СЕКЦІЯ 2
ПРИРОДНИЧО-ГЕОГРАФІЧНІ ТА ГЕОЕКОЛОГІЧНІ ДОСЛІДЖЕННЯ

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# GRANULOMETRY OF COASTAL SEDIMENTS AS AN INDICATOR OF LITHODYNAMIC PROCESSES: KINBURNSKA-POKROVSKA-DOVGIY COASTAL SYSTEM, BLACK SEA, UKRAINE

Global climate change could lead, already by 2100, to an increase in the average sea level of the World's oceans by 0.63–1.01 meters. Rising levels will lead to active transformation of the coastal zone, especially within coastal sandy accumulative forms. The evolution of sandy coastal accumulative forms can have different trends.

In this context, there are two opposing viewpoints in the scientific world. One view suggests that coastal sand molds will experience severe erosion, while another view suggests that these molds will adapt to the new hydrodynamic conditions and gradually rebuild.

To gain the most accurate understanding of how sandy coastal accumulation forms may change over time, it is important to consider both the hydrodynamic conditions of their formation and the unique granulometry composition of these forms. The granulometry composition represents one of the most important factors in the stability of coastal accumulative forms.

In the north-western part of the Black Sea lies the Kinburnska-Pokrovska-Dovgiy coastal system. All morphological elements of the system are composed exclusively of sand-shell sediments and are characterized by insignificant morphometric parameters. The described conditions cause very high dynamism in coastal processes, a significant probability of destructive evolution of the whole system, and a significant risk of flooding coastal areas.

The granulometry analysis of the coastal-marine sediments comprising the coastal system under study is very important for understanding its stability and identifying possible evolutionary trends. This analysis is a very important source of information on the potential for creating artificial aeolian landforms as natural shore protection barriers along the seashore of the system.

To carry out the granulometry analysis, we collected sediment samples along the entire offshore contour of the system during field surveys between 2019 and 2021. The selected samples were analyzed in the laboratory of Kherson State University.

Granulometry analysis results determined the coastal-marine sediment's dominant sediment fraction, median, and sorting factor for the whole system and its constituent elements. The study of the spatial differentiation of the coastal-marine sediments made it possible to confirm the lithodynamic conditions and identify the most morpho-dynamically vulnerable areas within the system.

**Key words:** coastal accumulative form, coastal and marine sediments, leading fraction, median diameter, sorting coefficient, longshore sediment flow.

**Давидов О.В., Муркалов О.Б. Гранулометричний склад наносів берегової системи як індикатор літодинамічних процесів (на прикладі берегової системи Кінбурнська-Покровська-Довгий, Чорне море)**

Глобальні кліматичні зміни можуть зумовити вже до 2100 року підвищення середнього рівня Світового океану на 0,63–1,01 м. Здіймання рівня призведе до активної трансформації берегової зони, особливо в межах піщаних акумулятивних форм. Варто зазначити, що еволюція берегових піщаних форм може мати різні тенденції.

У цьому контексті в науковому світі існують дві протилежні точки зору. Відповідно до однієї, берегові піщані форми будуть сильно розмиті, проте, згідно з іншою думкою, представлені форми адаптуються до нових гідродинамічних умов і поступово перебудуються.

Для формування найбільш достовірного уявлення про можливі тенденції розвитку акумулятивних піщаних форм необхідно впроваджувати комплексний підхід до вивчення умов їх розвитку. Саме тому варто аналізувати не лише гідродинамічні умови, вагоме значення має гранулометричний склад наносів, який являє собою один із найважливіших факторів стійкості берегових акумулятивних форм.

У північно-західній частині Чорного моря розташована берегова система Кінбурнська-Покровська-Довгий. Усі морфологічні елементи системи складені виключно піщано-черепашковими наносами й характеризуються незначними морфометричними параметрами. Описані умови зумовлюють дуже високу динамічність берегових процесів і значну ймовірність деструктивної еволюції всієї системи, що істотно підвищує ризик затоплення прибережних територій півострова.

Проведення гранулометричного аналізу прибережно-морських наносів досліджуваної берегової системи є важливим для розуміння її стійкості й визначення можливих еволюційних тенденцій. Цей аналіз є також вагомим джерелом інформації про потенціал створення штучних еолових форм рельєфу як природних берегозахисних бар'єрів уздовж морського берегу системи.

Для проведення гранулометричного аналізу ми під час польових досліджень, у період з 2019 по 2021 рр., відібрали проби наносів уздовж усього морського берега системи. Відібрані проби проаналізовано в лабораторії Херсонського державного університету.

За результатами гранулометричного аналізу, визначили провідну фракцію, медіану та коефіцієнт сортування прибережно-морських наносів як для всієї системи, так і для її складових елементів. Вивчення особливостей просторової диференціації прибережно-морських наносів дало змогу підтвердити літодинамічні умови й виділити найбільш уразливі в морфодинамічному стосунку ділянки в межах системи. Також визначено найперспективніші ділянки для створення штучних еолових форм уздовж морського берегу системи.

**Ключові слова:** берегова акумулятивна форма, прибережно-морські наноси, провідна фракція, медіанний діаметр, коефіцієнт сортування, уздовж береговий потік наносів.

**Introduction.** Global climate change is projected to cause the planetary average sea level (SLR) to rise by 0.63–1.01 m by 2100 (Fox-Kemper, B. et al. 2021). The level rise will contribute to the active transformation of the coastal zone of the World Ocean, especially in areas where sandy coastal accumulative forms are located. The presented situation can lead to the wave erosion of more than half of these formations (Bruun, 1962; Vousdoukas, et al. 2020). However, some scientists believe that sea level rising will lead to the adaptation of sandy coastal forms, and the balance of sediments within the lithodynamic system will determine the direction of development of the coastal zone (Carter et al. 1987; Vykhovanetz et al. 2014).

In this regard, the property of stability of coastal accumulative forms under the influence of various hydrodynamic factors becomes of great importance.

The stability of seacoasts is known to be determined by a complex of factors, the leading of which are: wave climate parameters (Cooper & Navas, 2004; Corbella & Stretch, 2012); range of sea level fluctuations (Bruun, 1962; Nicholls et al., 1995; Zhang et al., 2004); sediment volume within a lithodynamic cell (Carter et al., 1987; Healy, 1996; Storms et al., 2002). In this case, the value of sediment size is defined as important but secondary (Jarmalavičius et al., 2017, Honeycutt & Krantz, 2003).

In the northwestern part of the Black Sea, there is the abrasion-accumulative coastal system Kinburnska-Pokrovska-Dovgiy, which is a «winged foreland» (Davydov, 2019). Sand and shell deposits compose all components of the coastal zone of the studied system (Zenkovich, 1960; Pravotorov, 1966; Shuisky, 1999). The presence of shells in coastal marine sediments does not contribute to the development of large coastal aeolian forms. In this regard, the absolute heights of the coastal zone have insignificant parameters, and the maximum height is about 3.5 m, which occurs in areas where the "kuchugurs" approach the shore (Shuisky, 1999; Krivulchenko, 2016). The presented conditions of the geological environment cause very high dynamics of coastal processes and a significant risk of flooding of coastal areas (Davydov et al., 2021a; Davydov et al., 2021 b).

The intensity of coastal processes depends on the lithodynamic mechanisms that ensure the stability of the coastal system. The exchange of sediment between various sections of the system reflects in the granulometry distribution of coastal sediments, ensuring its stable state. At the same time, analysis of the mechanical composition of sediments is a very important source of information about the reality of creating artificial aeolian landforms as natural bank protection barriers that stabilize the entire system (Davydov et al. 2022).

Partial granulometric analysis of coastal-marine sediments in the studied system was carried out several times (Zenkovich, 1958; Pazyuk, Rychkovskaya, 1965; Tsaytts et al., 1979). However, most of the sediment samples were collected in the Kinburnska Spit area. Therefore, at first, only a general idea of the mechanical composition of sediments in the system under study was formed. Odessa scientists obtained the most complete understanding of the granulometric composition of sediments on the frontal coast of the Kinburn Peninsula, but their research did not cover the entire system (Shuisky, 1999).

Accordingly, the materials presented in the publication are the first complete studies of the particle size distribution of sediments, covering all the constituent elements of the coastal system under study.

The purpose of the study is to determine the patterns distribution patterns of sediments granulometric parameters along the Kinburnska-Pokrovska-Dovgiy coastal system as a reflection of the hydrodynamic and lithodynamic conditions of the coast.

The information obtained is very important for assessing the possibility of creating artificial aeolian landforms as natural coastal protection along the entire coast of the system.

To achieve this goal the field expeditionary and stationary studies were carried out in the coastal zone of the studied system from 2019 to 2021.

During the research, samples of coastal-marine sediments were collected within 20 sites along the entire frontal coast of the system. Subsequent analysis of the samples was carried out using standard methods, and the interpretation of the results was based on general theoretical elaborations in the lithodynamics of the coastal zone of a non-tidal sea (Longinov, 1963; Aybulatov, 1966; Shuisky, 1986; Dolotov, 1989).

**Materials and methods**

***Study area.*** The Kinburnska-Pokrovska-Dovgiy coastal system (Davydov, 2019) extends along the sea edge of the Kinburn Peninsula, located in the northwestern part of the Black Sea in the mouth area of the Dnieper and Southern Bug (Fig. 1). The total length of the coastal system is 32.2 km, it includes coastal accumulative forms and adjacent sections of the underwater slope of the Black Sea, the Dnieper-Bug liman and the Yagorlytsky Bay.

Within the coastal system under study, four structural elements are distinguished (Pidhorodetsky, 1965; Shuisky, 1999; Krivulchenko, 2016; Davydov, 2019):

a) *Kinburnska (North-Kinburnska) spit.* A free coastal accumulative form, a barrier type, separates the waters of the Dnieper-Bug estuary and the northwestern part of the Black Sea. The spit has a triangular shape; the total length of the seacoast is about 7 km, and the width of the base is about 1.5 km (рис. 1 d). In genetic terms, this coastal form is an arrow (Zenkovich, 1960; 1962; Davydov, 2019), formed under conditions of two-way supply with a significant role of the biogenic factor. (Zenkovich, 1960; Pravotorov, 1966);

b) the front shore is a section of the sandy Kinburnska arena, 8.12 km long, leading directly to the sea. Within this territory, in the coastal zone, periodically eroded aeolian forms of continental origin (aeolian mounds or kuchugurs, deflationary basins or sagas), as well as beaches of incomplete profile and narrow coastal accumulative terraces, are found (Fig. 1 d) (Pravotorov, 1966; Shuisky, 1999; Krivulchenko, 2016; Davydov, 2019);

c) Pokrovska Spit, Sukha Spit, and underwater barrier Zagreba. The presented coastal forms represent a dynamically active southeastern branch of the system, the total length of which is 15.7 km (Fig 1 d). The base of this branch is represented by the Pokrovska Spit, and the central and southern parts are represented by the underwater barrier of Zagreba, on the surface of which the youngest coastal form of the Black Sea, the Sukha spit, is actively developing (Chaus et al., 2022);

d) Kambalna Spit with Krugly and Dovgiy islands. The presented coastal forms constitute the relict southeastern part of the coastal system, the length of which is about 10.5 km (Fig. 1 d).


**Fig. 1. Geographical location and constituent parts of the Kinburnska-Pokrovska-Dovgiy coastal system: a – location of the system within the European subcontinent; b – location of the system within the Black Sea; c – location of the system within the Dnieper – Bug mouth; d – constituent morphological elements of the studied system (image source: GoogleEarth™)**

In this part, the Kambalna Spit stands out, which is a newer generation of the Proto-Pokrovska Spit, which was actively developing before the attachment of the Zagreba underwater barrier to the body of the modern Pokrovska Spit. The Krugly and Dovgy islands, with the straits separating them, are relict remains of the middle and distal parts of the Proto-Pokrovska Spit (Zenkovich, 1960). After covering this part of the system with an underwater shaft, supply practically ceased and developed under conditions of local accumulation caused by biogenic and silty material, as well as the predominance of erosion of the frontal coast.

***Methods.*** We sampled coastal-marine sediments along the entire length of the coast of the studied system. We laid out 20 coastal-marine sections and profiles to conduct research in various areas, recording their locations using Garmin eTrex 10 GPS receiver.

At each site, we conducted trigonometric leveling to a depth of 3 m using an NTS-350 total station, while also collecting samples of coastal marine sediments. Samples were collected in 2019 and 2021 from the surface layer (0–10 cm) of sediments (Shuisky, 1972). Within each profile, the number of sampling points varied from 8 to 15 and was determined by the shape of the topography on the profile and sediment distribution.

In the laboratory, we processed the selected samples by mechanically sieving them using a rotary machine and a set of 10 sieves (with sieve cell sizes ranging from 0.1 to 1.0 cm). When conducting granulometric analysis, the dominant sediment fraction ($C_o$), median diameter (Md), and sorting coefficient ($S_o$) were determined. To assess the nature of the variability in sediment composition, these characteristics were calculated both within the entire system and its components and directly within the underwater slope, beach, and aeolian zone along the profile. The results obtained are characterized by a reliable spatial reference and are interpreted in comparison with the materials of previous researchers.

**Results.** Granulometric analysis of coastal-marine sediments of the Kinburnska-Pokrovska-Dovgiy coastal system made it possible to determine within its coastal zone the distribution patterns of granulometric characteristics: median diameter (Md), dominant sediment fraction ($C_o$), and sorting coefficient ($S_o$).

Along the coastal zone of the system, there are certain local differences due to hydrodynamic, morphological, and environmental conditions. In order to understand the patterns of spatial distribution of the different sediment fractions, let us consider their mechanical composition within individual structural elements.

***Kinburnska Spit.*** Within the presented morphological element, the dominant sediment fraction ($C_o$) 0.1–0.25 mm is 40.17%. The content of the fraction 0.25–0.5 mm is 37.62%, and fractions >10 mm – 8.56%. The presented three fractions, amounting to a total of 86.35%, form the structural features of the coastal sediments of the coastal zone of the spit (Shvanov, 1969). The median diameter is 0.31 mm, and the sorting coefficient is 1.88. Within the constituent parts of the coastal zone, the parameters of the mechanical composition of sediments have certain differences.

Along the underwater slope of the spit, the $C_o$ content (0.1–0.25) decreases from 72% (root part) to 40% (distal end part). In the same direction, the content of the medium-grained fraction increases from 12% to 21%, as well as the coarse fraction – from 9 to 12%. The presented trends are confirmed by the Md value of the sediment (increases from 0.2 to 0.37 mm), as well as the nature of $S_o$ sorting (deteriorates from 1.39 to 2.88).

In the composition of the beach of the root sections of the spit, $C_o$ (0.1–0.25 mm) makes up 64%, but towards the distal direction, the dominant sediment fraction becomes medium-grained (0.5–0.25 mm), with a content of 47%. Md increases from the root to predistal sections from 0.35 to 0.41 mm, but in the distal section, it decreases to 0.25 mm. $S_o$ deteriorates in the same direction from 1.34 to 2.7, and in the distal end area, it improves to 1.58.

In the composition of coastal aeolian forms, $C_o$ (0.1–0.25 mm) makes up 69%, while Md is 0.28 mm, and $S_o$ is 1.38.

***Frontal coast.*** In the coastal zone of this part of the system, $C_o$ (0.25–0.5) makes up 57.81%, fine-grained – 33.18%. The presented fractions account for 90.99% and form the structure of coastal-marine sediments of this part of the system. It should be noted that the content of these fractions in the sands of Kinburnska arena is 96% (0.25–0.5 mm – 65%; 0.1–0.25 mm – 31%). The sediment Md is 0.29 mm, and $S_o$ is 1.38, which indicates their good sorting.

The pattern of sediment distribution on the underwater slope indicates certain differences between the northwestern and southeastern parts of the coast. In the northwestern part, $C_o$ (0.1–0.25) decreases from 80% to 50.5%, towards the root of the Kinburnska Spit, and in the southeastern part $C_o$ (0.25–0.5) dominates, which is 47.33%.

Sediment Md increases from the central part of the coast (0.19 mm), both to the northwest (0.24 mm) and to the southeast (0.29 mm). Sediment sorting worsens from the central part of the coast ($S_o$ 1.28), towards the northwest ($S_o$ 1.51), and southeast ($S_o$ 1.49).

The composition of the beaches is dominated by $C_o$ (0.25–0.5), the content of which gradually decreases from the center (70%), both to the northwest (56.13%), and to the southeast (65.25%). The sediment Md in the center is 0.34 mm, in the northwest 0.35 mm, and in the southeast 0.37 mm. The sediments $S_o$ in the central part is 1.31, in the northwestern part 1.43, and in the southeastern part 1.27.

In aeolian forms located in the northwestern part of the frontal coast, $C_o$ (0.1–0.25 mm) is 57%, and in the southeastern part $C_o$ (0.25–0.5 mm) is 69%. Sediment Md is 0.23 mm (northwestern part) and 0.32 (southeastern part). At the same time, sediments $S_o$ in the northwestern part is 1.48, and in the southeastern part, it is 1.34.

***Pokrovska Spit, Sukha Spit and underwater barrier Zagreba.*** The presented accumulative forms consist of medium-grained (52.93%) and fine-grained (29.09%) sand, with a fairly high content of coarse fraction (6.82%). These three fractions determine the structural features of the sediment, with a total sum of 88.84%. Sediment Md is 0.34 mm, with $S_o$ 2.34. $M_d$ sediment is 0,34 мм, at $S_o$ 2,34.

On the underwater slope, the $C_o$ content (0.25–0.5 mm) decreases from the junction of the pass (57.6%) to the distal part of the Sukha Spit (42%). In the same direction, the content of the fine-grained sand fraction decreases (36.6–31%), but the amount of the coarse fraction increases (from 0.5 to 17%). In the same direction, the sediment Md increases (from 0.31 to 0.36 mm), and their sorting also deteriorates ($S_o$ from 1.45 to 2.31).

In the composition of beach sediments, $C_o$ (0.25–0.5) also decreases towards the distal of the Sukha Spit from 69.00 to 44.6%, while the content of the coarse fraction increases from 4.75 to 24%. This trend affects the median diameter, which increases from 0.37 to 0.44 mm, and also impairs sediment sorting. $S_o$ at the beginning of the bay – 1.28, and within the Sukha Spit – 4.87. The aeolian zone is dominated by medium-grained sand, with a median diameter of 0.32 mm, and a $S_o$ of 1.47.

In the composition of the underwater barrier, $C_o$ (0.25–0.5 mm) makes up 55.78%, the 0.1–0.25 mm fraction is determined to be 23.11%, and the coarse sand fraction (0.5–1.0 mm) – 7.89%. The presented fractions form the structural features of coastal marine sediments and account for 86.78%. Sediment Md is 0.354 mm, with a total $S_o$ of 1.53.

The mechanical composition of the underwater barrier is heterogeneous and is characterized by certain differences. In the root part of the barrier, the $C_o$ content (0.25–0.5 mm) is 54.67%, in the middle the $C_o$ content increases to 55.67%, and near the distal part to 57.00%. At the same time, attention is drawn to the sharp increase in the middle part of the content of coarse (21.00%) and coarse-grained (10.00%) fractions, with a significant decrease in the fine-grained (2.00%) fraction. At the same time, the content of the fine-grained fraction is quite high in the root part (32.33%) and in the distal part (35.00%).

Md changes from 0.33 (root part) to 0.44 (middle part) and decreases to 0.29 (distal end part). A similar trend is typical for $C_o$, so in the root part it is 1.45, in the middle part – 1.67, and in the distal end part – 1.47.

***Islands Krugliy-Dovgiy.*** In the composition of the presented islands, $C_o$ (0.25–0.5 mm) is 47.1%. The fine-grained fraction is 31.1%, and the coarse-grained fraction is 8.35%. Accordingly, the content of the three fractions is 86.55%. The sediments Md is 0.44 mm, with moderately good sorting, $S_o$ 1.53.

The distribution patterns of the mechanical composition of sediments on the beaches of the islands under study are similar to the spatial patterns of the distribution of fractions on the Zagreba underwater barrier. Within Krugliy Island and the narrow part of Dovgiy Island, $S_o$ (0.25–0.5 mm) is 67.00%, in the middle part it decreases to 38.00%, and in the distal area it increases to 67.00%. The high content of coarse (16%) and coarse-grained (17%) fractions in the middle part of Dovgiy Island is particularly noteworthy. Md is determined in the narrow part (0.38 mm), in the middle (0.54 mm), and in the distal area (0.39 mm). The sorting coefficient in the area of Krugliy Island and the narrow part of Dovgiy Island is 1.19, in the middle part of Dovgiy Island – 2.13, and in the area of its distal part – 1.28.

**Discussion.** This publication presents the results of a granulometric analysis of coastal sediments of the Kinburnska-Pokrovska-Dovgiy coastal system. The studied system differs significantly from other coastal barrier forms in the Black Sea. The specificity of the system is due to its formation within the western part of the Kinburnsky Peninsula and the Odeska bank, composed of sands of alluvial origin. The mechanical composition of sands is characterized by a predominance of fractions of 0.25–0.5 mm (peninsula) and 0.1–0.25 mm (underwater bank). The surface of the peninsula and its banks are eroded during strong storms and are sources of sandy material for the system under study. It should be noted that under these conditions, in the process of the formation of coastal-marine sediments, there is no stage of decay for destroyed rocks. In this case, we are dealing with rocks that, after erosion, are ready for the facies conditions of the coastal zone and immediately turn into sediment.

Studies of the granulometric composition have shown that $C_o$ (0.25–0.5 mm) predominates in the system; its average content is 49.63%. The second most common fraction is 0.1–0.25 mm; its content is 33.29% (Fig. 2).

The total sum of the represented fractions is 82.92%, accordingly sand fractions of 0.1 to 0.5 mm in size form the structure of the coastal-marine sediment within the coastal zone of the studied system. Accordingly, the predominance of fine- and medium-grained sand fractions is fully consistent with the mechanical composition of the sands of the Kinburnska arena and Odeska bank.

The presence of coarse sand (4.55%) and a coarser fraction (4.46%) is due to a biogenic factor, namely the introduction of mussels into the coastal zone. We believe that it is the input of mussels that influences the median diameter of the sediment and its sorting behavior.

In the coastal zone of the system, there is also sediment differentiation in the transverse direction. On the underwater slope and within the aeolian zone, the fine-grained fraction predominates, while within the beach, the medium-grained fraction predominates. The described situation is due to the hydrodynamic conditions of the shallow, accumulative shore of the non-tidal sea (Shuisky, 1986).

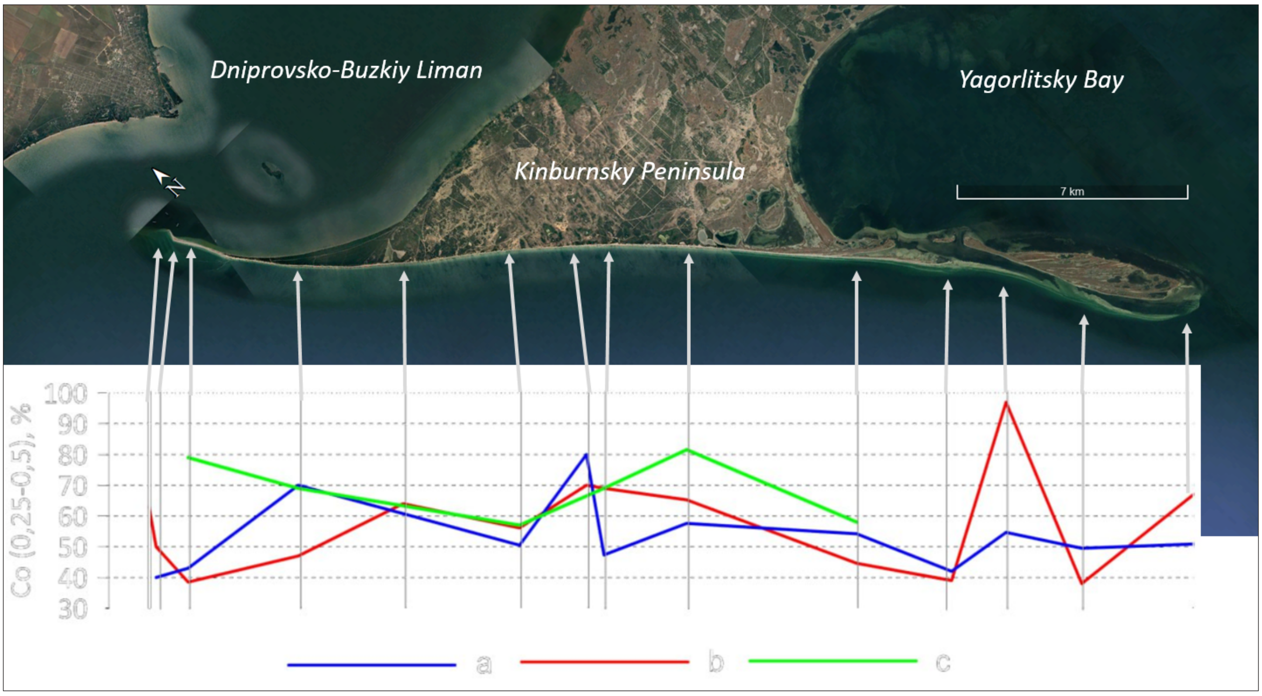


**Fig. 2. Spatial distribution of the dominant sediment fraction (0.25–0.5 mm) along the seashore of the Kinburnska-Pokrovska-Dolgiy system: a – underwater slope; b – beach; c – aeolian zone (image source: GoogleEarth™)**

A pattern of spatial arrangement of coastal-marine sediment fractions is evident along the studied coastal system. The dominance of the dominant sediment fraction distinguishes two parts along the seashore of the system: the northwestern (Co 0.1–0.25 mm) and the southeastern (Co 0.25–0.5 mm). The granulometric parameters presented may be lithological evidence of the existence of two longshore drifts of sediment and their divergence zone (Zenkovich, 1960; Pravotorov, 1966).

The northwestward flow of sediment develops from the root part of the Kinburnska Spit to its distal end part. The dominance of $C_o$ (0.1–0.25 mm) within its limits may be due to the feeding of the northwestern flow from the underwater slope, which has a connection with the Odeska bank, composed of fine-grained sand.

The southeast flow of sediment develops from the root part of the Kinburnska Spit to the distal part of the Zagreb underwater barrier. The predominance of Co (0.25–0.5 mm) within its limits, indicates its dominant feeding by erosion of continental sand massifs located within the frontal shore of the system.

Field studies and granulometric analyses show that the zone where sediment flows diverge is between the root part of the Kinburnska Spit and the northwest part of the front shore. At the multiyear stage, the divergence zone experiences a reversible displacement along the presented shoreline section. It should be noted that it is within the divergence zone that the most active processes of wave erosion manifest (Davydov et al., 2021 b). The described granulometric and lithodynamic features support the idea that the studied coastal system represents a «winged foreland» (Shuisky, 1999; Davydov, 2019).

The predominance of Co (0.25–0.5 mm) in the southeastern part of the system suggests that it contains the most favorable conditions for sandy coastal protection aeolian forms.

Along the seashore of the studied system, the mean value of the median sediment diameter is 0.33 mm. Within the frontal shore, the sediment's minimum Md is determined to be 0.29 mm. In the north-west direction, Md increases to 0.31 mm, in the southeast direction, first to 0.34 mm (distal of the Sukha Spit) and then to 0.4 mm (head of the Zagreb underwater barrier) (Fig. 3).

Within the constituent parts of the coastal zone, similar trends in the median parameters are manifested: a) on the underwater slope, in the center 0.24 mm, towards the distal of the Kinburnska Spit Md increases to 0.30 mm and towards the head of

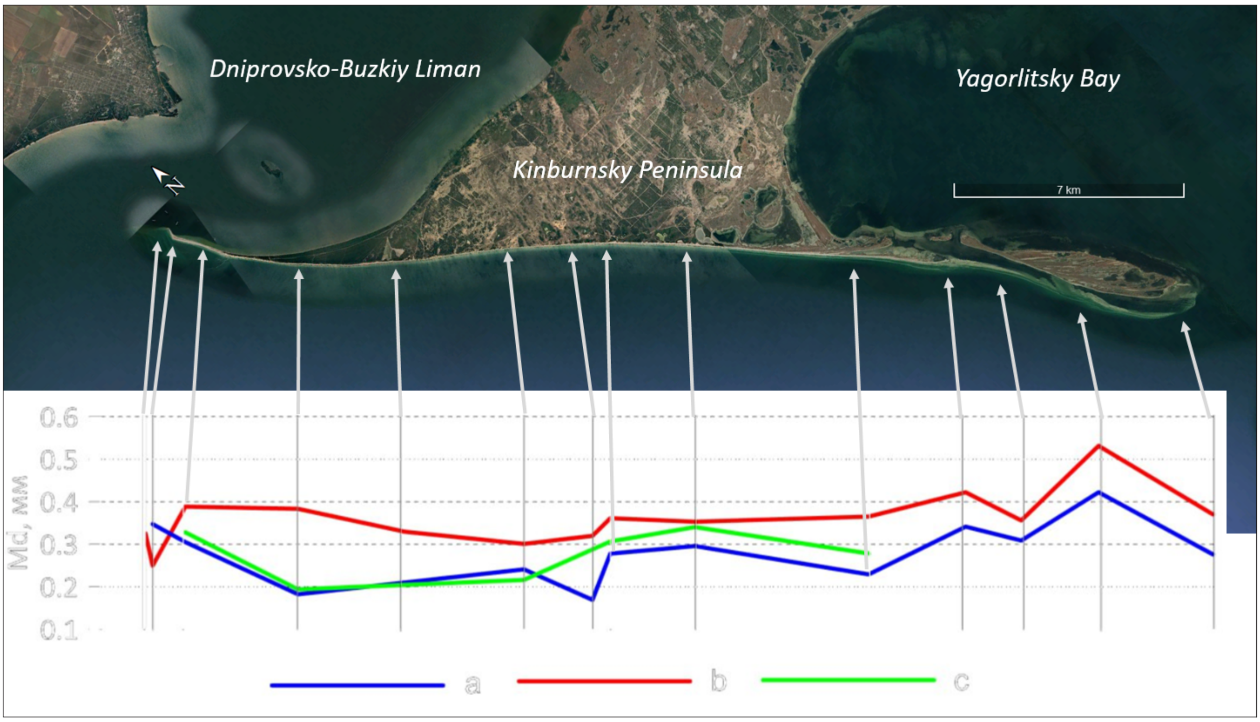


**Fig. 3. Spatial distribution of the median sediment diameter along the seashore of the Kinburnska-Pokrovska-Dolgiy system: a – underwater slope; b – beach; c – aeolian zone (image source: GoogleEarth™)**

the Zagreb underwater barrier to 0.35 mm; b) within the beach, the increase is from 0.35 to 0.36 mm in the north-west direction and up to 0.44 mm in the south-east direction; c) in the aeolian zone, the median increases from 0.27 mm to 0.28 mm (towards the distal of the Kinburnska Spit) and up to 0.32 mm (the root part of the Sukha Spit).

These trends in the median are due to the influence of biogenic factors on longshore sediment transport. Shellfish is the material for the coarse and coarse fraction of coastal-marine sediment.

Within the coastal zone of the system under study, the mean value of sediment $S_o$ is 1.56, indicating moderately poor sorting. Spatially, the sorting coefficient is characterized by worsening trends, from the middle part of the frontal shore (1.38) in diametrically opposite directions – towards the Kinburnska Spit (1.88) and the head of the Zagreb underwater barrier (1.53) (Fig. 4). These trends in sediment sorting also indicate the presence of two oppositely directed sediment fluxes and the significant role of biogenic input.

**Conclusions.** The following conclusions were formulated based on granulometric analyses of coastal-marine sediment samples collected in the field within the Kinburnska-Pokrovska-Dolgiy coastal system:

– coastal-marine sediments prevailing within the system are the product of erosion of alluvial sandy sediments of the Kinburn Peninsula and Odesка вank, ready for the facies conditions of the coastal zone;

– the process of further differentiation of sandy material occurs in the coastal zone of the system under conditions of active movement and enrichment with biogenic material.

– within the $C_o$ system (0.25–0.5 mm) is 49.63% and the fraction (0.1–0.25 mm) is 33.29%. Together both fractions form the structural framework of the coastal-marine sediment, as their total content is about 82.92%;

– along the seashore of the system, there is a spatial differentiation of the sediments, with $C_o$ (0.1–0.25 mm) predominating in the north-western part (about 7 km) and $C_o$ (0.25–0.5 mm) dominating in the south-eastern part (about 25 km). This situation is a feature of the feeding and functioning of two oppositely directed longshore flows;

– the obtained Md values indicate its increase in the direction from the central part of the system to its distal ends. $S_o$ deteriorates in the same direction, which is a consequence of the influence of biogenic material on coastal-marine sediments;

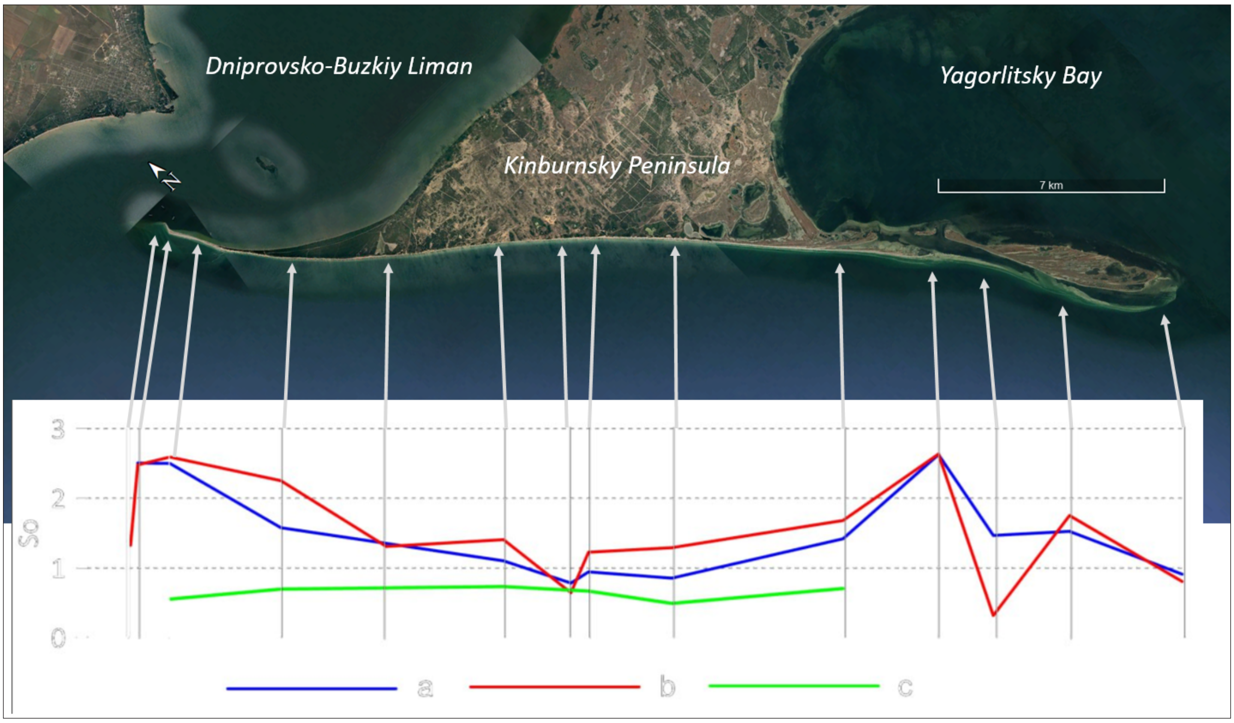


**Fig. 4. Spatial distribution of the sediment sorting coefficient along the seashore of the Kinburnska-Pokrovska-Dolgiy system: a – underwater slope; b – beach; c – aeolian zone (image source: GoogleEarth™)**

– analysis of the spatial distribution of granulometric parameters allows us to state that the most favorable conditions for the creation of sandy shore protection aeolian forms take place in the south-eastern part of the system.

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