заливы) обмелеют. На месте этих бассейнов в недалеком будущем возникнут новые мелководные лагуны. Будущее лагун Восточной Балтики (Куршский и Вислинский заливы) будет подобно состоянию современной береговой зоны Польского Приморья, где озера Леба, Гардно и др. – некогда бывшие обширными лагунами, находятся на заключительной стадии деградации.

Прогнозируемое развитие Восточной Балтики произойдет, если не изменятся направления тектонических движений и изменений уровня моря и если не произойдет сверхсовременное технологическое вторжение человека в ход природных процессов.