DE GRUYTER OPEN

*Archives of Hydro-Engineering and Environmental Mechanics*
Vol. 65 (2018), No. 2, pp. 109–122
DOI: 10.1515/heem-2018-0008
© IBW PAN, ISSN 1231–3726

# Structure of the South-Western Part of the Curonian Spit

**Ekaterina N. Badyukova, Leonid A. Zindarev, Svetlana A. Lukyanova, Galina D. Solovieva**

Lomonosov Moscow State University, Leninsky Gory 1, Moscow, Russia
e-mail: badyukova@yandex.ru

(Received October 15, 2018; revised November 22, 2018)

**Abstract**

This article addresses the southern sector of the Curonian Spit, the largest coastal barrier of the Baltic Sea. A comparative analysis of the deposits that make up parts of the Curonian and Vistula Spits is given. The detailed analysis of the geological and geomorphological structure of the southern part of the Curonian Spit suggests that, within this sector, it is not a sedimentary barrier created by wave action and Aeolian processes in the Holocene, but a part of a pre-Holocene fluvioglacial plain. Field work has shown that the ancient alluvial or fluvioglacial plain is in the lagoon shore of the Vistula Spit.

**Key words:** coastal barrier, lagoon, erosion, underwater slope, fluvioglacial deposits

## 1. Introduction

A comprehensive geological and geomorphological study of the coasts of the spit, with their wide planetary distribution, will make it possible to address the fundamental problems of the formation and evolution of these geomorphological bodies, on which there is no universally agreed opinion yet. A significant part of the barriers began to be formed during a sea level rise at the beginning of the Holocene. The mechanism of their formation is identical in that deposits from the nearshore slope moved into the coastal zone and formed bars. Further, the bars could change their forms due to the longshore drifting of the deposits. In some cases, series of bars with interfaced lagoons were formed by sea level fluctuations (Zenkovich 1967, Schwartz 1973, Davis 1994). There are many examples of more ancient land fragments located in an accumulative body of a bar composed of marine deposits (Lamper and Janke 2004, Kabailene 2009, Badyukova et al 2007). The study of the barriers is of great importance for the understanding of palaeogeographic conditions under which they were formed and of their current development. This importance was acknowledged in one of the most recent generalizing articles (Otvos 2012).

The Curonian and Vistula Spits, which are situated in the southeastern part of the Baltic are both interesting and informative as study objects. Many detailed studies of their development history and present-day processes on their coasts have been carried out (Gudelis 1979, Mojski 1988, Bitinas et al 2002, Bitinas and Damusyte 2004, Bitinas 2007, Zhamoida et al 2009, Kobelyanskaya et al 2009). Over the last few years new data have been acquired about the geological constitution of the southeastern part of the Curonian Spit, the so-called "root" or "proximal" part.

The question about the place and nature of the contact between the Curonian Spit and the northern coast of the Sambia Peninsula massif has long been attracting attention from the region's explorers. One of the first monographs on the subject (Schlicht 1927) generalized study results and contained a geological map of the Zelenogradsk area (formerly Krantz). The map shows distinctly the surface constitution of the Sambia Peninsula and of the southernmost (proximal) part of the Curonian Spit. They are divided by a depression filled with fluvial deposits of small water channels that run into the Curonian Lagoon.

Another view has become dominant since the mid-20$^{th}$ century, namely, that the structure of the Curonian Spit is integral, that its proximal part is a uniform barrier, and that the spit developed from a growing strip of marine deposits (Gudelis 1954, p. 68). This opinion is also found in many publications today (Boldyrev et al 2007, Zhamoida et al 2009, Kunskas 1970, etc.). However, V. K. Gudelis eventually came to a conclusion akin to that offered by Schlicht (Schlicht 1927). Gudelis wrote that "the southern extremity of the spit stretching from Zelenogradsk to Lesnoe is a natural extension of the Sambia Peninsula and consequently does not belong to the barrier-spit body"(Gudelis 1960). Unfortunately, the author did not provide any proof of his view. This conclusion was seconded by subsequent explorers (Kabailene 1967, 2009) and it is supported by the authors of the present article (Badyukova et al 2007). We attempt in this article to provide a possibly complete generalization of the established facts confirming the non-marine origins of the proximal part of the Curonian Spit. We also rely on those facts to produce a tentative palaeogeomorphic reconstruction of this sector.

## 2. Material and Methods

The Sambia Peninsula is the most prominent seaward area of the Russian Baltic coast (Fig. 1). Its surface is a plain of glacial accumulation formed by the last (Weichselian) glaciations and characterized by multiple glacial relief forms: eskers, kames, drumlins, lake and outwash plains, etc. Glacial and glacial-lacustrine sediments (sand, silt and sandy silt) are exposed in active cliffs along the tip of the peninsula and are highly subject to wave erosion. The retreat rate of the cliffs often exceeds 2–3 m/year. To the north-east and south-west of the Sambia Peninsula extend two large accumulative forms, the Curonian Spit and the Vistula Spit, making the peninsula look like a "winged headland."

The Curonian Spit, the largest on the Baltic Sea, is a Holocene coastal barrier that separates a lagoon of the same name from the sea. The barrier was formed of marine

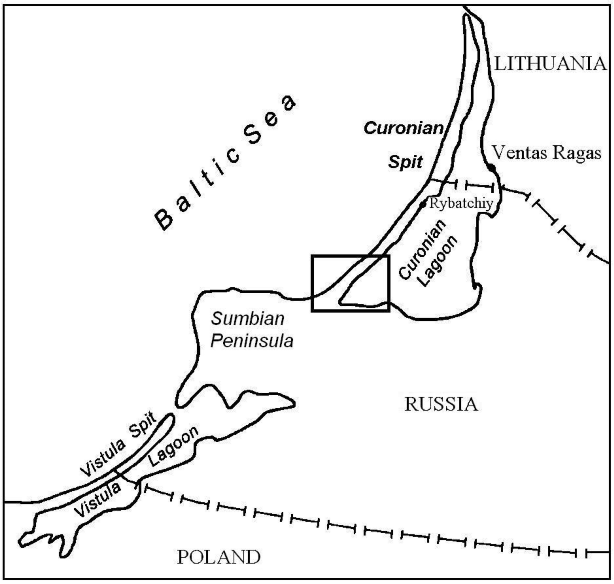


**Fig. 1.** A map of the research area

and Aeolian deposits. Its length is 97 km, and its width varies from 350 m to 4000 m. The surface of the barrier is substantially reworked by Aeolian processes, including the formation of diverse Aeolian features, the most significant of which are a large ridge along the lagoon coast of the barrier with heights of up to 68 m and a modern Aeolian ridge along the sea coast with a height of 10–12 m.

The coastal barrier is subject to wave action on its both sides: from the sea and from the lagoon. Storm waves reach a height of 2–3 m in the lagoon. The barrier is exposed to 60–65 storms of varied intensity during the year, with 30–35 storms having moderate wave heights of 1–2 m. Once in 10 years the coast is exposed to waves as high as 5 m, and every 20–30 years there is an extreme storm with a deep sea wave height reaching 8 m. Westerly wave disturbances are observed most frequently and constitute approximately 35% of all cases. They are also the stormiest. The recurrence of waves coming from SW and NW is 23% and 24%, respectively. Thus, there is a clear predominance of waves coming from western compass points, to which all of the northern coast of the Sambia Peninsula and the entire Curonian Spit are exposed.

## 3. Geological and Geomorphological Characteristics

The landscape characteristics of the proximal part of the spit differ considerably from those of its other portions. The study of the current state of different objects in the national natural reserve "Curonian Spit" shows that the landscape of the southernmost 10-km section of the spit that spans from the town of Zelenogradsk to the settlement of Lesnoe is geomorphologically distinct from the more northern segments of the spit. The low flat and wet terrain is dominant here. It is almost completely covered with woods, considerably boggy and has some peat moors (Fig. 2). Located in the southernmost part of the spit, the common "Royal Forest" consists of old fir, pine and mixed forests (Kozlovich 2008). According to V. I. Alekseev (2008); they are closer to mixed firwoods and small-leaved forests found in the central part of the Sambia Peninsula than to the woodlands covering most of the spit (Fig. 3). Another prominent feature of this part of the Curonian Spit is the absence of dunes. Aeolian accumulations are notable only in the foreshore zone, where they form a separate, intensively eroded ancient coastal dune barrier, within which some poorly developed soil horizons are found. The barrier is often completely eroded or represented only by a narrow coastal portion.

**Fig. 2.** SW part of the Curonian Spit

Modern Aeolian accumulations incidentally form rudimentary features at the cliffs foot and are normally eroded during winter storms. In fact, the sand from the beach does not reach the inland area, because of its lack in the coastal zone and the sufficient height and monolithic nature of the cliff. Large dunes occur on the surface of the spit only beyond the 9$^{th}$ km and farther to the north, where they become one of characteristic elements of its landscape.

The geological data available (Harin and Harin 2006, Badyukova et al 2007; etc.) indicate that the base of the Curonian Spit is represented by Pleistocene glacial deposits cropping out around the settlement of Rybatchiy in the Russian part of the spit. The deposits form a moraine plateau at a height of approximately 5 m. In the southern part of the spit, moraine sediments (till) rise above the modern sea level by 2 m at one location.

**Fig. 3.** Forest in the SW part of the Curonian Spit

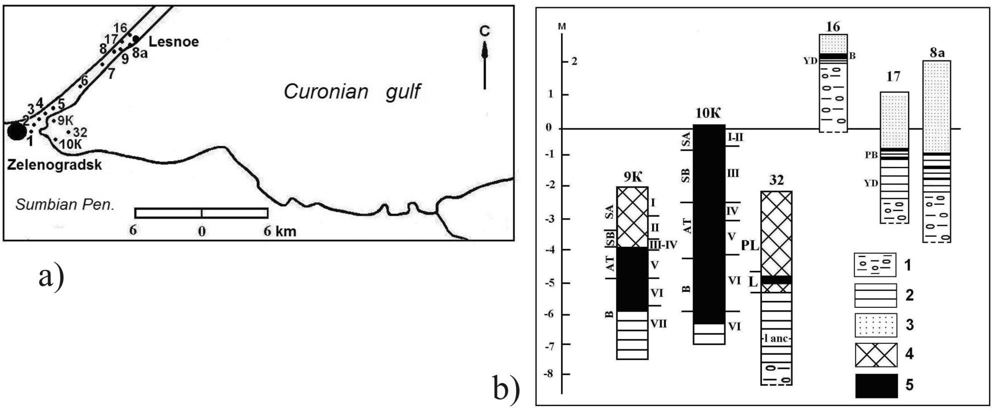


**Fig. 4.** (a, b) Boreholes drilled in the southern part of the Curonian Spit: No. 9K, 10K – (from Kozlovich 2009); No. 32 – (from Chubarenko and Chubarenko 1995); No. 8a, 16, 17 – (from Kabailene 1967); 1–9 – (from Kunkskas (1970): 1 – moraine, 2 – lacustrine clay and aleurite of the pre-Holocene age, 3 – Aeolian sand, 4 – sapropel (lagoon silt, gyttja), 5 – peat. I–VII – spores-pollen zones; Anc – limnic deposits of the Ancylus age; ED – Younger Dryas; PB – Preboreal; B – Boreal; AT – Atlantic; SB – Subboreal; SA – Subatlantic; L – Litorina; PL – Post-Litorina

Complex series of mainly sandy sediments are deposited on the irregular top of the moraine; they were dissected in boreholes (Fig. 4a, b) and found in outcrops of an eroded coastal cliff extending over almost 10 km to the northeast of Zelenogradsk. In the cliff foot, there is a brown-grey till with a considerable addition of boulder-pebbly material. Its visible thickness is sometimes up to 2 m (Fig. 5). Large boulders and pebbly materials are found at the water line and on the slope, where they form a bench. Boulders of different dimensions are found as well on the surface of this part of the spit; they come up through the turf.

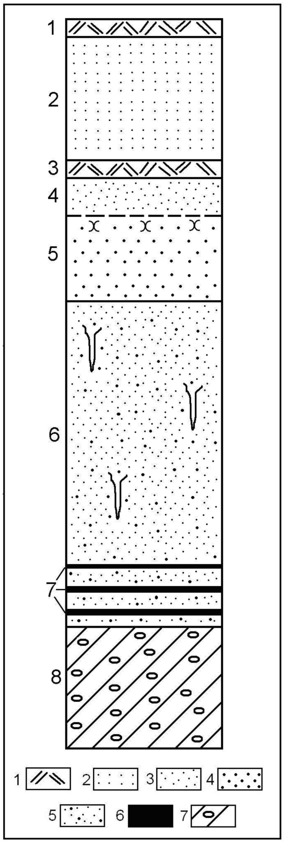


**Fig. 5.** A summary sequence of the outcrop in the sea cliff between Zelenogradsk and Lesnoe: 1 – modern and buried soils; 2 – Aeolian sand; 3 – grey-ashy fine-grained sand; 4 – red-brown sand cemented in its roof; 5 – green-grey different- grained sand; 6 – gyttja; 7 – moraine

The top section of the geological sequence is normally represented by two soil horizons: the modern soil (5 to 20 cm thick) and a peaty buried soil with abundant plant roots (Fig. 5, the beds 1, 3). Between them there is an interlayer of sorted light yellow sand, the thickness of which varies from 15 cm to 3 m. The dominance of sand (up to 90%) of the 0.5–0.25 mm fraction suggests it is an Aeolian sediment (Fig. 5, bed 2). Under the buried soil lies a bed of pale grey, whitish to ashy, fine-grained quartz-feldspar unevenly laminated sand, whose thickness varies from 20 cm to 40 cm (Fig. 5, bed 4). It becomes darker and almost black towards the bottom of the bed; the border with the underlying bed is uneven and has leaks and pockets of peaty fossil plants.

Under those depositions lies a bed of yellow-brown dense bedly sorted and unevenly laminated sand containing plant debris (Fig. 6). In the upper portion of the bed, the sand is partially cemented. It is characterized by ferrous inclusions in the lower portion (Boldyrev et al 2007). The lamination becomes more manifest, as it is defined by the change in bed colors (from dark brown to almost yellow) and the granulometric composition of the sediments. The thickness of this sand bed is sustained enough and equals 0.5–0.6 m (Fig. 6, bed 5).

**Fig. 6.** Outcrop in the SW part of the Curonian Spit

Upwards, a 2–2.5 m series of light green, medium- to fine-grained and clearly laminated sand occurs. The lamination is most distinct in the middle part of the horizon. The incorporations of small pale grey gravels and peaty plant debris (Fig. 6, bed 6) are observed. The sands are characterized by the presence of subhorizontal layers of gyttja ranging from 3 cm to 6 cm in thickness. The silty clay gyttja has a fresh look and is black and thick; it contains abundant non-decomposed plant roots and stalks (Fig. 6, bed 7). All series of deposits described above overlie a brown moraine loam with numerous inclusions of gravels, subangular pebbles and boulders. The visible thickness of the moraine is up to 2 m (Fig. 6, bed 8).

The results of a grain-size study of sandy deposits in this geological succession do not allow us to identify their origin as either marine or Aeolian. The presence of silty-pelite fractions (< 0.1 mm) together with quite coarse-grained sediments (> 1 or even 5 mm) precludes the shoreface origin of the sand. Sand of shoreface origin is better sorted and does not contain fine fractions. It is possible to speculate that the presence of fine-grained deposits is related to the periodic muddiness of water during floods or high waters in lake-glacial water bodies. Indeed, the lamination in the bottom part of the succession (the interbedding of gyttja and light green sands) can be explained by periodic sand introductions by constant or temporary streams, and an argument against the marine origin of the sand constituting the bottom part of the outcrop is the presence of gyttja, the accumulation of which is possible only under calm conditions and without wave impacts. Such conditions apparently characterize the probably periglacial shallow lakes and their gulfs, as well as oxbow lakes and other landlocked water reservoirs. Aeolian sands are also characterized by a high degree of sorting and the prevalence of 0.5–0.25 mm fractions, which are absent in the root portion of the spit. The deposits observed in the cliff extend inland and compose the surface of the southern part of the spit. Along the profile across the spit, there are the same deposits in pits that characterize the top part of the outcrop described above: ash-grey and pale grey sands and reddish-brown sand. Our granulometric study confirms the similarity between the grey and yellow-brown sand outcropping in the cliff and the sand on the surface of the spit. That sand is cemented sporadically both in the spit and within the cliff. The deposit composition of the cliff changes along the coastline. One of geological sections near Lesnoe was described by M. V. Kabailene (1967, 2009). In the outcrop of the coastal cliff of the spit there is a 0.3 m thick silt layer resting on till, the top of which is 2 m above the sea level, which, in turn, is overlain by a 0.2 m thick peat layer. Many explorers have studied this outcrop since the 19$^{th}$ century. They have dated the peat accumulation to the Early Boreal age and the underlying silt layer with rich molluscan fauna remnants to the Late Glacial age.

Sporo-pollen and diatomic studies of those deposits allowed M. V. Kabailene (2009) to draw the conclusion that they were formed under freshwater conditions in a cold climate. According to those data, there was a fresh-water reservoir in the Late Glacial age that was discharged at the end of the Upper Dryas. There were residual reservoirs within the bottom depressions of a Periglacial lake in the Preboreal age; lacustrine sediments were found in the outcrop near Lesnoe. The peat recovered from depths of 0.8–0.9 m on the lagoon side in Lesnoe dates to 10 050±170 BP (MSU–1245).

Deposits similar to those revealed near Zelenogradsk were found by us on the Vistula Spit, in the territory of Poland. Near the village of Przebrno, a low near-shore terrace has accreted with a distinct scarp 1.5–2 m high, which has developed at the margin of an extensive flat terrace that differs significantly from other areas of the barrier in its topographic features. According to the relief and nature of vegetation, this flat surface, free of Aeolian forms, slightly rising towards the central part of the barrier, resembles the foot of the Curonian Spit. Around Przebrno, the forest has been cut down, but farther, the forest massif continues, dominated by fir trees, which is unusual for the other landscapes of the Vistula Spit. In a small quarry on the outskirts of the village, the upper part of the following sequence is opened from the top down:

(1) soil, 5 cm; (2) light gray, whitish to ashy, quartz-feldspar fine-grained sand, 3 cm; (3) yellow-brown layered sand with dark sinters and pockets, which is determined by variations in the color of the layers (from dark brown to yellow), 10 cm; (4) bright yellow and light yellow sand with interlayers of darker sand, more uniform in color in the lower part of the layer, 20 cm (observable thickness) (Fig. 7).

**Fig. 7.** Outcrop on the Vistula Spit, near Przebrno

Apparently, this site is a remnant of a more ancient form preserved in the body of the barrier. Such ancient remnants of different origin were identified earlier in the Curonian and Vistula spits by the present authors, who interpreted them as lacustrine or lacustrine-glacial. In addition, ancient remnants of a delta plain were found at 23 km of the Russian part of the Vistula Spit (Badyukova et al 2011).

Interesting structural information about the southwestern part of the Curonian Spit has been provided by engineering-geological research carried out along an existing gas pipeline (Harin and Harin 2006). Boreholes showed different heights of the moraine, ranging from 8 m to 10 m below the sea level at the beginning of the spit and from 2 m to 3 m around Lesnoe (Fig. 8). Lacustrine bluish-grey silts of 1 m in thickness and without gravelly-pebbly materials are deposited on dense boulder-gravel till; they are substituted by peat up the sequence. A peat lens of 10 m in thickness and about 4 km in width is located in a valley-form depression in the moraine base of the spit at its 1–3 km. Another peat lens of about 1 m in thickness is found in a sand bed lying immediately on moraine loam near Lesnoe.

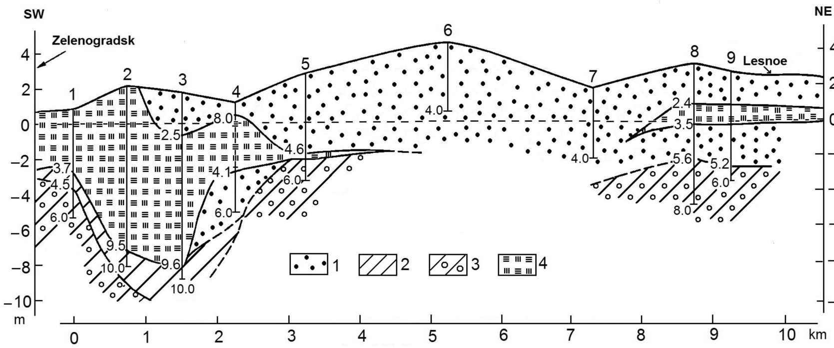


**Fig. 8.** Longitudinal geological profile of the southern part of the Curonian Spit (from Harin and Harin (2006), with some changes): 1 – medium-grained quartz-feldspar sand; 2 – lacustrine-glacial deposits; 3 – glacial deposits; 4 – brown reed-sedge peat, various degrees of decomposition; 5 – boreholes

One of the boreholes that reached 10 m in the northeast suburb of Zelenogradsk revealed deposits similar to those described above. Those were pale grey quartz sands with a low humus content occupying the uppermost 2 m of the sequence, as well as beds of yellow quartz-feldspar sand located under them and peat overlying the moraine. Deposits similar to those forming the root part of the spit also outcrop in some other parts of the Sambia Peninsula. For example, they are found in the cliff to the west of Zelenogradsk. They are overlapped by a small dune ridge and occur at approximate heights of 2.5–3.0 m. Findings by Lithuanian scientists show that the elevated surface of the Cape Ventas-Ragas that forms an island in the Pra-Nemunas deltaic plain is also composed of similar deposits (Bitinas 2007). Earlier studies of this key section of the Lithuanian coast revealed Younger Dryas deposits and probably also those of the Baltic Glacial Lake. In the sequence on the brown-grey till of the latest glaciation there is gyttja with fresh-water mollusk shells overlain by compacted peat deposits (Bitinas 2007). A. Bitinas interprets gyttja as lacustrine deposits and peat as bog accumulations. Their ages are identified as the Alleröed and the Younger Dryas (13740±290 and 12400±350 BP, respectively).

Opinions on the genesis of the peat are divided. A number of researchers disagree with A. Bitinas because of the often encountered mineralization of the peat. The presence of sand, silt, clay, and sometimes also gravel in the peat makes them believe that peat accumulation occurred episodically and together with the basic alluvial sedimentation process. Other published sources connect the formation of peat deposits in the Curonian Spit with the accumulation of plant residues in those straits and inlets through which water exchange between the Baltic Sea and the gulf took place. According to their authors (Harin and Harin 2006), the largest strait existed for a long time, and rivers developed wide valleys, as deep as 10 m, in the Pleistocene moraine tills (Fig. 8). A similar valley existed until recently in the root part of the spit. Its axial and deepest part was within the first kilometer of the spits axis. Thus, plant detritus was carried mainly from the bay, as can be seen from the prevalent sedge-reed composition of the peat. Apparently, the Dejma river mouth corresponds to this depression in the moraine top and to the strait of Brokist, which was active until relatively recently. Thus, a generally identical nonmarine complex of deposits consisting of peat, gyttja and sand of presumably fluvioglacial origin overlies the moraine in a vast area including the northern coast of the Sambia Peninsula, the root part of the Curonian Spit and the Lithuanian coast of the Curonian Lagoon.

## 4. Hydrodynamic Conditions around the Study Area

The southern 10 km span of the spit is a narrow ledge of the coastal plain composed of glacial and fluvioglacial deposits. From both the sea side and the gulf side, it is being actively destroyed by wave erosion processes that have led to the isolation of this part of land and its subsequent transformation into a narrow spit. The intensive sea-side erosion is explained by the hydro- and lithodynamic climatic features of this coastal section, resulting in a severe deficiency of sediments and a rapid rate of coast retreat. Big-radius circulating whirlwinds, which are characteristic of the South-East Baltic, play a significant role in the intensive movement of erosion products to the outer part of the coastal zone and the shelf. Their occurrence is favored by the non-uniformity of the moraine surface, the coastline and the entering angle formed by the latitude-oriented northern coast of the Sambia Peninsula and by the extended submeridional Curonian Spit (Aibulatov et al 1987). Here, the general values of wave energy arriving at the coastal zone are augmented as a result of the protrusion of the spit from the wave shadow created by the Sambia Peninsula. The compensatory outflow and rip currents play a rather important role in the coastal erosion process (Zhindarev 1997). In addition, the situation is aggravated by intensifying erosion at the lee side of the Zelenogradsk groin series, which results in an impressive bay stretching all the way to Lesnoe. In this section, the fastest rates of wave erosion and coastal retreat are observed, having reached 100 m over the last 70 years (Boldyrev and Teplyakov 2003). The current coastal erosion is most probably inherited from earlier periods in the development of the coast, to which eloquently testifies a wide boulder-block bench on the underwater coastal slope. In some places, moraine outcrops at the bottom are covered with thin layers of gravelly-pebbly or sandy materials that are probably of fluvioglacial origin. As a whole, the character of the bottom deposits testifies to intensive hydrodynamic processes that prevented sedimentation of depositional materials (Zaromskis 2002). The lagoon coasts of the southern part of the spit are currently quite well protected by a wide strip of reed vegetation planted in the shallow offshore waters of the lagoon as a coast protection belt in the mid-20$^{th}$ century. Earlier, however, erosion in that area was much stronger than in other sectors of the spit lagoon coast. The approximate average rate of shoreline retreat obtained by comparing topographic maps for different years was as high as 3.3 m a year near the 6$^{th}$ km of the spit (Badyukova et al 2005). The rapid destruction of the lagoon coasts is related to the complicated hydrodynamic conditions in the southwestern part of the Curonian Gulf, where stronger and more frequent western winds impact its aqueous surface. The mathematical modeling of the flows formed under such conditions has shown that their vortex system develops in the gulf (Chubarenko and Chybarenko 1995). The vortex stream is divided in two branches, one of which moves to the northeast along the coast of the spit, and the other to the east along the southern coast of a gulf. Apparently, those transformations of the flow system, which are especially notable during the autumn-winter intensification of western winds, did promote the intensive erosion of the lagoon coasts that have retreated in places by 250–350 m over the past 100 years (Badyukova et al 2005). It is characteristic that the underwater coastal slope of the southwestern part of the Curonian Gulf is the steepest, with a depth of 1 m observed at a distance of 20 m from the shoreline, while in the other sections of the lagoon coast of the spit this depth occurs at distances ranging from 50 m to 100 m (Zaromskis 2002). According to R. Zaromskis, it is only there that *Schoenoplectus lacustris* alga grows on the underwater slope, as it prefers clay or the loamy substrate of the moraine.

## 5. Conclusions

The geological structure of the proximal part of the Curonian Spit (almost to Lesnoe) indicates that the accumulative barrier was not created by wave and Aeolian processes in the Holocene. The strip between Zelenogradsk and Lesnoe became a narrow isthmus between the sea and the gulf and was merged morphologically with the accumulated barrier formed in the Holocene through intensive destruction of the primary fluvioglacial pre-Holocene plain from both the sea side and the gulf side. This formation occurred under tributary hydrometeorological conditions.

## Acknowledgements

The Russian Foundation for Basic Research (RFBR) provided financial support for this work (project No. 16-05-00262).

## References

Aibulatov N. A., Zhindarev L. A., Piskareva M. A. (1987) Sediment transport in the coastal zone of the South-Eastern Baltic, [in:] *Natural bases of coast protection*, Moscow, 99–115 (in Russian).

Alekseev V. I. (2008) New materials on the fauna of the order of Coleoptera, [in:] *Problems of study and protection of natural and cultural heritage of the national park "Curonian spit"*, Kaliningrad, 34–61 (in Russian).

Badyukova E. N., Zhindarev L. A., Lukyanova S. A., Solovieva G. D. (2005) Morphodynamics of the gulf shores of the Curonian Spit of the Baltic Sea, [in:] *New and traditional ideas in geomorphology. V Shchukin readings. Proceedings*, Moscow, 72–75 (in Russian).

Badyukova E. N., Zhindarev L. A., Lukyanova S., Solovieva G. D. (2007) Analysis of the geological structure of the Curonian Spit (Baltic Sea) in order to clarify the history of its development, *Oceanology*, **47** (4), 594–604 (in Russian).

Badyukova E. N., Zhindarev L. et al (2011) The geological-geomorphological structure of the Baltic (Vistula) spit, *Oceanology*, **51**, 632–639.

Badyukova E. N., Zhindarev L. A. et al (2017) Large accumulative forms of relief on the southeastern coast of the Baltic Sea, *Oceanology*, **57** (4), 580–588.

Bitinas A., Damusyte A., Stancikaite M. et al (2002) Geological development of the Nemunas River Delta and adjacent areas, West Lithuania, *Geological Quarterly*, **46** (4), 375–389.

Bitinas A., Damusyte A. (2004) Littorina Sea at the Lithuanian maritime region, *Polish geological institute Special papers*, **11**, 37–46.

Bitinas A. (2007) *The Quaternary of Western Lithuania: from the Pleistocene glaciations to the evolution of the Baltic Sea. The INQUA Peribaltic Group Field symposium*, Vilnius, pp. 110.

Boldyrev V. L., Teplyakov G. N. (2003) Formation, condition and problems of preservation of landscapes of the Curonian spit, [in:] *Problems of studying and protection of natural and cultural heritage*, Moscow, 20–40 (in Russian).

Boldyrev V. L., Bobykina V. P., Burnashov E. M. (2007) Results and future prospects of monitoring the coasts of the Curonian Spit, [in:] *Problems of study and protection of natural and cultural heritage of the national Park "Curonian spit"*, Kaliningrad, 76–93 (in Russian).

Chubarenko B. V., Chubarenko I. P. (1995) Simulation of the current field in the Curonian Lagoon under storm wind impacts, *Meteorology and hydrology*, **5**, 83–89 (in Russian).

Davis J. R. A. (1994) *Geology of Holocene barrier island systems*, Berlin, pp. 465.

Gudelis V. K. (1954) Some data on the structure and development of the spit Kurshju Nerija, *Prodeceedings of the Institute of Oceanology, USSR Academy of Sciences*, Vol. 10, 62–69 (in Russian).

Gudelis V. K. (1960) Geology and history of the coastal dunes on the spit Kurshju Nerija, *Prodeceedings of the Institute of Geology. Estonian Academy of Science*, Vol. 5, 305–313 (in Russian).

Gudelis V. (1979) The quaternary history of the Baltic, *Acta Universitatis Upsaliensis Symposia Universitatis Upsaliensis Annum Quingentesimum Celebrantis*, **1**, 159–173.

Harin G. S., Harin S. G. (2006) Geological structure and composition of the Curonian Spit (Baltic Sea), *Lithology and Minerals*, **4**, 354–361 (in Russian).

Kabailene M. V. (1967) The development of the spit Kursy-Mares, the Delta of the Nemunas and coastal wetlands, *Proceedings of the Institute of Geology*, **5**, 181–207 (in Russian).

Kabailiene M. (2009) Post-glasial stratigraphy and palaeoenvironment of the northern part of the Curonian Spit, Western Lithuania, *Quaternary International*, **207**, 69–79.

Kobelyanskaya J., Piekarek-Jankowska H., Boldyrev V. L. et al (2009) The morphodynamics of the Vistula Spit seaward coast (Southern Baltic, Poland, Russia), *Oceanological and Hydrobiological Studies*, **XXXVIII**, Suppl. I, 1–16.

Kozlovich I. I. (2008) Especially valuable landscapes of the national Park "Curonian spit", [in:] *Problems of studying and protection of natural and cultural heritage of the national Park "Curonian spit"*, Kaliningrad, Vol. 6, 166–175 (in Russian).

Kunskas P. (1970) On the development of the Curonian lagoon, the Nemunas Delta and coastal marshes, [in:] *History of lakes*, Vilnius, 391–410 (in Russian).

Lamper R., Janke W. (2004) The Holocene sea level rise in the Southern Baltic as reflected in coastal peat sequences, *Polish Geological Institute Special papers*, **11**, 19–30.

Mojski E. (1988) Development of the Vistula river delta and evolution of the Baltic Sea, an attempt at chronological correlation, *Geological Survey of Finland, Special Paper*, **6**, 39–51.

Otvos E. G. (2012) Coastal-barriers – nomenclature, processes and classification issues, *Geomorphology*, (139–140), 39–52.

Schlicht O. (1927) *Die Kurische Nehrung in Wort und Bild*, Königsberg, pp. 180.

Schwartz M. I. (Ed.) (1973) *Barrier islands. Benchmark papers in geology*, Stroudsburg, PA, pp. 451.

Zaromskis R. (2002) Kuršiu mariu priekrantės makrofitai ir jų augaviečių litodinamines sąlygos, *Geografija*, **38** (2), 35–41.

Zenkovich V. P. (1967) *Processes of coastal development*, New York, pp. 738.

Zhamoida V. A., Ryabchuk D. V., Kropatchev Y. P. et al (2009) Recent sedimentation in the coastal zone of the Curonian Spit (Kaliningrad region, Baltic Sea), *Z. dt, ges. Geowiss.*, **160** (2), 143–157.

Zhindarev L. A. (1997) Morphodynamics of irregular shallow shores of non-tidal seas, *Doctoral thesis*, Moscow State University, pp. 250 (in Russian).