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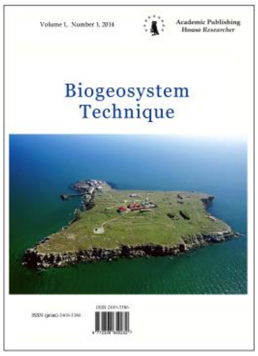

Sands of the Curonian Spit

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Abstract

The Curonian Spit, a massive sandy barrier separating the Curonian Lagoon from the Baltic Sea, is one of the unique places in Europe. It stretches as a narrow (ranging from 0.4 to 3.8 km in width) slightly concave arc for 98 km (46 km in Russia and 52 km in Lithuania) from the Peninsular of Kaliningrad to the city of Klaipeda. The main environmental problem of the Spit is the wind movement of the sands. The sand-fixing works were initiated in the second half of the XVIII and continues to this day, but the problem of sand fixing is still relevant. However the formation of relatively stable columnar and layered sand structures was observed on the lagoon and the sea coast. The task of this work was to determine the reasons for the formation of such structures, which is important for the continuation of work on strengthening the coastal zone of the Spit. The main methods used in this work were scanning electron microscopy and EDS analysis for determining the morphology and composition of particles, laser and x-ray diffractometry for determining the size distribution and the mineralogical composition of particles. The study was focused on sands of the coastal line, where wind activity is greatest. Sands of the sea and lagoon coast differ not only in the size of the predominant fraction and morphology of particles, but also in the type of relatively stable structures formed by them (layered structures of horizontal stratification on the sea coast and columnar sands on the lagoon coast respectively). The formation of sandy contact-aggregate structures (contacts of the edge-to-edge and face-to-face type, respectively) occurs with the participation of clay structural bridges, without them the sands remain incoherent. The use of lagoon marl with a high content of fine particles and $CaCO_3$ can be very promising for creating such clay-sand structures, fixing and stabilization of the sands.

Keywords: Sands, composition, mineralogy, morphology, properties, Curonian Spit

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1. Introduction

The Curonian Spit, a massive sandy barrier separating the Curonian Lagoon from the Baltic Sea, is one of the unique places in Europe in both environmental and geological terms. The spit belongs to the largest accumulative phenomena in the Baltic Sea (Łabuz et al., 2018), it stretches as a narrow (ranging from 0.4 to 3.8 km in width) slightly concave arc for 98 km (46 km in Russia and 52 km in Lithuania) from the Peninsular of Kaliningrad to the city of Klaipėda. It represents a typical erosional-accumulative body (Zenkovich, 1962; Boldyrev, 1998) related to the erosion of cliffs on the Sambian Peninsula and bottom sediments of the Baltic Sea.

The Curonian Spit is a young geological structure (an ephemeral in the geological time scale) that appeared in the Middle – Late Holocene as a result of sediment transport by coastal currents and wind (Kharin G., Kharin S., 2006; Zhukovskaya, Kharin, 2009). The formation of its core started 6–8 thousand years ago and is related to the end of the transgression of the Littorina Sea (Bitinas et al., 2001, 2002, 2005; Bitinas, Damušytė, 2004; Česnulevičius et al., 2017). The Spit assumed its present-day position and appearance approximately 3–5 thousand years ago at the Littorina and post-Littorina stages (Blazhchishin, 1998) and 2 thousand years ago it reached the continental coast (Kabailiene, 1967; Kunskas, 1970; Starkel, 1977; Gudelis, 1979, 1998a, b; Kliewe and Janke, 1982; Mojski, 1988; Müller, 2004). Curonian barrier–lagoon conjugated system likely formed simultaneously during the Holocene optimum (Badyukova et al., 2008, 2011).

Geologic structure of the Spit is made up by eolian, marine and water-glacial Quaternary deposits of the contemporary and upper sections. The eolian complex composes the avandune, the upper layer of palve and the thick layer of the dune massifs. Beneath it there is the sea generation of sands with the stringers of loam, peat, silt and so on, that are underlain by moraine and inter-moraine loam of the Valdai Glaciation. According to Gudelis's model (Gudelis, 1954) widely accepted today, the Curonian Spit consists of sand dunes, including immobile dunes of first generation, mobile dunes of second generation, and avandunes. Their thickness (height) reaches 60 m.

Wind-blown sand movement is the main geomorphological geodynamic process that currently occurs in the Spit (Česnulevičius et al., 2017). The dune complexes are the main relief elements of the Curonian Spit. Its dunes are the highest dunes in Northern Europe and reach more than 30 m in many areas; the Vicekrugo dune (67 m height) is the highest dune form along Baltic Sea coast. All the biggest dune's massifs are forming so-called Great Dune Ridge that stretches along the entire lagoon coast of the Spit. The history of geological development of the Great Dune Ridge is poorly known except the fact that the Great Dune Ridge has been formed only starting from the XVI century due to extremely high aeolian activity influenced by destructive human practices – clearcutting of forests in the greater part of the Spit (Gudelis, 1998a; Bucas, 2001; Dobrotin et al., 2013; Bitinas et al., 2018).

Vegetation plays a key role in sand stabilization and relief stability. A sandy surface that is devoid of vegetation tends to be deflated (Łabuz et al., 2018). Starting in the beginning of XIX century, a substantial part of the Curonian dunes was artificially forested. It arrested some aeolian activity and protected the villages against sand invasion. At the same time, starting in 1805, the artificial foredune was formed along the entire length of the marine coast of the Curonian Spit. This foredune protected (as a barrier) the inner part of the Spit from the seashore sand drift. The sand-fixing works continues to this day. However, as proved by observations and demonstrated in many publications, sands of the Curonian Spit cannot withstand the destructive wave and wind activity. The problem of sand fixing is still relevant.

Since the middle of the 20th century, the Curonian Spit has become an object of comprehensive investigations (aeolian process, geological context, morphogenesis of dunes, granulometric composition of sand, age and composition of the lagoon marl, etc.). Whereas mineral and granulometric composition of sand and the outcrops of lagoon marl have been known for decades, their important features such as particle morphology, composition and form of manifestation of minerals, are overlooked. It should be noted that the latter can largely affect the physical properties of sand deposits, their fixing and stabilization. For example, the formation of relatively stable unusual columnar sand structures was observed on the lagoon coast and layered sand structures on the sea coast. The task of this work was to determine the reasons for the formation of such structures, which is important for the continuation of work on strengthening the coastal zone of the Spit.

2. Materials and methods

Study area and samples

The climate of the Curonian Spit is maritime – sub-continental and is characterized by frequent and intensive changeability of weather, by mild winter and moderately warm summer (Orlyonok, 2002). The mean annual temperature in February is –4.1 °C and in August 17.3 °C (Peyrat, 2007; HELCOM, 1996). The average annual air temperature is +7.0 °C, with the absolute minimum of –26 °C (January) and the absolute maximum of +31 °C (June). The average annual precipitation is 660 mm, the maximum falls on the period from October till February. The height of the snow cover is up to 15–20 cm. Westerly and south-westerly winds from the Baltic Sea are prevailing on the Spit, their mean velocity being 5.5 m/s. The study area is located in a zone of high wind activity with a wind power up to 600–700 W/m^2. Strong winds with a speed of 15 m/s and more (stormy) occur in the region in autumn and winter, on average up to 5–10 times a year. Storm winds sometimes reach hurricane force – up to 25–40 m/s. It influences the sand movements and causes a phenomenon called "drunk forest", especially on the windward slopes and on the coastal line (UNESCO WHN, 1999; Kalinauskaite, Laaka-Lindberg, 2013).

The study was focused on sands of the coastal line, where wind activity is greatest. The most distinct morphology sampling sites and samples along onshore and offshore of the Curonian Spit were selected. The samples were taken to the depth 0–10 cm in June 2019. The sampling sites are briefly characterized in Table 1 and are shown on a schematic map (Figure 1) and photos (Figure 2).

Table 1. Brief characteristics of the sampled sites in the coastal line of the Curonian Spit

No	Site	Morphology of sampling site and samples
1	Lagoon coast 55°17'33"N, 20°59'58"E	sandy cliff near Neringa, columnar sand 10x10 cm top face of the column, height up to 25 cm
2	Lagoon coast 55°12'01"N, 20°52'59"E	dunes, leeward side (wind shadow) of the dune, its foot
3	Sea coast 54°59'31"N, 20°33'36"E	the sandy cliff, grey layered sand at its base
4	Sea coast 54°59'53"N, 20°34'30"E	the sandy cliff, outcrop of buried podzolic paleosol, the fallen part of the illuvial horizon paleosol
5	Sea coast 55°02'23"N, 20°38'57"E	beach, dark crimson sand
6	Lagoon coast 55°02'40"N, 20°40'37"E	beach, dark crimson sand
7	Sea coast 55°09'48"N, 20°48'53"E	sand beach, piece of layered compacted clay 10x20x5cm in size with fine white inclusions

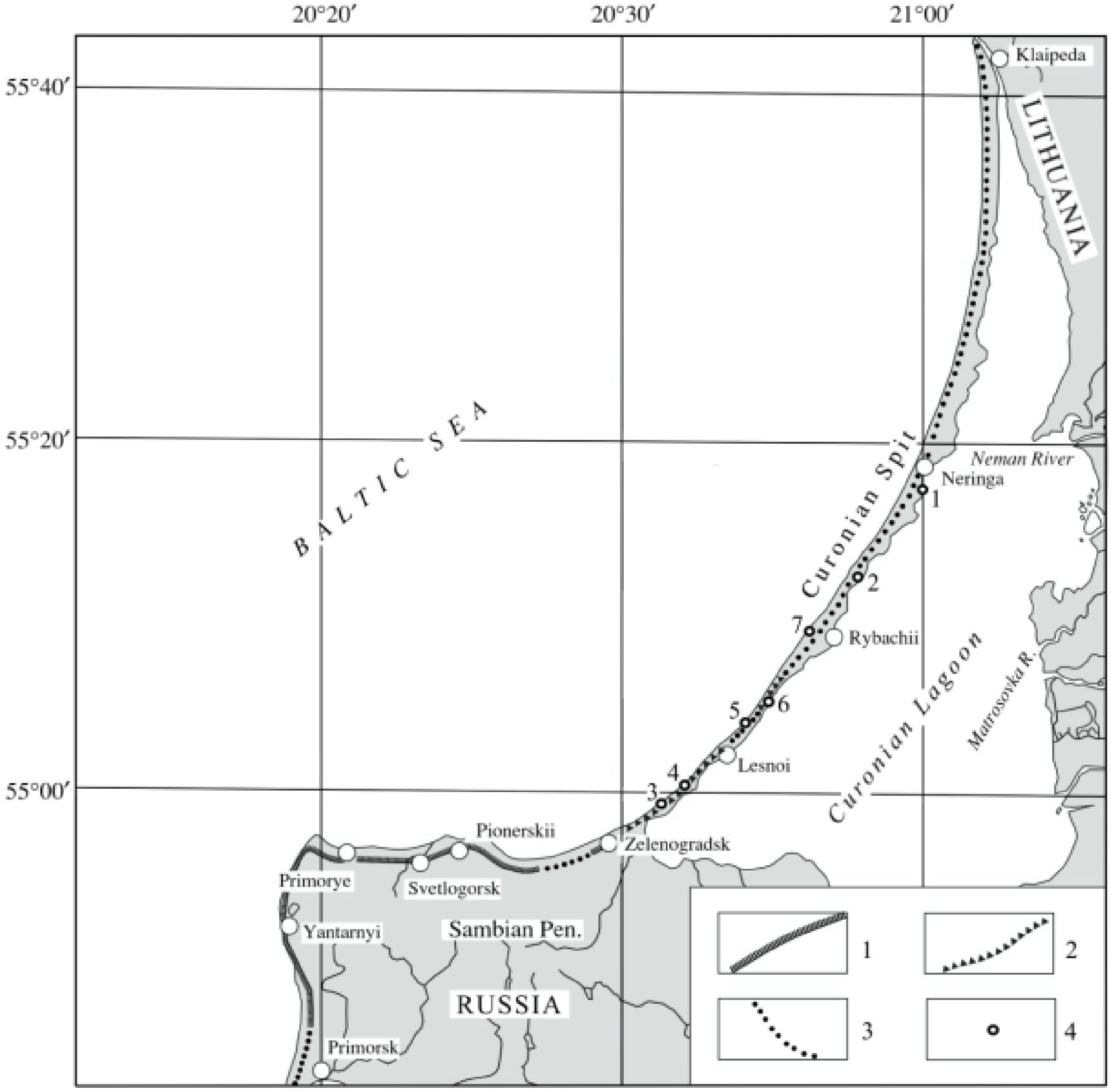

Fig. 1. Schematic map showing coastal sections characterized by the present-day processes: (1) abrasion, (2) destruction of avandunes, (3) accumulation (Kharin G., Kharin S., 2006) and sample site locations (4)

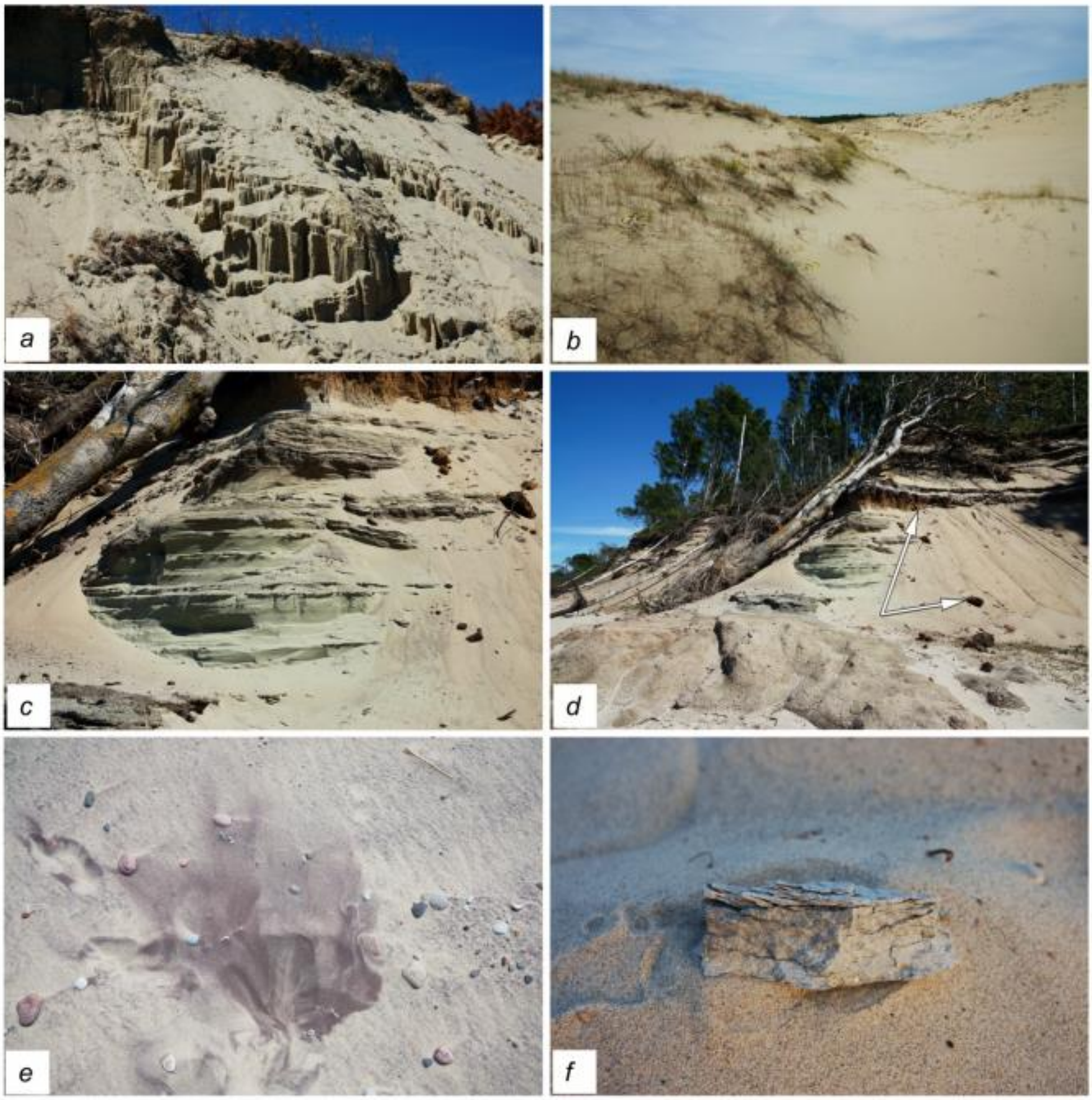

Fig. 2. Landscapes of the sampling sites: *a* – sand cliff of the lagoon coast, columnar sand (site 1); *b* – dune wind shadow of the lagoon coast (site 2); *c* – the sandy cliff of the sea coast (site 3); *d* – outcrop of buried podzolic paleosol, the fallen part of its illuvial horizon, arrows (site 4); *e* – dark crimson sand of the sea and lagoon beaches (sites 5 and 6); *f* – layered compacted clay of the sea beach (site 7)

Methodology

The major methods were granulometric and gross analyses, optical (OM) and scanning electron microscopy (SEM). Optical studies were performed on a Discovery V.12 microscope with an AxioCam MRc5 camera (Carl Zeiss, Germany). The SEM analysis was carried out using VEGA 3 LMH (TESCAN, Czech Republic). For the analysis, the samples, after grinding and sieving through a 2-mm sieve, were prepared via pouring, Pt-spraying and magnification of up to 20,000. A backscattered electron detector (BSE detector) was used for the analysis of phases with a high atomic number. When images are acquired using a BSE detector, phases with a high average atomic number are reflected in contrast more vividly than those with a lower atomic number. The X-max 80 energy-dispersive spectrometer (Oxford Instruments, UK) was used to analyze the elemental composition of the most representative regions. The capture area of the microanalysis was about 1 µm in diameter. If a smaller object was scanned, the result was distorted due to the influence of the surrounding matrix or the carbon table of the device. The particle size composition (without decomposition of carbonates) from 0.01 to 2,000 µm determined with the laser diffraction method on a particle size analyzer SALD-2300 (SHIMADZU, Japan). Before the analysis on the SALD-2300 (flow cell), a water suspension of the test sample (~0.5 to 1 g depending on the suspension absorption) was treated with ultrasound (built-in disperser for sample homogenization) (Wolform, 2011; Rawle, 2017; Kharitonova et al., 2017). The contents of selected chemical elements were determined via the X-ray fluorescence method (XRF) (Pioneer S4, Bruker AXS, Germany), using the silicate technique. Desktop X-ray diffractometer "MiniFlex II" (Rigaku Corporation, Japan) was used to determine mineralogical composition. X-ray diffraction patterns were recorded in Bragg–Brentano geometry, sample preparation and interpretation according to Moore and Reynolds recommendations (Moore, Reynolds, 1997).

The SEM, XRF and X-ray diffraction analyses were carried out in the Analytical Centre at the Institute for Tectonics and Geophysics, Khabarovsk, Far East Branch of the Russian Academy of Sciences.

3. Results and discussion

Before characterizing sand and their structures observed on the coastal line, we introduced data on particle-size distribution (PSD), which is one of the fundamental features of sediments, in many ways determining their physical and chemical properties. Additionally, PSD is a source of important information about the origin of sediments (alluvial, marine, and eolian), their transport history and sedimentation conditions. According integral analysis PSD, samples of both the lagoon and the sea coast are coarse sand (particle size 200–2000 µm), the content of which is 90 % or more (Table 2). An exception is a sample of compact clay from the sea coast (Figure 3), the content of coarse sand is less than 10 %, main fraction is fine sand (particle size 50–200 µm).

Table 2. Selected physical and chemical properties of sandy samples

No	Particle size distribution, %			Gross composition, %									
	Particle size, µm												
	<50	50–200	200–2000	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	Na_2O	K_2O	P_2O_5
1	0	0.1	99.9	95.7	0.1	1.4	1.0	0.0	0.3	0.2	0.4	0.5	0.1
2	0	0.3	99.7	96.4	0.0	1.1	1.0	0.0	0.2	0.2	0.4	0.4	0.1
3	0	9.6	90.4	93.0	0.1	2.6	1.5	0.0	0.4	0.4	0.6	1.1	0.2
4	0	1.1	98.9	92.9	0.1	2.5	2.2	0.0	0.3	0.3	0.6	0.8	0.2
5	0	10.8	89.2	33.4	19.2	5.6	17.4	0.9	2.3	1.4	0.7	0.1	0.4
6	0	7.2	92.8	28.2	23.6	4.8	17.6	0.9	2.0	1.3	0.8	0.1	0.5
7	31.8	59.0	9.2	34.4	0.5	3.5	5.4	0.2	26.1	1.7	0.7	1.3	0.2

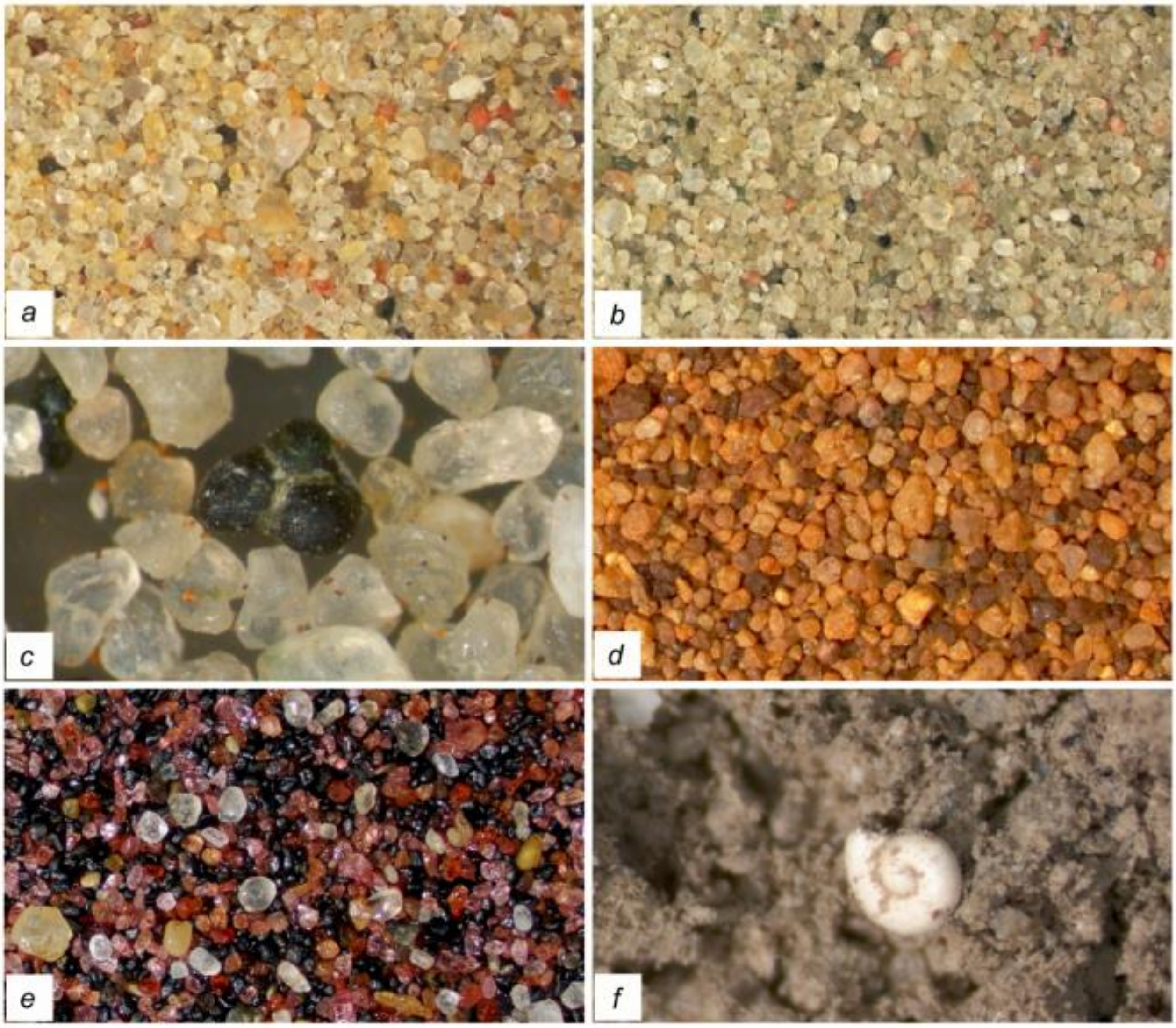

Fig. 3. Photomicrographs of sandy samples: *a* – site 1; *b*, *c* – site 3 (arrow – kidney sepiolite microaggregate); *d* – site 4; *e* – site 5, 6; *f* – site 7. For other explanation see text

The sand of the sea and lagoon coasts differs significantly in the differential particle size distribution (Figure 4), which is associated with the wind and wave activity of the coasts (it is much higher on the sea coast). Thus, the most representative fraction of the lagoon coast sand (sites 1 and 2) is the coarse sand fraction 500–1000 μm (Lozet, Mathieu, 1990). It is characterized by a peak in differential curves with a maximum of 700 μm and an intensity of 12.4 %. For the sea coast sand (sites 3, 5), the peak of the differential curves falls on the medium-coarse sand fraction 200–500 μm (290 μm and 12.2–14.4 %, respectively). They differ also in the asymmetry of the peaks. If for the sands of the lagoon coast the asymmetry is left (Figure 4*a*), then for the sands of the sea coast it is right (Figure 4*b*). The shift of the maximum particle size peak for sample 4 appears to be related to the formation of cutanes from iron hydroxides and siderite on the surface of sand grains. Sample 7 is characterized by the smallest particle size, the maximum peak of the main fraction 113 μm with an intensity of 6.0 % and left asymmetry (Figure 4*c*). Next we will return to the consideration of the properties and genesis of the latter.

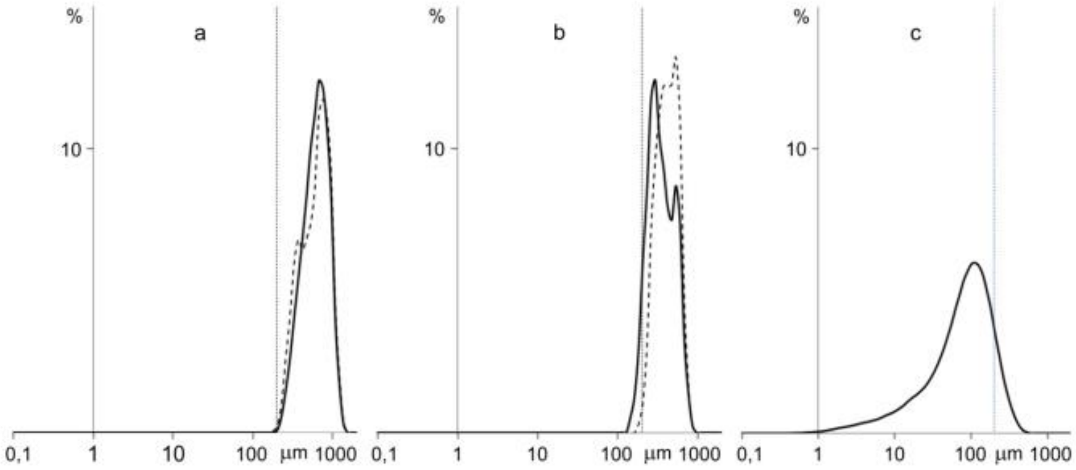

Fig. 4. Particle-size distribution in samples, differential curves: *a* – lagoon sand, thick line – site 1, dashed line – site 2, thin vertical line – upper limit of fine sand size 200 μm; *b* – sea sand, thick line – site 3, 5, 6; dashed line – site 4; *c* – site 7

Light colored sands (samples 1–3, Figure 3) are represented by well sorted coarse-grained sand. Quartz prevails in their mineralogical composition (Figure 3*a, b*), their SiO_2 content reaches 90 % or more (Table 2). Amount of feldspar and sepiolite (kidney shaped microaggregate – Figure 3*c*) is subordinate. Differing from them by a more brown color and weak sorting of particles, sample 4 (the illuvial horizon of the buried podzolic paleosol) contains significantly more oxides and hydroxides of iron, due to which the particles are cemented. Dark colored sands (samples 5 and 6, Figure 3*e*) differ significantly from light sands (samples 1–3). Their grains are more rolled, they contain significant amounts of heavy minerals (magnetite and ilmenite); the content of lightweight silicates (quartz and feldspar, mainly K-feldspar) in them is much smaller (Table 2). Sample 7 (sea coast, sand beach) is represented by fine-grained gray clay-clastogenic mass with rare grains of quartz, micro-flakes of clay minerals and shells of micromollusks (Figure 3*f*) and characterized by an abnormally high CaO content (>25 %).

Thus, according to the basic methods of analysis (gross and granulometric analyses, optical microscopy), which characterize the properties of the sample as a whole, the proximity (similarity) of the physical and chemical properties of samples 1–4 (1st group, light colored sands), samples 5–6 (2nd group, dark colored sands) is clearly diagnosed. Lagoon and sea coast sands of the 1st group differ in granulometric composition and content of Al_2O_3, which is associated with wind activity coasts and participation in the composition of sands clay minerals. However, it is very difficult to explain why relatively stable (without external influence) columnar sands are formed in one case (site 1); in the other there is the formation of stable sand structures of horizontal stratification (site 3). Attempts to explain the stability of certain sand structures on the Curonian Spit have already been, and very interesting. Thus, Jarmalavičius and colleagues (Jarmalavičius et al., 2015) found that the height of the dune depends on the granulometric composition of the sand and the ratio of its individual fractions. But the authors used mainly a statistical approach for the explanation.

Without the involvement of new approaches and methods of analysis it is also difficult to explain the extremely high content of CaO (26 %) in sample 7 (layered compacted clay), in which the content of SiO_2 is close to that in the sands of 2nd group (~30 %). The contribution of micromollusk shells to the content of CaO does not exceed 10–15 %. We suppose that the most relevant approach may be the use in this case of high-local analytical methods, such as scanning electron microscopy, XRF and X-ray diffraction analyses, in conjunction with standard physical and chemical methods.

SEM methods allow high resolution determination of the morphology of individual particles and their qualitative composition (at a "point" of ~ 1μm² and selected fragments). The use of SEM and EDS-analysis revealed differences in the morphology and fine structure of the studied samples, the characteristics of which were similar at standard methods of analysis. Thus, sample 1 (columnar sand, site1) is characterized by a significant number of grains with flat faces and relatively clear edges. Clay particles are concentrated on them, forming thin structural bridges (Figure 5*a*). The grains of grey layered sand (site 3) are also flat, but more rolled and smaller. In contrast to sample 1 clay particles is concentrated on flat surfaces of sand grains; herewith the area of the formed structural bridges is much larger (Figure 5*c*). Apparently, the formation of columnar structures (site 1) occurs due to clay structural bridges – separate contacts of edge-to-edge type – between sand grains (van Olphen, 1977; Osipov, 1989). The formation of stronger contacts of the face-to-face type leads to the formation of more stable sand structures of horizontal stratification (site 3). Since the strength of the structure is determined not only by the strength of the individual contact, but also by the number of contacts per unit surface area (Osipov, 1989). In turn, the overwhelming number of quartz grains of sample 2 (leeward side of the dune, the base) have large cavities, cavities and pits in place of the destroyed vacuoles and cracks of an annular nature. Allocation of clay bridges structure on them is not diagnosed (Figure 5*b*), so the formation of contact-aggregated structures does not occur.

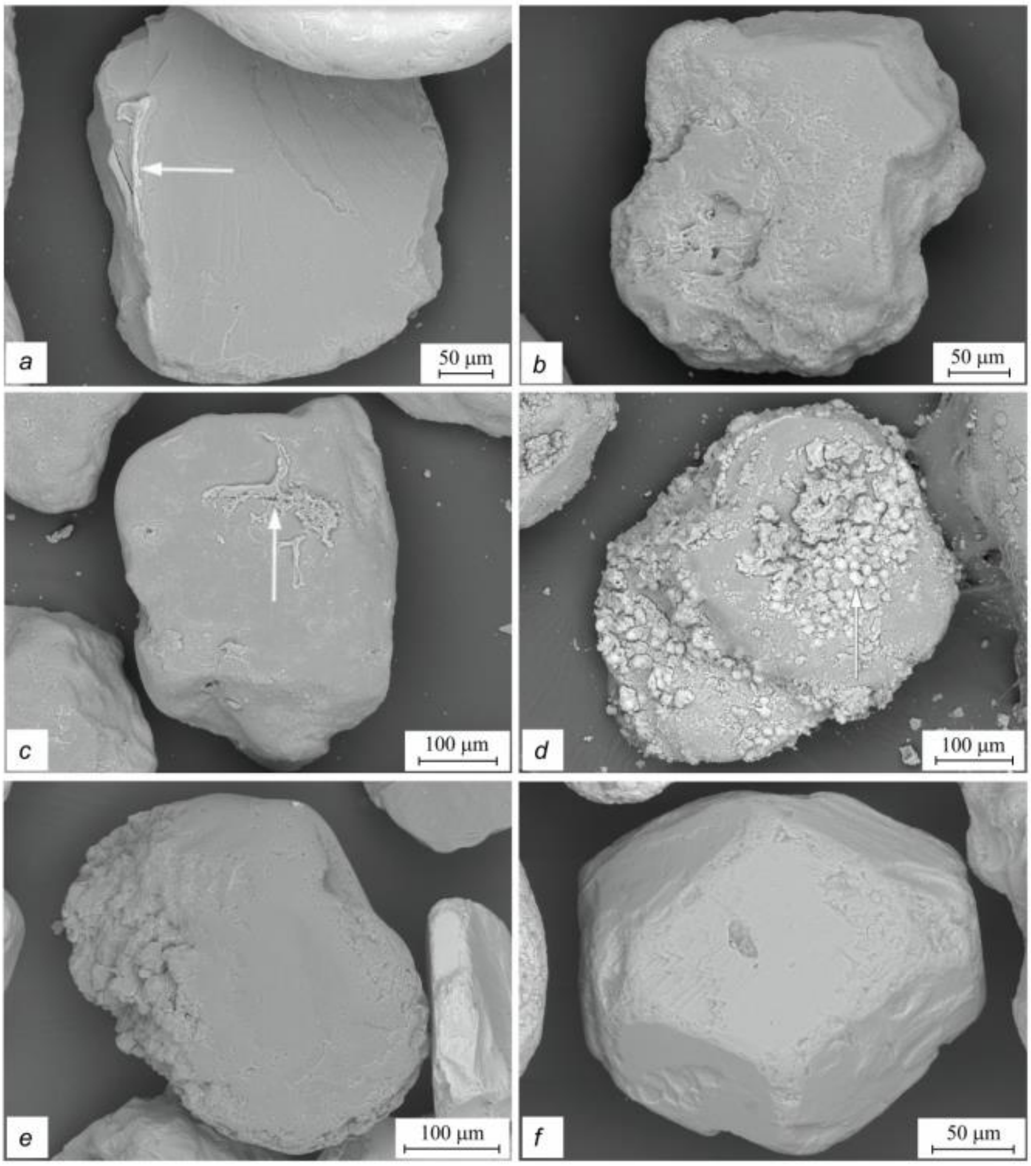

Fig. 5. Micrographs of the quartz sand in sampling sites of the Curonian Spit: *a* – site 1, arrow – clay “bridge” on edge of the grain; *b* – site 2; *c* – site 3, arrow – clay “bridge” on the face of the grain; *d* – site 4; *e*, *f* – sates 5 and 6. SEM, BSE-detector, for other explanation see the text

The cemented neoformations (ortzands) found on the sea coast are the falls of the illuvial horizon of buried podzolic paleosol. Their high connectivity and hardness in the dry state is determined by the formation of a large number of ferrous organomineral contacts (bridges structure) on the surface of clastogenic grains, mainly quartz (Figure 5*d*). According to EDS-analysis, the carbon content in them reaches 40 at. % , iron and aluminum – up to 6 and 2 at. % respectively (Figure 5*d*, arrow).

Due to the long-term influence of wind and wave activity the quartz grains of the dark sands (sites 5 and 6) compared to grains of the light sands are more rounded in shape and have small cavities and pits on the lateral surfaces (Figure 5*e*). Grains of diagnosed heavy minerals – garnet (Figure 5*f*), magnetite Fe_3O_4, ilmenite $FeO{\cdot}TiO_2$, kyanite Al_2SiO_5, monazite (Ce, La)PO_4, are also well rolled. Quite unusual rounded shape of the grains is observed for zircon $ZrSiO_4$ (Figures 6*a-e*). It should be noted that the composition of the dark sands of the sea and lagoon coast is close (Table 2), except for the presence of freshwater diatoms in the composition of the latter (lagoon sands) (Figure 6*f*). According to gross analysis data, SEM and EDX-analysis, ilmenite $FeO{\cdot}TiO_2$ predominates in heavy minerals. There is quite large size up to 400 μm grains of monazite, containing in addition to the basic elements (La and Ce) Pr, Nd and Th.

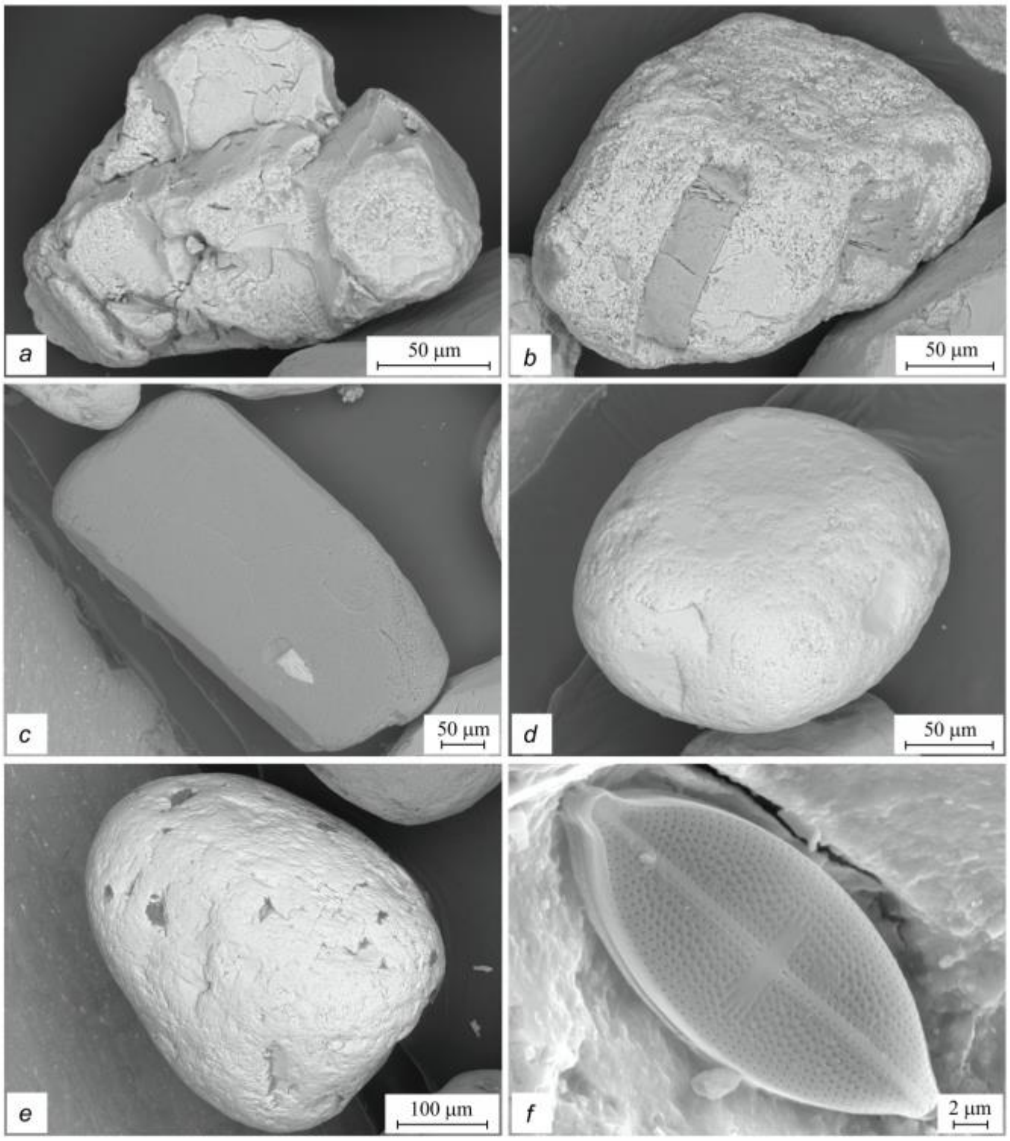

Fig. 6. Micrographs of the heavy minerals in sand of the Curonian Spit (sampling sites 5 and 6): *a* – magnetite Fe_3O_4; *b* – ilmenite $FeO{\cdot}TiO_2$, inclusion of apatite $Ca_5(PO_4)_3(OH)$ in the center of the grain; *c* – kyanite Al_2SiO_5; *d* – zircon $ZrSiO_4$; *e* – monazite (Ce, La)PO_4; *f* – diatom on ilmenite grain. SEM, BSE-detector, for other explanation see the text

The similarity (with significant differences) of the mineralogical composition of sandy samples of the studied territory is that all of them, including the sample of layered compact clay, contain sepiolite and calcium phosphate (apatite). Sepiolite and apatite are diagnosed mainly in the form of rolled kidney shaped grains with a size of 300–1000 μm (Figures 7, 8). Single microaggregates of fine weathered sepiolite (Figure 7*d*, arrow) and destroyed weathered grains of apatite (Figure 8*d*, arrow) were additionally diagnosed in the grey layered sand sample (site 3). The detection of fine sepiolite microaggregates can serve as an indirect confirmation of its participation (as fine sepiolite bridges) in the formation of layered sand structures.

It was not possible to detect sepiolite in sample 4 (the falls of the illuvial horizon of buried podzolic paleosol) by SEM and EDX-analysis methods, because the particles are covered with thick ferrous organomineral films. For the same reason it was not possible to find grains of apatite in this sample. However, phosphorus has been diagnosed in the ferrous organomineral films (Figure 8*e*). According to EDS-analysis its content in films reaches 1.2 at. %. In a sample of layered compact clay, P is fixed only in the composition of clay microaggregates (Figure 8*f*), its content reaches 2.5 at. %, and the atomic ratio of P and Ca in them is close to that in apatite.

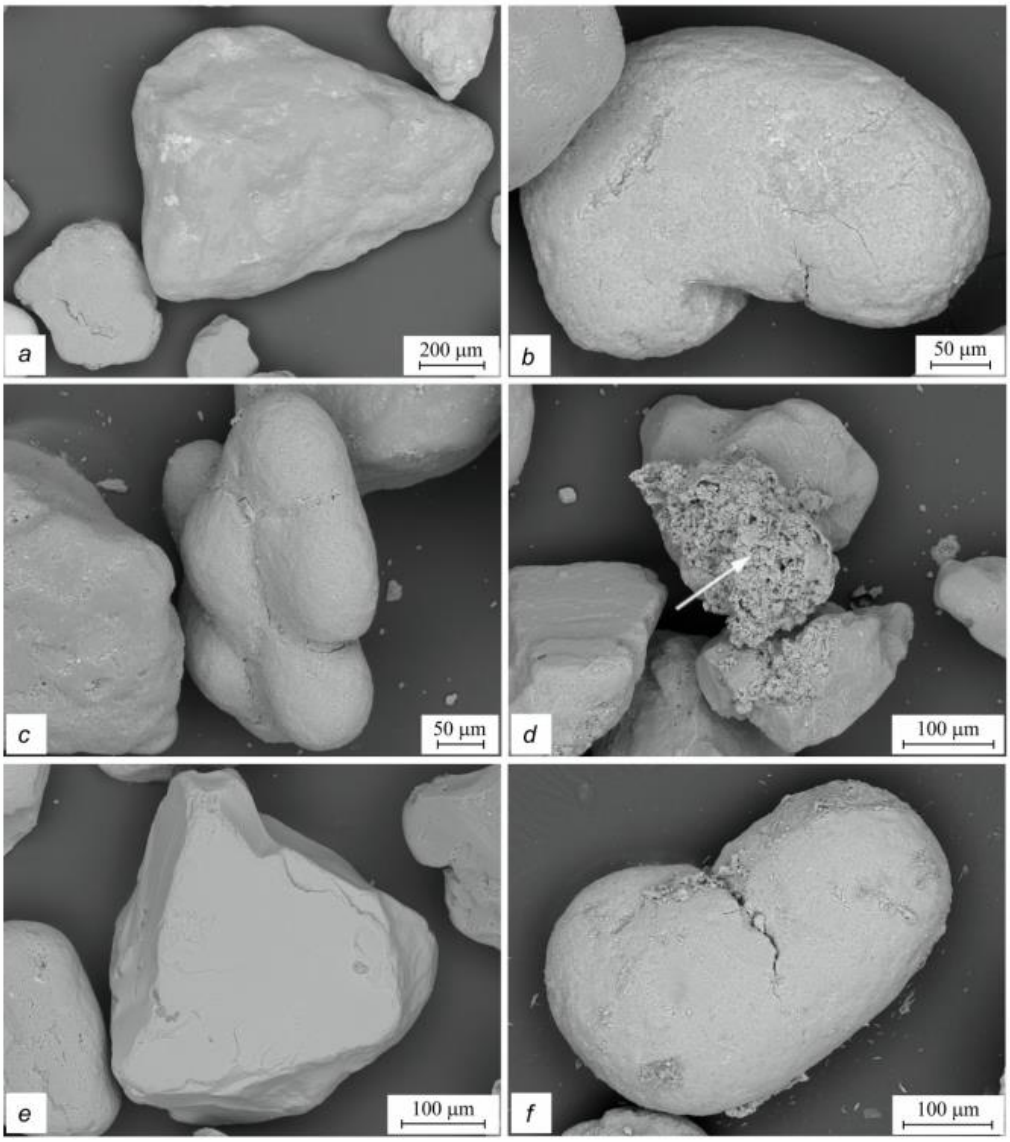

Fig. 7. Micrographs of the sepiolite grains in the sands of the Curonian Spit: *a* – site 1; *b* – site 2; *c*, *d* – site 3, arrow – microaggregate of weathered sepiolite; *e* – site 5; *f* – site 7. SEM, BSE-detector, for other explanation – see the text

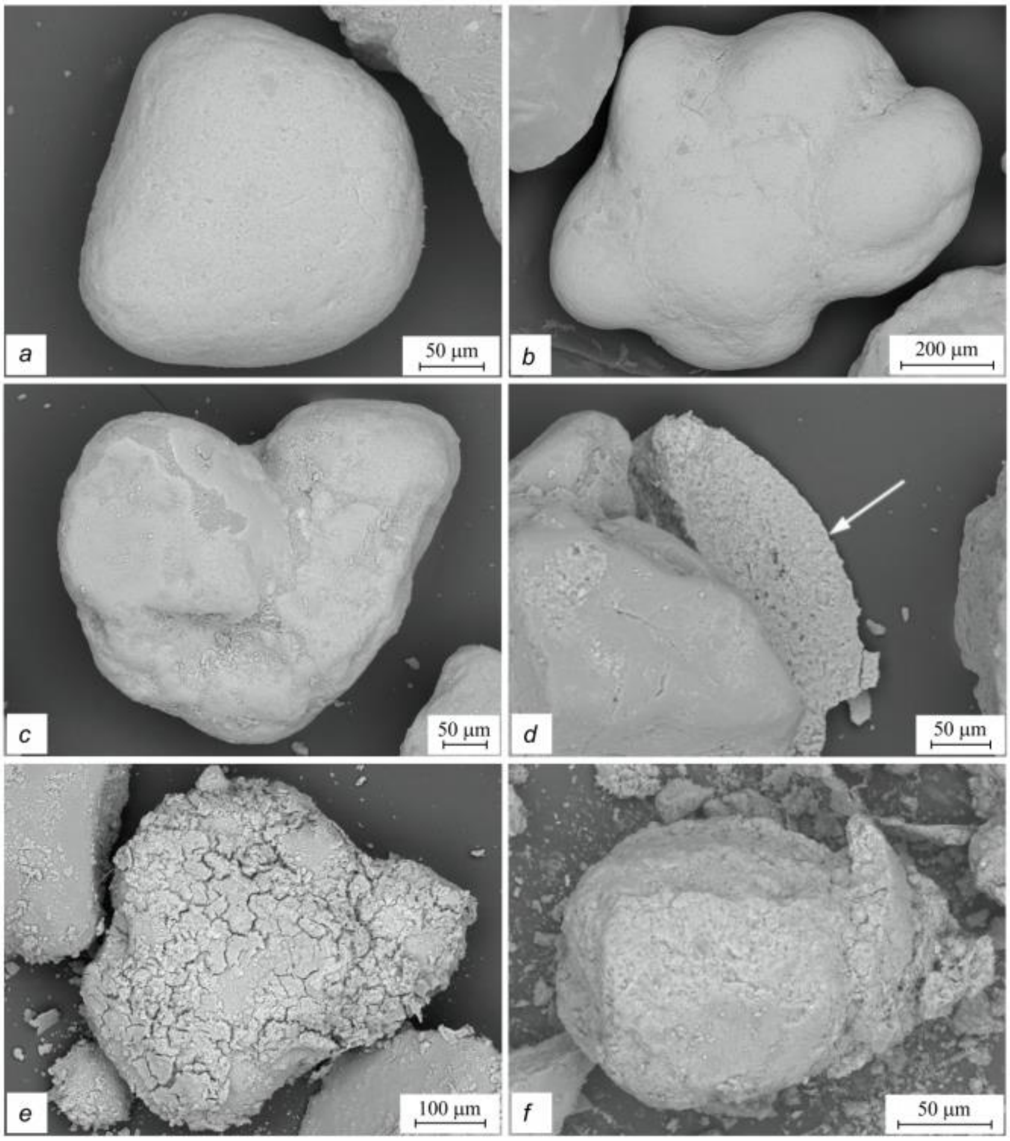

Fig. 8. Micrographs of the apatite grains in the sands of the Curonian Spit: *a* – site 1; *b* – site 2; *c*, *d* – site 3, arrow – weathered apatite grains; *e* – site 4; *f* – site 7. SEM, BSE-detector, for other explanation – see the text

It should be noted that the extremely high content of CaO in the sample of layered compact clay is associated not only with the presence of micromollusks, but also high-carbonate clay (sepiolite) microaggregates (Figure 9*a*), calcite microaggregates (Figure 9*b*), mesocrystals (Figure 9*c*) and multiple toroid-shaped microforms of $CaCO_3$ (Figure 9*d*). These toroid-shaped microforms of $CaCO_3$ are characterized with internal diameter of 8–10 μm and cross-sectional radius of about 1 μm. The formation of such microstructures was recorded for vaterite (the most soluble and unstable polymorphic modification of $CaCO_3$) *ex situ* and *in situ* (Jiang et al., 2017; Kharitonova et al., 2018). X-ray diffraction data confirmed the presence of not only the calcite phase in the sample, but also the vaterite phase. According to the nonclassical mesocrystal concept (Cölfen, Antonietti, 2008), stability of vaterite *in situ* is explained by the formation of hierarchically organized superstructures from separate nanocrystallites under the influence of steric constraints. In these conditions, a framboidal pyrite also is formed (Figure 9*e*).

The most interesting result, from our point of view, should be considered the detection of freshwater diatoms in the sample of layered compact clay from the sea coast (Figure 9*f*). These data correlate well with the results of diatom analysis Kabailiene M. (Kabailiene, 1967, 1997) of the lagoon marl. Coupled with data from the study of 'dune tectonics' or extrusion of lagoon marl from beneath sand dunes (Buynevich et al., 2007, 2010; Bitinas et al., 2010; Sergeev et al., 2017), the latter circumstance with a high degree of confidence allows us to assert that the sample of layered compact clay is relict lagoon marl from the sea-floor. Due to the contribution of river sediments, it is characterized by an increased content of potassium.

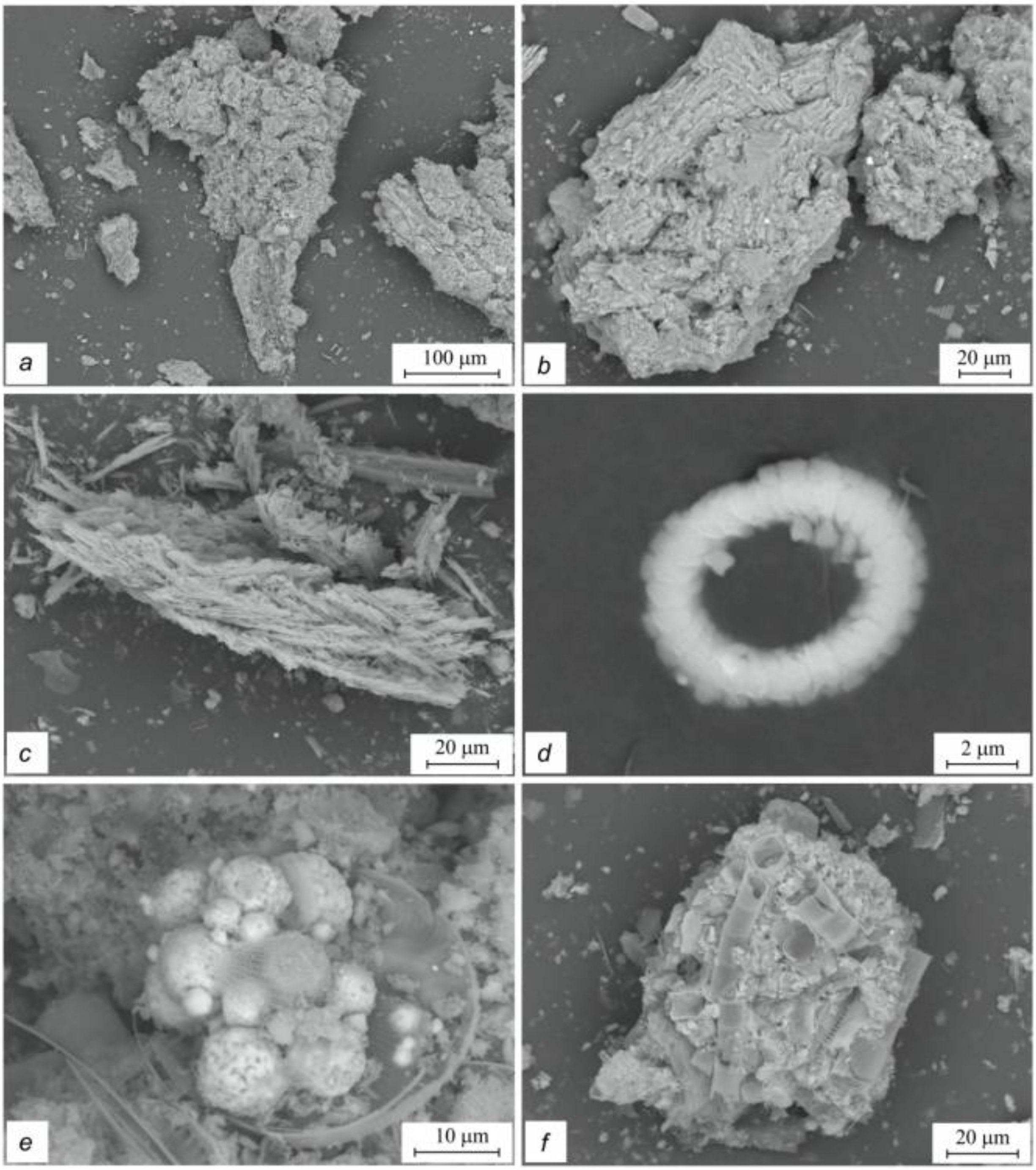

Fig. 9. Micrographs of layered compacted clayey sample (site 7): *a* – aggregate of $CaCO_3$-sepiolite; *b* – aggregate of $CaCO_3$; *c* – mesocrystal of $CaCO_3$; *d* – toroid-shaped microform of $CaCO_3$; *e* – framboidal pyrite; *f* – microaggregate with freshwater diatoms. SEM, BSE-detector, for other explanation see the text

Note that calcium carbonates as well as clay minerals are important structuring agents of soils and sands. So the use of lagoon marl with a high content of fine particles and $CaCO_3$ can be very promising for creating sandy contact-aggregated structures, fixing and stabilization of the sands.

4. Conclusion

The paper presents data on particle size distribution, morphology, composition and manifestation of minerals in light and dark colored sands on the coastal line of the Curonian Spit, where wind activity is greatest. Samples of both the lagoon and the sea coast are well sorted coarse-grained sand (particle size 200–2000 μm), the content of which is 90 % or more. Quartz prevails in mineralogical composition of the light sands. The dark sands of the coastal line contain a significant amount of heavy minerals (ilmenite, magnetite, zircon, garnet and monazite) and are less susceptible to wind erosion. Grains of diagnosed heavy minerals are relatively well rolled, which is due to the long-term influence of wave activity. Quite unusual rounded shape of the grains is observed for zircon.

Light sands of the sea and lagoon coast differ not only in the size of the predominant fraction (200–500 and 500–1000 μm respectively) and morphology of particles, but also in the type of relatively stable structures formed by them (layered structures of horizontal stratification on the sea coast and columnar sands on the lagoon coast respectively). The formation of sandy contact-aggregate structures (contacts of the edge-to-edge and face-to-face type, respectively) occurs with the participation of clay structural bridges, without them the sands remain incoherent.

In turn, the lagoon marl is characterized by a high content of clay and silt particles and calcium carbonates, which are important structuring agents of the sands. So use of the lagoon marl can be very promising for creating clay-sand contact-aggregated structures, fixing and stabilizing of the sands.

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