LARGE BARRIER-LAGOON SYSTEMS ON THE EASTERN AND SOUTH-EASTERN BALTIC SEA COASTS: CONDITIONS OF DEVELOPMENT

Ekaterina Badyukova, Moscow State university, faculty of geography, Russia
Leonid Zhindarev, Moscow State university, faculty of geography, Russia
Svetlana Lukyanova, Moscow State university, faculty of geography, Russia
Galina Solovieva Moscow State university, faculty of geography, Russia

badyukova@yandex.ru

The paper considers the geological structure and evolution of large barrier-lagoon systems in the eastern and southeastern coasts of the Baltic Sea. The data available on some coastal deltaic plains in the Leningrad Region, Latvia and Lithuania are discussed in some details. The considered materials lead the authors to the conclusion about a unified mechanism of the systems' development. A considerable rise of the sea level at the Littorina Sea transgression fostered large transgressive bars developing at the margins of deltaic plains and lagoons formation on the surface of these plains.

Keywords: sea-level oscillation, coast, barrier-lagoon system, paleogeography

INTRODUCTION

The geological and geomorphological context of large barrier-lagoon systems have been recently studied in details in the SE Baltic region including the Curonian and Vistula Spits and the adjacent coasts of the central and eastern Poland [23]. The results strongly suggest the sea level fluctuations to be the leading factor in the barrier system appearance and evolution. The same factor was undoubtedly crucial in the evolution of large constructional landforms on the eastern coasts of the Baltic, including the Gulf of Finland, Latvian and Lithuania coasts. The field studies were confined to several key regions.

I. NEVA LOWLAND

The lowland is confined to the land between the Gulf of Finland and the Ladozhskoye Lake. It is noted for small elevations and flattened surface. Two terrace levels are distinguishable; the upper of them is attributed to the Baltic Ice Lake, which is a freshwater lake formed at the southern margin of the Scandinavian ice sheet. The younger – Littorina Sea terrace – forms a gently sloping plain that occurs as a narrow fringe surrounding the Gulf coasts. Its boundaries marked by ancient beach ridges and scarps modeled by marine erosion [13].

The Neva Lowland includes Sestroretsk and Lakhti depressions, together with the land adjoining the lowermost part of the Neva River . In spite of extensive materials obtained on the geological history of the eastern part of the Gulf of Finland in the Holocene, there are a lot of questions still to be solved.

Sestroretsk basin and Sestroretsk Razliv Lake.

The Sestroretsk Razliv Lake did not come into being until the early 18th century. Instead, there existed two rivers named Sestra and Chernaya; below their confluence the resulting water stream is known under the name of the Gagarka R. The dam construction on the latter in 1723 resulted in flooding of the lowermost parts of the Sestra and Chernaya valleys and a part of the coastal plain. The flooded areas formed the Lake Razliv about 5 km long and 4 km wide; the lake is drained by way of artificial canal (Sestra Zavodskaya) going between two dune ridges.

The Sestroretsk depression enclosing the lake is separated from the Gulf of Finland by a sandy barrier 1–3 km wide and 10 km long. The sandy accumulations are thickest in the western part of the barrier; there they form several ridges of dunes up to 10–12 m high [13] arranged en echelon along the sea coast. The prevalent winds determine the dune movement from west to east, with trunks of earlier buried trees exposed in deflation basins [20]. Similar processes are typical of the Curonian and Vistula spits [23]. There are vast marches at the back of each large sand ridge, such as Kanavnoye and Sestroretsk ones, the latter being the largest of all.

The dune formation on the Gulf of Finland coasts started about 3000–3500 years ago. By that time the region had been already peopled, as follows from archeological finds recovered from under the dunes near the town of Sestroretsk. 11 archeological sites were excavated on the western coast of the Lake Razliv under the dunes; they yielded some Stone Age tools and numerous ceramic fragments attributed to the 3rd – 2nd centuries BC. The Neolithic sites Sosnovaya Gora and Sosnovaya Gora 1 were found on the eastern coast of the Sestroretsk Razliv Lake, within a rather narrow sand ridge. The Sosnovaya Gora 1 site has been studied in details in respect to its stratigraphy, lithology, and geochemistry. The results obtained make possible reconstructing the principal stages in the regional environment evolution and its colonization by the primitive man. The ceramic fragments recovered from that site are dated to ~4th millennium BC – 4890±35 yr. BP (3715–3636 cal. BC) [8].

There are ridges 10–13 m a.s.l. overgrown with pines in the NE of Sestroretsk marsh. Judging from the map and description of them compiled in the 19th century, they may be interpreted as the coastline of the Littorina Sea (one of its stages) and related dune massifs. The former coastline was a barrier bar with a lagoon at its back. (Fig. 1).

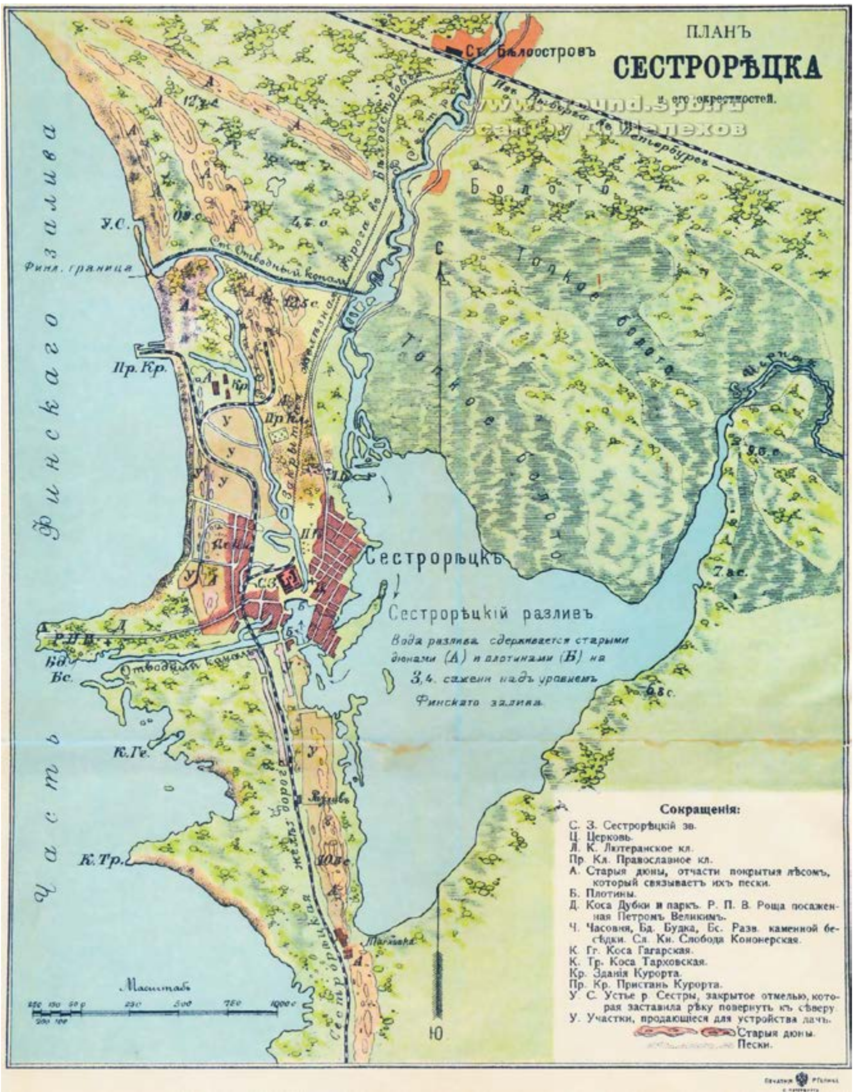

Fig. 1. The Sestroretsk Razliv Lake, mapped at end of the 19th century.

All the boreholes drilled on the Sestroretsk marsh penetrated a peat layer 1.5 to 3 m thick and reac17.hed a diatom gyttja attributable to the Littorina Sea at a depth of 4–5 m. The gyttja is 3–4 m thick, occasionally up to 10 m [3].

Similar deposits are found on the right bank of the Sestra Zavodskaya Canal, 200 m downstream from the railroad bridge; the diatom gyttja of the Littorina age occurs there at a depth of ~3 m under eolian sands. Such a sequence is traceable over a large area [22].

The above facts give grounds to suggest that the infilling of the ancient Sestra R. valley with sediments up to 50 m thick began at the time of Littorina transgression and proceeded along with the coastal plain flooding. The coastal plain was separated from the sea by bar, the first lagoon formed which presents a swamp at present. All the subsequent fluctuations of the sea level and the post-glacial isostatic uplift of the land surface resulted in the shoreline moving gradually seaward and in development of a series of barrier-lagoon systems. The Sestroretsk dunes are the latest large barrier.

Lakhti depression and Lakhtinsky Razliv Lake.

The Lakhtinsky Razliv Lake is in the Lahti depression at a level no more than 3 m a.s.l. The lake receives two rivers – Kamenka and Chernaya and is connected with the Nevskaya Guba bay by a channel. A large barrier bar up to 4 m high separates the lake basin from the sea. The barrier extends towards southeast as a peninsula with alternating ridges and linear hollows oriented from W to E [19].

In the Primorsky district there is a very deep buried valley confined to a deep-seated regional tectonic fault of sublatitudinal trend. The Lakhti depression partly coincides with the buried valley (the side tributaries of the latter are found in the vicinities of Ol'gino village) and partly – with an active submeridional fault [14].

The Lakhti depression occupied for the most part with wetland has been studied since the early 20th century. Of particular interest are detailed works by K.K. Markov [17], the geological sections exposed by boreholes being described in his monograph (fig. 2 A, B). There are two peat horizons with a layer of sandy loam between them. Judging from diatoms assemblages and from pollen diagrams, the layer may be attributed to the Littorina time. Later multidisciplinary studies of the Lakhtinsky Razliv deposits permitted the sequence to be subdivided into series of the Yoldia Sea, the Ancylus Lake and the Littorina Sea sediments (fig. 2 C, D) [18]. A layer of gyttja from a depth of 2.6 to 2.9 m was dated by ^{14}C to 9160±150 yr. BP (10 746–9891 cal. BP).

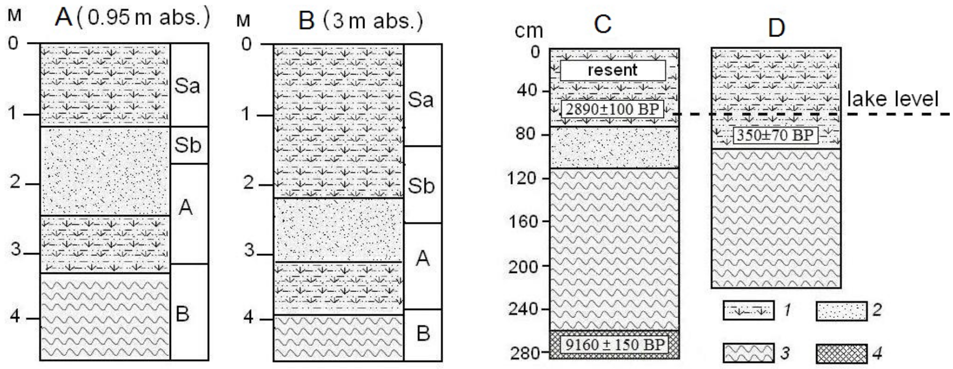

Fig. 2. Boreholes in the Lakhti wetland. A, B – according to [17], C, D – according to [18]. 1 – peat, 2 – sand, 3 – clay, 4 – gyttja

In the borehole C the deposits change upwards first into bluish-gray silty clay with occasional black hydrotroilite interlayers, then into light brown fine sands and clays of the Littorina stage. Still higher they are gradually replaced with dark brown peat. The radiocarbon date obtained for a sample taken at the base of the peat suggests the Littorina Sea regression and the peat accumulation in the region began according to ^{14}C 2890±100 yr. BP (3268–2790 cal. BP [18]**.**

Boreholes drilled near the Ol'gino settlement penetrated marine sands and reached buried peat layer of the Littorina age at a depth of 4–6 m [22]**.** As follows from the drilling results of the barrier has been gradually migrating landwards. Under conditions of the rising sea level the coastal plain was partly inundated, a lagoon being formed behind the bar. Such a mechanism of the barrier-lagoon system development is universal and has been observed in many coastal regions [1].

Several boreholes drilled within the Lakhtinsky Razliv Lake at different depths reached a poorly decomposed horizon of peat. The age of the latter was estimated at about 300 years old (314±100 ^{14}C yr BP). Therefore, the Baltic Sea level at that time was below this of the present-day. Geological and geomorphological analysis of the Curonian and Vistula Spits also provided evidence of the Baltic Sea level oscillations at the historical time. In particular, there are traces of a high stand of the sea level (0.5–1.0 m above that of today) datable to ~1700 yr ago and to the Viking epoch (the 9th – 10th centuries) [24].

The Neva Lowland within the limits of St.-Petersburg

Paleoenvironmental reconstructions in the eastern part of the Gulf of Finland are particularly hindered by the man-induced changes in landscapes. That makes studies of archeological objects particularly significant. The first archeological site of the Neolithic – Early Metal age discovered in the Neva River basin – Okhta 1 – is positioned near the St.-Petersburg center, on the Okhtinsky Point [10, 15].

Detailed studies, with recent scientific approach and methods being applied, identified the Littorina Sea coastline within the city limits. The coastline is distinctly seen in the topography as a series of erosion scarps and beach ridges [21] traceable on the Neva Lowland at a distance up to 13 km from the today's coastline. One of the largest constructional landforms on the Neva Lowland within the city boundaries is the sand Ligovka Spit extending from the southern coast of Neva Guba towards NE as far as the Neva channel (fig. 3).

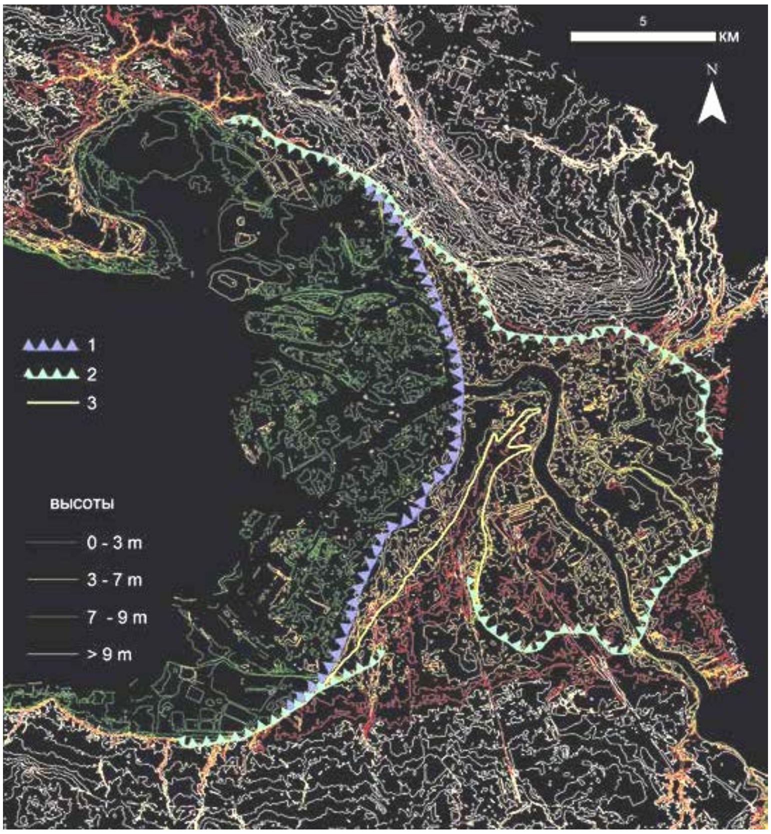

Fig. 3. Areas of the Littorina Sea coastal landforms. 1 – boundary of the "Vasileostrov" terrace 0–3 m a.s.l. attributed to Old Baltic transgression; 2 – "Okhtinskaya" terrace boundary dated to the maximum stage of the Littorina transgression; 3 – Ligovka Spit (outlined by 6 m isohypse), according to [21].

The Ligovka Spit surface under the banked earth is at 7–8 m a.s.l., while the Littorina surface around the spit is 3 to 4 m lower. The spit is about 10 km long and 600 m to 2 km wide. It is composed of cross-bedded (diagonal-bedded) sands of Littorina age replaced upwards with coarse sands with gravel and pebbles. The total thickness of sands varies from 5 to 7 m. The entire spit body does not lie on marine sediments as it is most typical of such constructional landforms; it occurs directly on the continental deposits. The sands superpose peat beds over the entire length of the spit. The deposit of peat (changing occasionally into gyttja) "exceeds in size all the known buried peatlands of the Littorina age" [22]. Within the city boundaries the Littorina deposits up to 13.6 m thick are mostly bluish and gray sands, sandy silts and loams, occasionally they include vivianite particles and peat interlayers traceable along the strike. The gyttja clays, including those known as therapeutic muds in the Sestroretsk Razliv Lake [6] are also assigned to the Littorina Sea deposits.

Judging from the morphological and lithological characteristics of the Ligovka Spit, that landform is not a marine formation emerged gradually to the surface in the course of the marine regression, though such is a viewpoint of a number of investigators [9, 17, 21, 22]. Rather than that, it may be considered to be a large barrier developed at the margin of the coastal plain against the background of rising sea level; in the process a lagoon was formed at the back of the barrier, while the bar itself grew in thickness and moved onto the lagoon. We have studied a similar scenario of the barrier-lagoon systems evolution on the Curonian and Vistula Spits. In fact, such a mechanism of the barrier formation is actually universal and may be observed on all the marine coasts [2, 23].

It may be concluded from the above that the lagoon developed at the initial stages of the Littorina transgression over a sizable part of the present day city area; it was separated from the Gulf of Finland by a large barrier. An undisturbed sedimentation proceeded in the lagoon and resulted in a series of thinly layered sands and silts; they are exposed at present at the confluence of the Neva and Okhta rivers. The environments on the lagoonal coasts were beneficial for human habitation. The earliest archeological sites on the Okhtinsky Point are dated to that time – the first half of the 5th millennium BC [9]. The lagoon was undoubtedly drained at that time (as it received rivers) and was permanently connected with the sea. During the large-scale Littorina transgression and the subsequent regressive stage of the sea, some oscillations of the Baltic Sea level occurred (recorded in particular in the geological context of the Okhta I archeological site). The sea level lowering gave way to its rising which resulted in development of a wide arc of the 'Vasileostrov' terrace modeled by marine erosion [21].

II. THE NARVA–LUGA LOWLAND

The lowland is situated at the mouth of the Narva and Luga rivers and is distinct for a rather complicated topography. Lakes and swamps occupy a considerable proportion of its surface, with constructional coastal landforms of various ages between them. The lowland includes three isolated plateau fragments known as Kurovitsky, Krikovsky and Kurgalsky, the latter forming a peninsula of the same name separating the Narva Bay from the Luga Bay.

The western slope of the peninsula drops towards the Narva Bay as a scarp with a high dune ridge stretching along its edge (Fig. 4 A). The source of the eolian sand was fluvioglacial sediments exposed in a paleo-cliff at the plateau margin.

Fig.4A. An overgrown downwind slope of the dune. Fig.4B. Fluvioglacial deposits

There are several generations of spits on the lowland varying widely in their size, age, and orientation. The largest of them – Riygiküla, Kudruküla, and Meriküla ones – were first described in details by K.K. Markov [17].

The Riygiküla Spit is the farthest from the sea. It forms an arc encircling the southern periphery of the lowland and is composed mostly of coarse littoral deposits. A radiocarbon date obtained on the archeological site – 5305–5040 yr BC (6212±48, Hela-2742) [7] permits to assign this ancient coastline to an early stage of the Littorina transgression.

A younger constructional landform – that is Kudruküla Spit – extends as an arc 25 km long and 0.2 to 1.5 km wide along the Narva Bay coast. A chain of dunes up to 15 m high marks its axis, though no traces of sands being recently wind-blown have been found on the surface composed mostly of coarse-grained sand and pebbles. In the central part of the arcuate spit there are archeological sites dated at 2215–2020 yr BC (37250±40, Hela-2744). Further on there are dunes up to 20 m high forming a scarp facing east, towards the swamped surface of the ancient lagoon.

To the north of it there is another archeological site dated at 1910 yr BC (3607±31, Hela-2516). The Kudruküla spit borders on the southern slope of the Kurgalsky plateau remnant ~20 m high composed of fluvioglacial deposits (Fig 4 B). There are archeological sites arranged along its edge, their age being estimated at 3970–3940 yr BC (5090±40, Hela-1945) [7].

The Kudruküla spit sites are localized on sandy ridges of a moderate height alternating with swamped hollows. Quite possibly the ridges are former foredunes having developed at the back of the beach under conditions of the slowly receding sea [25]. Similar eolian landforms steadily gaining in elevation landwards are found in other parts of the Narva-Luga Lowland. Both relative elevation and the altitude a.s.l. increase southwards and reach 4–6 m at the distance of 2 km from the sea.

At present the lowland is separated from the sea with a lengthy barrier beach of Meriküla. The presence of sand in large quantities within the littoral zone was instrumental in the development of a series of massive dune ridges up to 20 m high and up to 2 km across on the whole.

As follows from the drilling data given in the monograph by K.K. Markov [17] (Fig. 5), a series of lagoons developed successively on the coastal waterlogged plain during the Littorina. That suggestion is corroborated by the peat occurrence at the base of diatomaceous gyttja of the Littorina age. An abundance of sand in the coastal zone favored development of large bars and undisturbed deposition of diatom gyttja in lagoons.

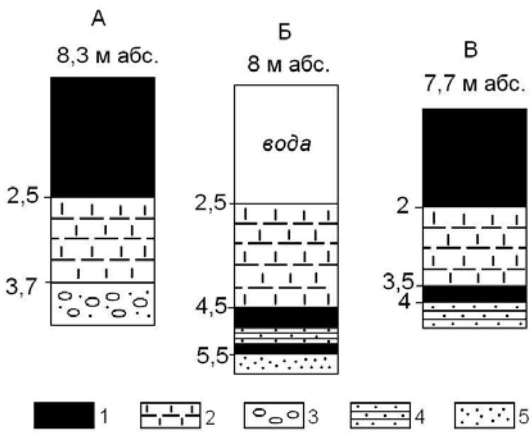

Fig. 5. Boreholes on the Narva-Luga Lowland (according to [17]). 1 – peat, 2 – gyttja, 3 – sand with gravel and pebbles, 4 – sandy loam, 5 – sand

It should be noted in conclusion that facts established by drilling, along with dated archeological artefacts and the results of geomorphological analysis of the Narva-Luga Lowland allow a definite conclusion that the barrier-lagoon systems evolved there throughout the Littorina time which resulted in several generations of lagoons to have been formed on the coastal plain. The lagoons separated from the sea by sand barriers (Riygiküla, Kudruküla, and Meriküla Spits) developed in a successive order on the low deltaic plain advancing slowly seawards. The latter may be ascribed both to isostatic uplift of the Earth's crust and to sediments accumulation in the nearshore zone. Another evidence in favor of the land advancing seawards is given by the age of archeological artefacts (the nearer is the archeological object to the coastline, the younger it is).

III. THE COASTS OF LATVIA

The barrier-lagoon systems are widely spread over the Latvian and Lithuanian coasts. The largest and most thoroughly studied is Ventspils Lagoon 30 km long and up to 15 km wide crossed by the Venta River. The lagoon is separated from the sea by a large barrier bar with several dune massifs on its surface. Both the barrier and the lagoon include a few islands composed of glacial till and fluvioglacial sediments. There are known several sections with lagoonal or beach deposits attributed to the Littorina sea basin occurring above the gyttja or peat beds formed under subaerial conditions on the coastal plain. To take but a few examples, there is a section near Varve settl. 10 km south of Ventspils where a peaty sapropel dated at 7110±170 yr BP occurs under the barrier and lagoon deposits of the Littorina Sea (Fig. 6B) [11]. In the northern part of the lagoon there are sands of lagoonal and fluvial origin 2.5 m thick overlying sapropel dated at 8970±180 yr BP (Fig. 6 C). There is another section on the left bank of the Venta River near Ventspils at 4 m a.s.l. where gyttja is unconformably overlain with marine sands (Fig. 6 A) [12].

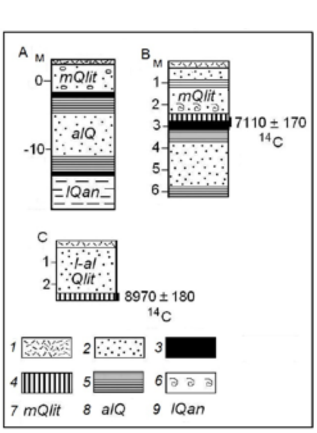

Fig. 6. Boreholes in the Ventspils Lagoon (according to [11, 12]). 1 – soil, 2 – sand, 3 – peat, 4 – gyttja, 5 – clay, 6 – mollusk shells

IV. THE COASTS OF LITHUANIA

An extensive barrier-lagoon system extends for more than 60 km southwards from Liepaja to the Lithuania boundary and further south to Šventoji settl. It abounds in lakes, Liepājas and Tosmares being the largest ones. Formerly the lakes were connected with each other, forming a large gulf the Curonian Gulf same behind the Curonian barrier. At present the lowland surface lies hardly above the sea level and is heavily waterlogged. The peat drilled in one of the largest wetlands is up to 10 m thick [16].

The coastal lowland is separated from the sea with a sandy barrier that includes occasional morainic hills forming minor cusps of the shoreline. The sandy barrier is occasionally up to 2 km wide and bears a series of dune ridges 20–30 m (and more) high. Locally the barrier is partly eroded and reduced in width and elevation.

The considered part of the coast is noted for a presence of a linear uplift in the offshore zone traceable almost from the water edge to a depth of 40 m (Fig. 7). It is known as Liepaja Swell and marked with boulder fields (eroded till) and outcrops of Pre-Quaternary rocks [5].

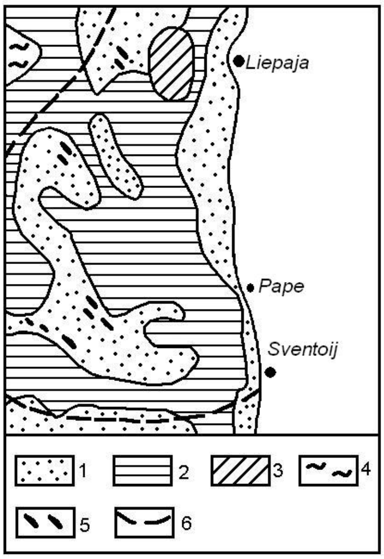

Fig. 7. Underwater slope (foreshore) between Liepāja and Šventoji (according to [5]). 1 – sand, 2 – till (boulder loam), 3 – outcrops of solid rocks, 4 – clays, 5 – ridges.

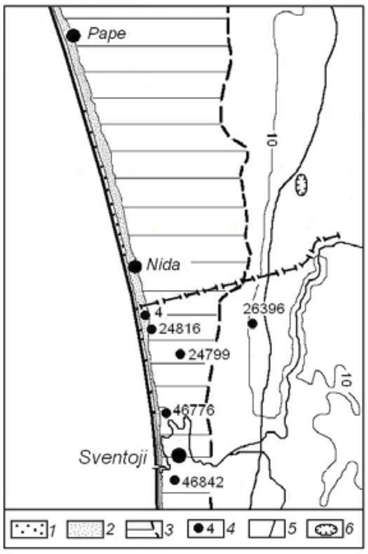

Fig. 8. Boreholes near Šventoji (according to [26]). 1 – beach, 2 – dunes, 3 – paleo-lagoon, 4 – boreholes, 5 – road, 6 – quarry

There is a load deficiency in the coastal zone which accounts both for the barrier erosion and for its displacement landwards, the coastal wetland being overlain. The process is indicated by some rounded lumps of peat found on the beach and was observed directly. During strong storms (such as in 1967) the lower segments of the barrier are overwashed by waves, the sediments being moved into the lagoon [4]. The most detailed studies of the coastal lowland were performed in the vicinities of the Šventoji town, several boreholes having been drilled there (Fig. 8).

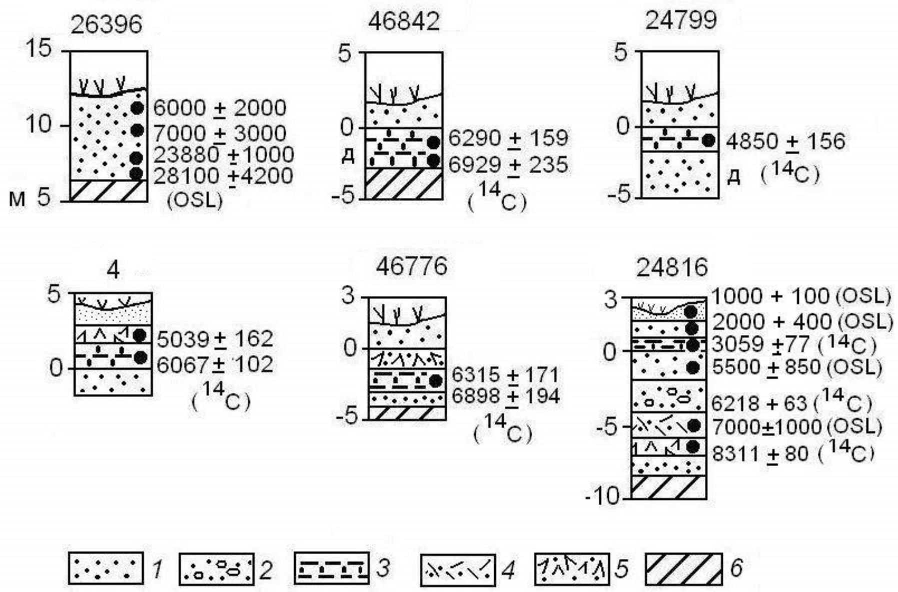

Fig. 9. Cores of sediments drilled in the Šventoji vicinities, according to [26]. 1 – sand, 2 – sand with gravel and pebbles, 3 – gyttja, 4 – sandy peat, 5 – peat, 6 – till

The material thus obtained was further thoroughly studied using palynological analysis and dating by radiocarbon and OSL techniques [26]. As can be seen in given sections, the Littorina transgression deposits are dominated by lagoon facies (Fig. 9).

They occur immediately above the deposits formed earlier on the coastal lowlands, namely fluvial sands, gyttja or peat. Beach facies of the Lttorina age penetrated by borehole 24816 were dated by ^{14}C at 6218±63, which is indicative of the shoreline advance. Similar advancing coastlines have been observed on the Curonian and Vistula Spits [24], as well as on all the above listed segments of the low land.

V. CONCLUSION

Large constructional landforms of barrier type have been studied for the purpose of better understanding of their structure and genesis. The studies were performed on the eastern Baltic coasts including the Gulf of Finland and the coasts of Latvia and Lithuania. The results obtained permitted a definite conclusion on a unified mechanism of their development originally as marine bars formed in the Holocene off the river mouths. The ice sheet retreat and decay produced a great volume of fluvioglacial sands and gravels that served as a construction material for the barrier formation all over the considered coastal region. Both the formation and further evolution of the barrier were greatly influenced by the sea level transgressive-regressive oscillations. Many of the constructional barriers are essentially syngenetic landforms and include of some earlier formations, such as fragments of deltaic plains, and remnants of till or glacio-lacustrine sediments.

REFERENCES

[1] E.N. Badyukova, A.N. Varushchenko, and G.D. Solovieva, "Impact of the sea level fluctuations of the coastal zone development," *Vestnik MGU*, Ser. 5, No. 6, 1996, pp. 83-89 (In Russian)

[2] E.N. Badyukova and P.A. Kaplin, "Barrier bars," *Geomorfologiya*, No. 3, 1999, pp. 3-13 (In Russian)

[3] V.V. Belikov, *A northern health resort of Russia. Secrets of the Lake Razliv*. St.-Petersburg, 1999, 175 pp. (In Russian)

[4] E.A. Bulgakova, Some specific features of morphology and dynamics of the Baltic Sea present-day coasts," in *The present-day exogenous processes and methods of their investigations*, G.Ya. Eberhards, Ed. Riga: Latvia Univ. Press, 1982, pp. C. 33-56 (In Russian)
[5] A.F. Veinberga, I.G. Veinbergs, Ya.R. Klavins, "Southeastern Baltic Sea bottom topography and specific features of the last ice sheet retreat from that region," in *Relief morphogenesis and paleogeography of Latvia*, O.P. Aboltyns, Ed. Riga: Latvia Univ. Press, 1986, pp. 130-145 (In Russian)
[6] Geological Atlas of St.-Petersburg. St.-Petersburg: Komilfo Publ., 57 pp.
[7] D.V. Gerasimov and M.A. Kholkina, "Archeological studies of ancient lagoon systems: Explorations of the Narva-Luga interfluve in 2012-2014". Electronic library of the Peter the Great Museum of Anthropology and Ethnography (Kunstkammer) RAS // www.kunstkamera.ru/lib/rubrikator/07/978-5-88431-287-6 (In Russian)
[8] E.F. Grinbergs, "Late-glacial and post-glacial history of the Latvian SSR coasts". Riga: Latvian Ac.Sc. Publ., 1957. 122 pp. (In Russian)
[9] T.M. Gusentsova, D.V. Ryabchuk, A.Yu. Sergeyev, M.A. Kul'kova, "Paleogeographic reconstructions of the Neolithic people environment on the eastern coasts of the Gulf of Finland and southern Lake Ladoga basin," in *Geology, geography, evolutionary geography*, vol. XII, E.M. Nesterov and V.A. Snytko, Eds. St.-Petersburg: the Herzen State Pedagogical University of Russia, pp. 157-160 (In Russian)
[10] T.M. Gusentsova, P.E. Sorokin, "Cultural-chronological complexes of the archaeological site Okhta 1 in Saint-Petersburg, Russia // *Geology, Geoecology, Evolutional geography*. 2010. St.-Peterburg. P.164-170 (In Russian).
[11] A.L. Devirts, N.G. Markova, L.R. Serebryanny, "The radiocarbon control over geological estimates of the old coastal formation age on the Baltic Sea," Doklady, the USSR Ac. Sc., vol. 182, No. 6, pp. 1387-1392 (In Russian)
[12] R.N. Djinoridze, G.I. Kleimenova, V.I. Serganov, "New data on the ancient Ventspils lagoon history," in *History of lakes in the North-West*, Materials of the 1st Symposium on the Lake History. Leningrad: Geographic Soc. of the USSR, 1967, pp. 51-56 (In Russian)
[13] O.M. Znamenskaya, "Geomorphological regions and types of relief in the Leningrad vicinities," *Vestnik LGU*, No. 24, 1956, pp. 152-162 (In Russian)
[14] Ya.A. Karpova. Geotechnical support of surface and subterranean construction work under conditions of an active technogenesis of the subterranean volume constituents in the Primorskiy district of St.-Petersburg. Ph. D. Dissertation in Geology. St.-Petersburg, 2014, 271 pp. (In Russian)
[15] M.A. Kulkova, T.V. Sapelko, A.V. Ludikova, D.D. Kuznetsov, D.A. Subetto, E.M. Nesterov, "Paleogeography and archeology of Neolithic – Early Metal age archeological sites at the Okhta R. mouth", *Izvestiya, Russian Geogr. Soc.*, vol. 142, 2010, pp. 13-31 (In Russian)
[16] Kurzeme. Riga: Latvian State Publ. House, 1960, 350 pp. (In Russian)
[17] K.K. Markov, "Relief evolution in the NW of the Leningrad Region", Proc. Geol.-Prospect. Dept., the USSR Supreme Council of National Economy (VSNKh), Iss. 117, 1931, 256 pp. (In Russian)
[18] D.A. Morozov, "Reconstruction of paleoenvironmental characteristics based on geochemistry of lake deposits," *Izvestiya, Herzen State Pedagogical University of Russia*, St.-Petersburg, No. 144, 2012, pp. 122-130 (In Russian)
[19] B.B. Polynov, M.M. Yuriev, "The Lakhti depression", *Izvestiya, Research Meliorat. Inst.*, Iss. 8-9, 1924, pp. 76-172 (In Russian)
[20] N.A. Sokolov, "Dunes, their development and inner structure," St.-Petersburg, 1884, 289 pp. (In Russian)
[21] P.E. Sorokin, T.M. Gusentsova, A.Yu. Sergeyev, D.V. Ryabchuk, M.A. Kul'kova, "Paleolandscape of the Litorina Sea coastal zone near the archeological site Okhta 1". Trans. the 2nd Intern. Confer. "Virtual archeology" 2015. St.-Petersburg: State Hermitage Publ., 2015, pp. 112-124 (In Russian)

[22] S.A. Yakovlev, “Deposits and relief in the city of Leningrad and its vicinities”, Leningrad, Pt. 1, 1925, 186 pp., Pt. 2, 1926, 264 pp. (In Russian)
[23] E.N. Badyukova, L.A. Zhindarev, S.A. Lukyanova, G.D. Solovieva, “Development of barrier-lagoon systems in the southeastern Baltic Sea,” *Oceanology*, vol. 48, No. 4, 2008, pp. 595-601.
[24] E.N. Badyukova, L.A. Zhindarev, S.A. Lukyanova, G.D. Solovieva, “Marine deposits of the Vistula Spit (Baltic Sea)”. Proc. of the 2nd Intern. Conf. “Dynamics of coastal zone of non-tidal seas” Baltiysk, 2010, pp.169-172.
[25] E.N. Badyukova, G.D. Solovieva, “Coastal eolian landforms and sea level fluctuations,” *Oceanology*, Vol. 55, No. 1, 2015, pp.139-146.
[26] A. Damušytė, “Post-glacial geological history of the Lithuanian coastal area”, Summary of doctoral dissertation, Vilnius, 2011, 84 pp.