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Peculiarities of sand sorting on the Lithuanian coast of the Baltic Sea

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Sand in the coastal zone is subject to a constant interchange between the nearshore and the coast. This process of sand dislocation involves mechanical sand sorting.

The research was conducted in the coastal zone of the Lithuanian part of the Curonian Spit. For analysis, eight lithodynamic research profiles were selected. The profiles covered the coastal area from the top of the dune ridge to a depth of 15 meters in the nearshore isobath. To analyze the change of the granulometric composition of sand, four sand fractions were chosen: 0.1–0.16; 0.16–0.2; 0.2–0.315 and 0.315–0.4 mm. These fractions form the basic part of the granulometric composition in the coastal zone of the Curonian Spit.

A thorough analysis of the transportation of different fractions across the coastal zone, has shown that the distribution of sand is quite regular. It matches the balance of the active factors that influence sand sorting and the coastal zone relief. The very finest fraction (0.1–0.16 mm) is carried beyond the limits of the sand ridge and deposited at greater depths (7–15 m). Larger particles accumulate closer to the coast, i. e. the 0.16–0.2 mm fraction clusters in the offshore sand ridge zone, 0.2–0.315 mm concentrates in the inshore sand ridge and in the dune ridge, and 0.315–0.4 mm is most abundant on the beach, in the influence zone of the swash.

The general distribution of sand particles shows distinct trends along the Curonian Spit coastal zone. Apart from the effect of waves, sand sorting is also influenced by the transportation directed towards the north. These changes are most obvious on the coast and less evident in the zone of the sand bars. Beyond the limits of the surf, the granulometric composition of sand remains basically unaffected.

Key words: coast, nearshore, sand sorting, grain size, Lithuania, the Curonian Spit, South-Eastern Baltic

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INTRODUCTION

Sand in the coastal zone is subject to a constant interchange between the nearshore and the coast. During a storm, the sand that gets washed off the shore is either transported deep into the sea or carried by currents along the coastline. When a storm calms down, the sand is brought back to the beach where the wind blows part of it onto the dune ridge. The same cycle repeats when a new storm takes place. Throughout this process of sand dislocation, also mechanical sand sorting occurs: the sand is sorted into particles of various sizes, which are distributed in various places along the coastal zone.

P. Cornaglia was the first to describe such sorting of sand back in the 19^{th} century. He noticed that depending on the inclination of an underwater slope and the energy of waves, the sand particles of different sizes tended to accumulate in certain areas of underwater slopes (Cornaglia, 1977).

This hypothesis was developed further in a set of experiments that recorded movement of marked particles of sand which were drowned for that purpose in the nearshore. As a result, such researches became the basis for the theory of sand sorting in the nearshore (Miller, Zeigler, 1958; Ingle, 1966; etc.). Simultaneously, sand sorting on the coast was observed (Harris, 1958; Mason, Folk, 1958; Shepard, Young, 1961; etc.).

In Lithuania, some aspects of sand distribution in the nearshore and on the coast were described in various works by Gudelis, Stauskaitė, 1959; Repečka et al., 1997; Gaigalas et al., 1999; Dolotov, 1989; Kairyte, 2000; Trimonis et al., 2005, Minkevicius, 1969; Stauskaitė, 1974; Dolotov et al., 1982; Jarmalavičius, Žilinskas, 1996; Žilinskas et al., 2001 and others. However, both Lithuanian and foreign scientists until now have mostly focused their research on either sand sorting on the coast or in the underwater nearshore slope.

Today, having collected enough data from both the underwater and the continental sides of the coast, we are able to analyze the sorting of the granulometric composition of sand without differentiating between the coast and the nearshore.

METHODS

The research area covers the Lithuanian part of the Curonian Spit from the national border with Russia to the southern pier of the Klaipėda harbor (51 km). The authors used data on the granulometric composition of surface sediments on nearshore bottom, published in the Geological Atlas of the Lithuanian Coast of the Baltic Sea (Baltijos…, 2004). The morphometric study of the sea bottom in the Curonian Spit nearshore zone was conducted along 46 cross profiles up to 15 meters deep. On average, seven sand samples were collected from different depths in each profile (Trimonis et al., 2005).

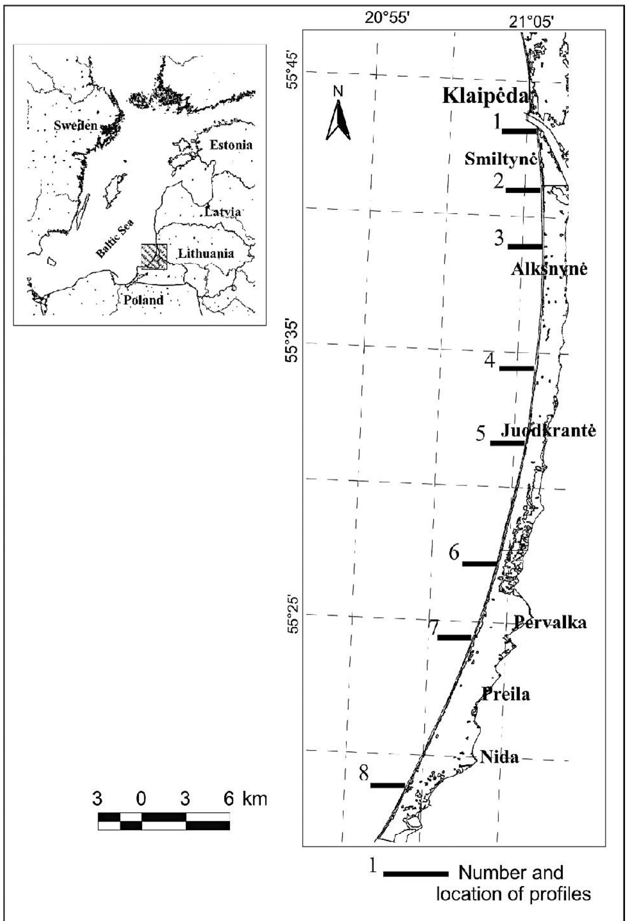

Fig. 1. Location of the study area and profiles
1 pav. Tiriamo rajono situacinė schema ir tirtų profilių vieta

Data on the granulometric composition of sand had been collected since 1993 in the coastal monitoring posts established by the Institute of Geography (in total 99 profiles). Four samples were collected from each profile: on the western slope of the artificial foredune, on the western foot of the artificial foredune, in the middle of the beach and near the dynamic coastline (Jarmalavičius, Žilinskas, 1996).

The research was conducted in the coastal zone of the Lithuanian part of the Curonian Spit (Fig. 1). According to data collected in 2003, eight lithodynamic research profiles that had a distinct cross-coastal zone granulometric composition and well represented the adjacent coastal zone sections were selected. The profiles covered the coastal area from the top of the dune ridge to the depth of 15 m in the nearshore isobath. To analyze the change of the granulometric composition of sand in the coastal area, the following four sand fractions were chosen: 0.1–0.16; 0.16–0.2; 0.2–0.315 and 0.315–0.4. These fractions form the major part of the granulometric composition in the coastal zone of the Curonian Spit.

RESULTS

Analysis of the change of various sand fractions in the nearshore (Fig. 2) shows that the distribution of different fractions is not the same. Sand particles of the size 0.1–0.16 mm concentrate at the greatest depths where they comprise about 40–60%.

Closer towards the coast, approximately 400–700 m from the coastline (4–7 m deep) the amount of these particles suddenly declines from 50% to 10%. Finally, at a depth of 1–3 m it comprises only 1–8% and in some places completely disappears. There are hardly any grains of this size on the coast (about 1%). The exception is the coastal area of Smiltynė–Alksnynė where the amount of sand of this fraction increases up to 5–15%. It is important to note that the sudden decline of the 0.1–0.16 mm fraction zone is confined to the distal sand ridge, the top of which is at a depth of 2–4 m. This zone corresponds with the beginning of the surf which mostly happens on the Lithuanian coast during the average strength waves. Hence, when the energy of active waves starts affecting the bottom, the 0.1–0.16 mm particles are transported out of the area of the sand ridge to greater depths.

The distribution of 0.16–0.2 mm participles in the cross profile has a different pattern (Fig. 2). Their largest amount (40–50%) accumulates mostly 500–700 m

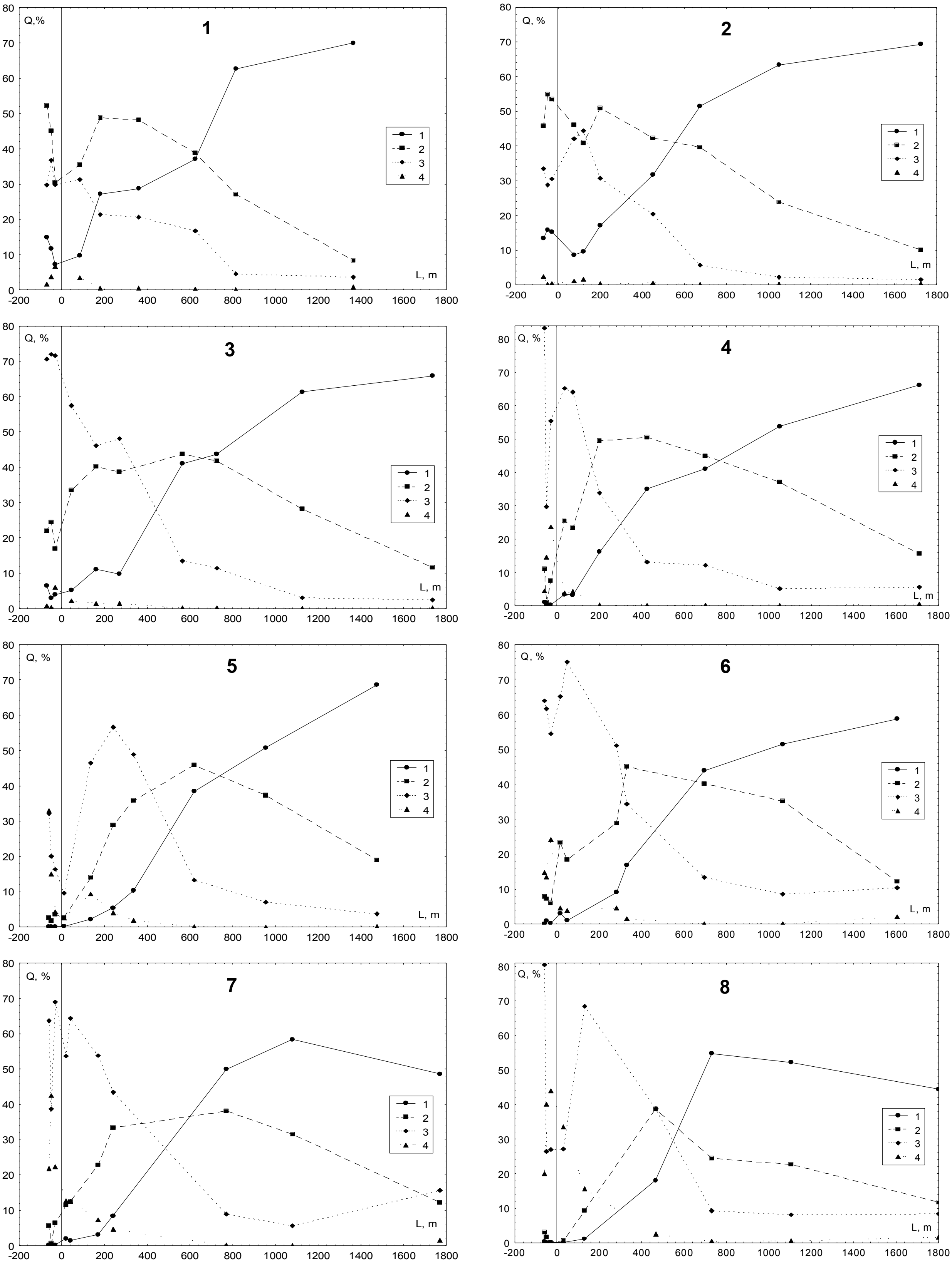

Fig. 2. Change of various sand fractions across the coastal zone. *1* – 0.1–0.16 mm fraction, *2* – 0.16–0.2 mm fraction, *3* – 0.2–0.315 mm fraction. The vertical line indicates the coastline. The location of the profiles is shown in Fig. 1. "0" of the abscissa axis – position of the coastline

2 pav. Įvairių smėlio frakcijų kaita skersai kranto zonos. *1* – 0,1–0,16 mm frakcija, *2* –0,16–0,2 mm frakcija, *3* – 0,2–0,315 mm frakcija, *4* – 0,315–0,4 mm frakcija. Vertikali linija nurodo kranto linijos vietą. Profilių vieta nurodyta 1 pav. „0" abscisių ašyje – kranto linijos padėtis from the coastline (5–7 m deep) in the southern part of the study area, and 200–300 m in the northern part (2–3 m depths). In the transition zone (approximately 10–12 km south from the pier of the Klaipėda harbor), a bimodal distribution of sands of this fraction has been noted. Here, the largest accumulation of 0.16–0.2 mm fraction occurs 600–700 m (6–7 m deep) and 100–300 m (2–3 m deep) away from the coast. The increase the 0.16–0.2 mm fraction in the shallower zone (2–3 m deep) is not very high, comprising only 30–40% of the total sand fraction. Particles of this size accumulate mostly (except the northern part of this particular study area) in the distal sand ridge and its offshore slope, i.e. at the beginning of the highest wave surf. On the coast, sand of this fraction comprises 5–10% in the section of an interval from Nida to Alksnynė and up to 30–55% from Alksnynė to Smiltynė.

The distribution of the 0.2–0.315 mm fraction shows mostly a reverse pattern to that of the 0.1–0.16 mm fraction. The largest amount is reported from the inshore sand ridge, about 100–200 m away from the coast (2–3 m deep), where they form 55–70%. Only near Smiltynė their content decreases to 30–50%. Deeper into the sea their content in the sand ridge zone gradually declines, and past the sand ridge zone it sharply decreases to 5–10%.

In comparison to the sand fractions described above, particles 0.315–0.4 mm in diameter make the smallest amount of sand in the coastal zone. They are mostly obtained closest to the coastline. Further from the coast its amount suddenly decreases, and particles of this size can be found only in small localized areas. They are almost absent beoynd the sand ridge zone. The largest content of 0.315–0.4 mm grains is found in the last surf and swash influence zone, as well as on the beach where they comprise up to 40% in the southern and only 5% in the northern part of the study area.

The study of the distribution of various sand fractions in the onshore cross-profiles indicates that the main fraction forming the coastal sand is 0.2–0.315 mm, comprising 30–80% (with an exception of Smiltynė where the dominant fraction is 0.16–0.2 mm). Finer particles (0.16–0.315 mm) are easily carried by the wind; therefore the difference between the beach and the dune ridge is not obvious. If any differences appear in this area, they are more likely to be influenced by local peculiarities of the coast sand composition. Much greater differences appear in the distribution of the 0.315–0.4 mm fraction. Sand of this size is not easily carried by the wind, thus it mostly accumulates on the beach. Incidentally, the content of the larger fraction sand in the dune ridge in the direction of south hardly ever exceeds 20%. The rest of the sand in the dune ridge is composed of 0.2–0.315 mm particles.

DISCUSSION

The distribution of sand is quite regular. It matches the balance of the active factors that influence sand sorting and the coastal zone relief. The very finest fraction (0.1–0.16 mm) is carried beyond the limits of the sand ridge and deposited at greater depths (7–15 m). Larger particles accumulate closer to the coast, i.e. the 0.16–0.2 mm fraction clusters in the offshore sand ridge zone, 0.2–0.315 mm concentrates in the inshore sand ridge and in the dune ridge, and 0.315–0.4 mm is most abundant on the beach, in the influence zone of the swash. The possible ways of migration of fractions mentioned above are shown in Fig. 3.

The general distribution of sand particles shows distinct trends along the Curonian Spit coastal zone (Fig. 3). Apart from the effect of waves, sand sorting is also influenced by a transportation directed towards the north. These changes are most obvious on the coast and are less evident in the zone of the sand bars. Beyond the limits of the surf, the granulometric composition of sand basically remains unaffected.

The concentration of 0.16–0.2 mm particles shows the most distinct change along the coastline. As the maximal concentration is gradually shifting closer to the coast in the direction of north, it results in an increase of the sand size in the Alksnynė–Kopgalis area, which is controlled by several factors:

1. Approximately 10–13 km south from the pier of the Klaipėda harbor the orientation of the coastline changes direction to the S–N. Hence the longitudinal transportation becomes weaker. The cross transportation becomes dominant. This is also proved by the evident decrease or even disappearance of the offshore runnel.

2. The northward flow of north becomes more saturated with sand, and part of the transported sand deposits when its concentration exceeds a certain critical level of saturation.

3. In the Smiltynė area, the inclination of the underwater slope becomes smaller, as well as the waves surge further away from the coast, thus decreasing the impact of waves on the coast.

4. The piers in the Klaipėda harbor are an obstacle for sand migration.

Sand sorting in the coastal area reflects the past rather than the present-day processes. The sorting was more intense in the past when the Curonian Spit was forming. This can also be proven by comparing the granulometric composition of sand samples collected over the last 50 years: the sand composition is hardly changing. Furthermore, sands of the underwater slope do not correlate by their composition with the sand on the coast. The finer (0.1–0.16 mm) sand particles prevailing in the 7–15 m depths are practically absent on the coast. On the contrary, 0.2–0.315 mm particles that prevail in the coastal deposits are rarely present in deeper waters.

It is worth noting that shingle deposits found in the last, deepest runnel zone reflect the washed out previous coastal deposits and not the transportation of gravel and shingle during the current storms. Sands that are closer to the coastal sands by their granulometric composition are found only in the nearshore bar where

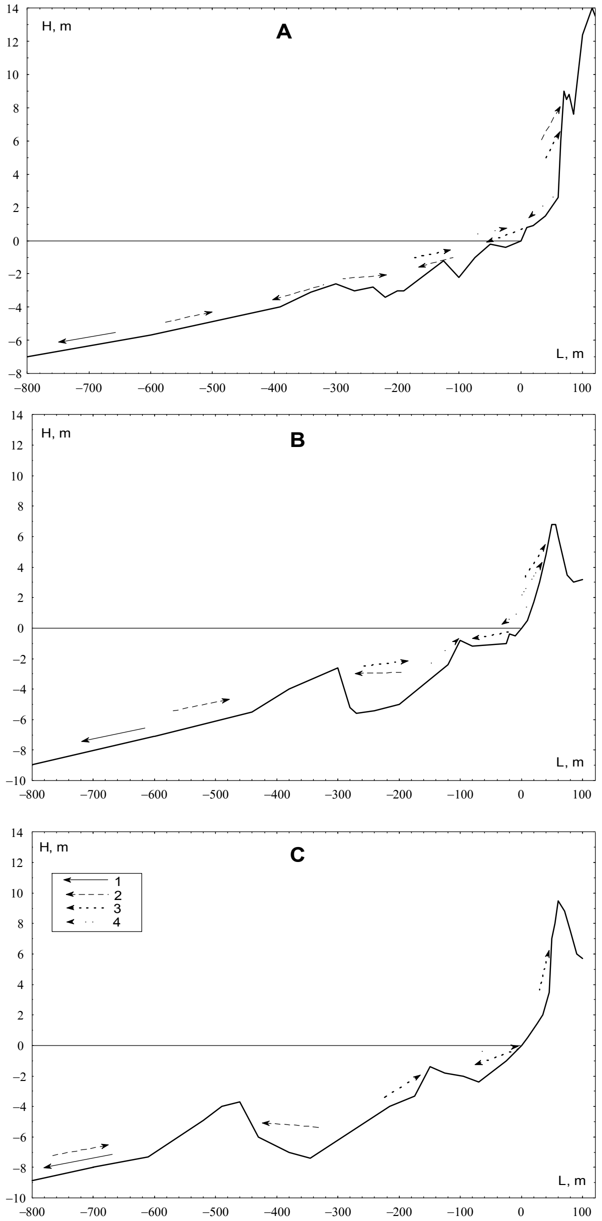

Fig. 3. Migration of various sand fractions in the coastal zone of the Curonian Spit. *A* – Smiltynė, *B* – Juodkrantė, *C* – Nida. *1* – 0.1–0.16 mm, *2* – 0.16–0.2 mm, *3* – 0.2–0.315 mm, *4* – 0.315–0.4 mm

3 pav. Įvairaus dydžio smėlio frakcijų migracija Kuršių nerijos kranto zonoje. *A* – Smiltynė, *B* – Juodkrantė, *C* – Nida. *1* – 0,1–0,16 mm, *2* – 0,16–0,2 mm, *3* – 0,2–0,315 mm, *4* – 0,315–0,4 mm

they were brought during the storm in the same or the nearest coastal zone.

Today, a discernible sand sorting in the coastal zone of the Curonian Spit can take place only due to the drastic changes in the environmental conditions or after extreme storms when the high waves are able to move sand particles to greater depths and wash large masses of sand away from the coast, where they have been accumulated during a period of a couple of years in the dune ridge.

During a storm, the blown-out sand in the sand ridge zone experiences the secondary sorting both across and along the coast. When the storm ceases, larger particles of sand (0.315–0.4 mm) remain on the beach and near the coastline; they are hardly ever carried any further. 0.2–0.315 mm particles are carried a longer distance, mostly in the direction of north, before they are again discharged on the coast. The finer particles, though they are already on the verge of disappearance on the coast, are carried along the shore in the zone of the furthest offshore sand ridge and reach the coast only in the Alksnynė–Kopgalis region.

CONCLUSIONS

1. Sand sorting in the coastal zone is influenced by hydrometeorological changes, the coastal relief and the mechanical composition of sand. During mechanical sorting in the coastal zone, sand particles of different size are shifted in a direction of equilibrium between their size and the influence from the surrounding environment. That is why, when carried away from their localization place, these particles tend to come back.

2. A comparison of the granulometric composition of the nearshore and coastal surface deposits has shown that the prevailing 0.1–0.16 mm fraction accumulates in the zone more offshore than the sand ridges (7–15 m deep) and basically does not participate in the formation of the coastal deposit. Meanwhile, the sands that are dominant in the coast (0.2–0.315 mm fraction) are mostly found in the sea only at a depth of up to 3 m (about 200–300 m away from the coast).

3. The change in sand particle size along the coast clearly shows the prevailing longitudinal transportation near the Curonian Spit in the northern direction, which gets weaker to the north due to the change of coast direction (from SW–NE to S–N), an increase in the degree of migrational swash saturation, a decrease in the inclination of the slope, and a physical barrier (the piers of the Klaipėda harbor). Near Alksnynė, cross transportation becomes dominant.

4. In order to stabilize the coast, considering the varying sand sorting in the coastal zone, it is recommended to use sand fractions no finer than 0.25 mm, and to dispense them no deeper than 3–3.5 m in the nearshore. Consequently, sand no finer than 0.2 mm should be used to form an artificial sand ridge (breakwater) in the nearshore.

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SMĖLIO DIFERENCIACIJOS YPATUMAI LIETUVOS BALTIJOS JŪROS KRANTO ZONOJE

S a n t r a u k a

Tyrimai atlikti Lietuvai priklausančioje Kuršių nerijos kranto zonoje. Remiantis kranto zonos paviršinių smėlių granuliometrinės sudėties duomenimis, buvo atrinkti aštuoni būdingą granuliometrinės sudėties kaitą skersai kranto zoną turintys, taip pat gretimus kranto zonos ruožus gerai reprezentuojantys litodinaminių tyrimų profilių duomenys. Granuliometrinės sudėties kaitos kranto zonoje analizei buvo pasirinktos keturios smėlio frakcijos: 0,1–0,16; 0,16–0,2; 0,2–0,315 ir 0,315–0,4 mm, kurios sudaro pagrindinę smėlio granuliometrinės sudėties dalį Kuršių nerijos kranto zonoje.

Smėlio diferenciacijai kranto zonoje turi įtakos hidrometeorologinių sąlygų kaita, kranto zonos reljefo ypatumai bei smėlio granuliometrinė sudėtis. Mechaninės diferenciacijos kranto zonoje metu skirtingų dydžių smėlio dalelės juda pusiausvyros tarp jų dydžio ir aplinkos poveikio intensyvumo kryptimi, todėl, išneštos iš savo įprastos lokalizacijos vietos, jos linkusios vėl grįžti atgal. Už sėklių zonos išneštos pačios smulkiausios, lengviausiai pernešamos smėlio dalelės (0,1–0,16 mm) nusėda didesniuose gyliuose (7–15 m). Stambesnės koncentruojasi arčiau kranto: 0,16–0,2 mm dydžio smėlio dalelės kaupiasi įjūriausio sėkliaus zonoje, 0,2–0,315 mm – priekrantiniame sėkliuje bei kopagūbryje, 0,315–0,4 mm – paplūdimyje, plūsmo srauto poveikio zonoje. Palyginus priekrantės ir kranto paviršinių sąnašų granuliometrinės sudėties ypatumus nustatyta, kad krante vyraujantis smėlis (0,2–0,315 mm frakcija) jūroje dažniausiai aptinkamas tik iki 3 m gylio (maždaug 200–300 m nuo kranto). Paplūdimio smėlio granuliometrinėje sudėtyje, palyginus su kopagūbrio, didesnę dalį sudaro smėlis, kurio dalelių skersmuo ir didesnis nei 0,35 mm, ir mažesnis nei 0,1 mm. Kopagūbris dažniausiai formuojasi iš 0,25–0,30 mm dydžio smėlio grūdelių.

Bendras įvairaus dydžio smėlio dalelių pasiskirstymas skersiniame Kuršių nerijos kranto zonos profilyje kinta ir išilgai kranto zonos. Tai rodo, kad smėlio dalelių diferenciaciją veikia ir išilginė, nukreipta šiaurės kryptimi, pernaša. Tiesa, šie pokyčiai labiausiai ryškūs krante, mažiau – sėklių zonoje, o už sėklių zonos ribų smėlio granuliometrinė sudėtis išilgai kranto zonos išlieka beveik nepakitusi. Vyraujanti išilginė pernaša ties Kuršių nerija šiaurės kryptimi dėl kranto ekspozicijos kaitos (pasisuka iš PV–ŠR į P–Š), didėjančio migracinio srauto prisotinimo laipsnio, sumažėjusio šlaito nuolydžio ir fizinės kliūties (Klaipėdos uosto molai) įtakos silpnėja šiaurės kryptimi ir maždaug ties Alksnyne įsivyrauja skersinė pernaša.

Дарюс Ярмалавичюс, Гинтаутас Жилинскас

ДИФФЕРЕНЦИАЦИЯ ПЕСКА В ЛИТОВСКОЙ БЕРЕГОВОЙ ЗОНЕ БАЛТИЙСКОГО МОРЯ

Р е з ю м е

Обобщены и проанализированы данные исследований гранулометрического состава песчаных наносов в береговой зоне литовской части Куршской косы. На основе многолетних исследований (с 1993 г.) отобраны 8 профилей, которые представляют различные участки береговой зоны вдоль Куршской косы. Анализировалось процентное содержание в поверхностных пробах 4 фракций песка (0,1–0,16; 0,16–0,2; 0,2–0,315 и 0,315–0,4 мм), которые составляли основную часть гранулометрического состава песка береговой зоны Куршской косы. Выделены и проанализированы особенности распределения процентного содержания этих фракций вдоль избранных 8 профилей.

На дифференциацию песка на отдельных участках береговой зоны влияют местные гидрометеорологические условия, особенности рельефа и гранулометрический состав песка. Во время механической дифференциации в береговой зоне частицы песка разной крупности движутся в направлении зон, где достигается равновесие между всеми воздействующими факторами, причем каждой крупности соответствует свое местоположение зоны равновесия. Вынесенные из этой зоны частицы песка стремятся опять туда вернуться.

Самые мелкие и легче всего переносимые частицы песка крупностью 0,1–0,16 мм выносятся за пределы зоны подводных валов и оседают на глубине 7–15 м. Более крупные концентрируются ближе к берегу: частицы крупностью 0,16–0,2 мм накапливаются в зоне мористого подводного вала, частицы крупностью 0,2–0,315 мм – на прибрежном подводном вале, а частицы крупностью 0,315–0,4 мм – на пляже, в зоне воздействия потока заплеска.

Сравнение особенностей гранулометрического состава поверхностных наносов на подводном склоне и на берегу позволило установить, что преобладающий на берегу песок крупностью 0,2–0,315 мм обнаруживается в море чаще всего только до трехметровой глубины (примерно в 200–300 м от берега).

Гранулометрический состав пляжевых песков отличается от состава песка, формирующего защитный дюнный вал. На пляже большую часть составляют пески, диаметр частиц которых не только более 0,315 мм, но и меньше 0,1 мм. Защитный береговой вал чаще всего формируют частицы песка крупностью 0,25–0,3 мм.

Характер распределения фракций в поперечном профиле изменяется вдоль береговой зоны Куршской косы, что свидетельствует о влиянии вдольберегового переноса северного направления на дифференциацию песка. Эти изменения наиболее заметны на берегу, меньше – в зоне подводных валов, а за их пределами гранулометрический состав песка вдоль береговой зоны остается почти неизменным. Изменение направления экспозиции береговой линии с ЮЗ–СВ на Ю–С, увеличение насыщенности миграционного потока, уменьшения откоса подводного берегового склона и влияния физического препятствия (молы Клайпедского порта) приводят к ослабеванию преобладающего вдольберегового переноса северного направления, и в районе поселка Алкснине преобладающим становится поперечный перенос наносов в береговой зоне Куршской косы.