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Original article

Granulometric Composition of Sediments in the Coastal Zone of Koktebel Bay (Crimea)

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Abstract
The paper aims to study the local features and factors of sediment fractional composition formation in the coastal zone of Koktebel Bay. The paper uses *in situ* data and the results of granulometric composition analysis of sediment samples from the swash and beach zones of Koktebel Bay to reveal that the beach sediments on the shoreline in the swash zone were represented by coarse gravel with the inclusion of medium and fine gravel. The material in the western and central parts of the coastal zone of the bay was moderately and poorly graded, while in the eastern part it was well graded. The granulometric composition of the beach material differed for the central and rear sections. The sediments in the central parts of the beaches were mainly represented by coarse gravel (27%) and coarse sand (26%) with inclusions of fine gravel (18%) and medium sand (14%). The material of gravel-sand beaches in the eastern part and the gravel beaches in the western part were well graded, while the beach material in the central study part was poorly graded. In the rear section of the beaches, the material was poorly graded and consisted mainly of coarse gravel, the portion of which decreases from the western part to the eastern one. In the samples from the rear part of the beaches, an increased proportion of silty material (1–13%) was noted. The features of the fractional composition of beach sediments are determined by the interception and retention of gravel material by numerous structures located directly in the shoreline, as well as by the supply of clay-sandy material as a result of wave abrasion of natural cliffs and its accumulation in the central section of the beaches as their width increases.

Keywords: Koktebel, coastal zone, sediments, beach, granulometric composition, anthropogenic impact

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Гранулометрический состав наносов береговой зоны бухты Коктебель (Крым)

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Аннотация
Цель работы – исследовать локальные особенности и факторы формирования фракционного состава наносов в береговой зоне бухты Коктебель. На основании данных натурных наблюдений и результатов исследования гранулометрического состава проб наносов из приурезовой полосы и пляжевой зоны бухты Коктебель установлено, что наносы пляжей на урезе в зоне заплеска представлены крупным гравием с включением среднего и мелкого гравия. Материал, отобранный в западной и центральной частях приурезовой полосы бухты, средне и плохо сортирован, а в восточной части – хорошо сортирован. По гранулометрическому составу материал пляжей в центральной и тыловой зонах различается. Наносы в центральной зоне пляжей представлены преимущественно фракциями крупного гравия (27 %) и крупного песка (26 %) с включениями мелкого гравия (18 %) и среднего песка (14 %). Материал гравийно-песчаных пляжей в восточной части исследуемой зоны и гравийных пляжей в западной ее части хорошо сортирован, а в центральной – материал пляжей плохо сортирован. В тыловой зоне пляжей материал плохо сортирован и состоит преимущественно из крупного гравия, доля которого от западной части к восточной уменьшается. В пробах наносов, отобранных в тыловой зоне пляжей, отмечается повышенная доля илистого материала (1–13 %). Особенности фракционного состава наносов пляжей определяются перехватом и удерживанием гравийного материала многочисленными сооружениями, расположенными непосредственно в приурезовой полосе, а также поступлением глинисто-песчаного материала в результате волновой абразии природных клифов и его накоплением в центральной зоне пляжей с увеличением их ширины.

Ключевые слова: Коктебель, береговая зона, наносы, пляж, гранулометрический состав, антропогенное воздействие

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Introduction

The coastal regions of Crimea are under active anthropogenic impact. Over the past 30 years, the intensification of anthropogenic activity in the coastal zone has caused disruption of the natural course of hydro- and geodynamic processes. As a result, the regulation of natural watercourses (a source of material for beach sediments), sand mining and active construction in the coastal zone led to the destruction of coastal infrastructure facilities.

The granulometric composition of sediments and the peculiarities of their distribution in the coastal zone are key parameters used in mathematical modelling of the morphodynamics of sand beaches [1].

The relevance of the study of coastal zone sediments on the Southeastern coast of Crimea in the zone of Koktebel Bay is primarily stipulated by the lack of current data on their granulometric composition (fraction content, average particle diameter, sorting coefficient), as well as a significant acceleration of development of the recreational potential of this region as a result of the implementation of the construction projects of the embankment and coastal protection structures.

The purpose of the paper is to investigate local features and factors of formation of the fractional composition of sediments in the coastal zone of Koktebel Bay. Previously, similar works were carried out by the author in relation to sections of the coastal zone of Kalamita Bay in general [2] and the Lake Sakskoye bay-bar in particular [3]. The obtained *in situ* data fill the gap of information about the structure and factors of bottom sediment formation in the area under study and can be used in the future when planning coastal protection measures aimed at the rational use of coastal zone resources.

Characteristics of study area

Koktebel Bay is a water area in the southeastern Crimea located from Cape Planerny in the west to Cape Chameleon in the east (Fig. 1). The length of the coastline of the bay is about 4000 m, the maximum depth is 15–20 m [4–6].

The shore of the bay is abrasion-landslide and abrasion-erosive. It is represented mainly by the cliff of homogeneous composition with a height of 3–30 m with narrow pebble-boulder beaches [4–6]. The cliffs are composed of Quaternary gravelly loams, Middle and Upper Jurassic clays [6]. The average rate of abrasion of the Koktebel Bay shores [1)] is 0.2–0.5 m/year. The width of the beaches is 5–10 m in the western, 30–40 m in the central and 3–10 m in the eastern parts of the bay.

After the regulation of shallow watercourses, which are a source of sediment material, the movement of clay-sand material into the study area decreased [4, 5]. Currently, the beach-forming material comes as a result of the destruction of cliffs in the western and eastern parts of the bay coastal zone. In the western part, most of the cliffs are actively built up. There is a cascade of coastal protection structures in the form of concrete groynes with a length of 65 m and a number of mooring walls up to 35 m long, located directly on the shoreline. These concrete structures disrupted the sediment transport system, which led to a complete reduction of beaches in this area. The most significant reason for the degradation of the natural complexes of the Koktebel Bay coastal zone was the construction of the embankment in the late 1960s and unauthorized private construction on adjacent sites in the 1990s, carried out without any necessary assessments of lithodynamic processes for this area [4].

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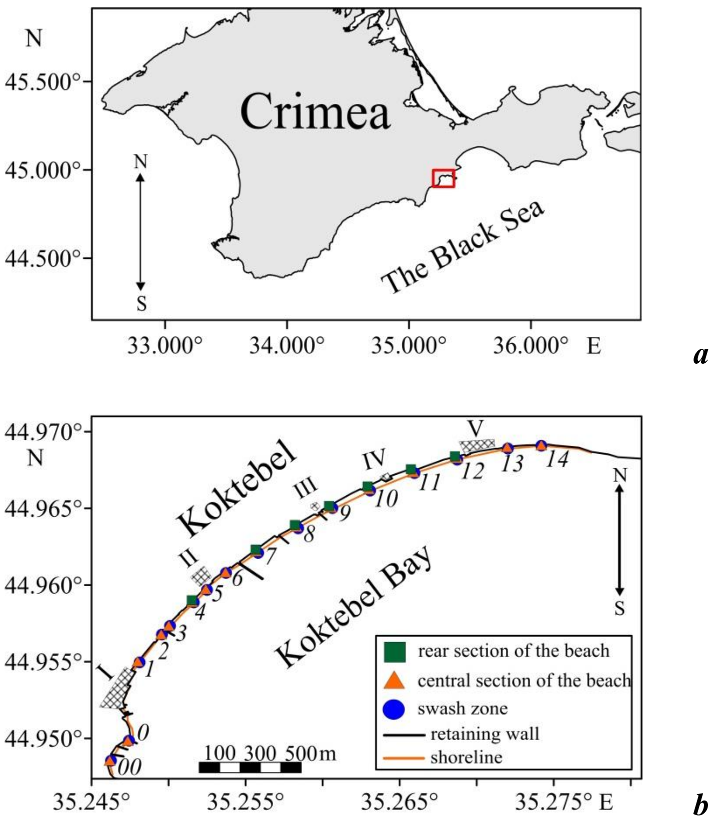
1) Shnyukov, E.F., ed., 1982. [*Geology of the Shelf of the Ukrainian Soviet Socialistic Republlic. Environment. History and Study Methods*]. Kiev: Naukova Dumka, 180 p. (in Russian).



F i g. 1. Location of the study area (the red rectangular) (*a*); a map of soil sampling from the beach surface and the shoreline in the swash zone on the Koktebel Bay coast, 2021 (the Arabic numerals denote station numbers; the Roman numerals denote the following objects: I – Beliy Grifon Hotel Resort, II – M. A. Voloshin Memorial House, III – Koktebel Dolphinarium, IV – Junge Hill, V – boat sheds *Zhemchuzhina Koktebelya*) (*b*)

Materials and methods

Sediment samples from the Koktebel Bay coastal zone in areas near the shoreline (in the swash zone), as well as in the central and rear sections of the beaches, were taken in November 2021. The granulometric composition of bottom sediments was determined by the mass content of particles of various sizes, expressed as a percentage relative to the mass of the dry soil sample taken for analysis

(GOST 12536-2014). The screening of the sediment samples was carried out using a set of sieves with 10; 7; 5; 2.5; 2; 1; 0.5; 0.25; 0.1; 0.05 mm holes. Sampling spots on the surface of beaches and near the water shoreline were selected in such a way that it was possible to assess how coastal protection structures affect the granulometric composition of the material moving along the shore.

Cumulative curves were used to visualize the data of granulometric analysis of sediment samples, as well as to calculate some characteristic coefficients.

Cumulative curves are especially valuable for calculating various granulometric coefficients, in particular those proposed by P. Trask [7] and W. Krumbein [8] of the average (median) particle diameter (M_d), grading coefficient (S_o) and asymmetry coefficient (S_k).

The average (median) diameter (M_d), i.e. the second quartile, or the grain size relative to which half of the grains is larger and the other half is smaller, is determined directly from the cumulative curve: from the point of the curve with an ordinate of 50%, the perpendicular is lowered onto the abscissa axis, thus determining the desired size. The average diameter is an important characteristic of the granulometric composition of the sample, since it determines its granulometric type, although often roughly [2)].

The grading coefficient is determined with the following formula:

$$S_o = \sqrt{\frac{Q_3}{Q_1}},$$

where Q_3 and Q_1 – values of the third and first quartiles, i.e. the particle sizes corresponding to the ordinates of 25 and 75%, respectively, when the values of the size and proportion of the largest fractions are set from the beginning of the coordinate axes.

In well graded sands and siltstones $S_o < 1.5$; in medium graded ones $S_o = 1.5–2$ and in poorly graded ones $S_o > 2$.

The asymmetry coefficient (S_k) is calculated in accordance with the following formula:

$$S_k = \frac{Q_1 \; Q_3}{M_d^2}.$$

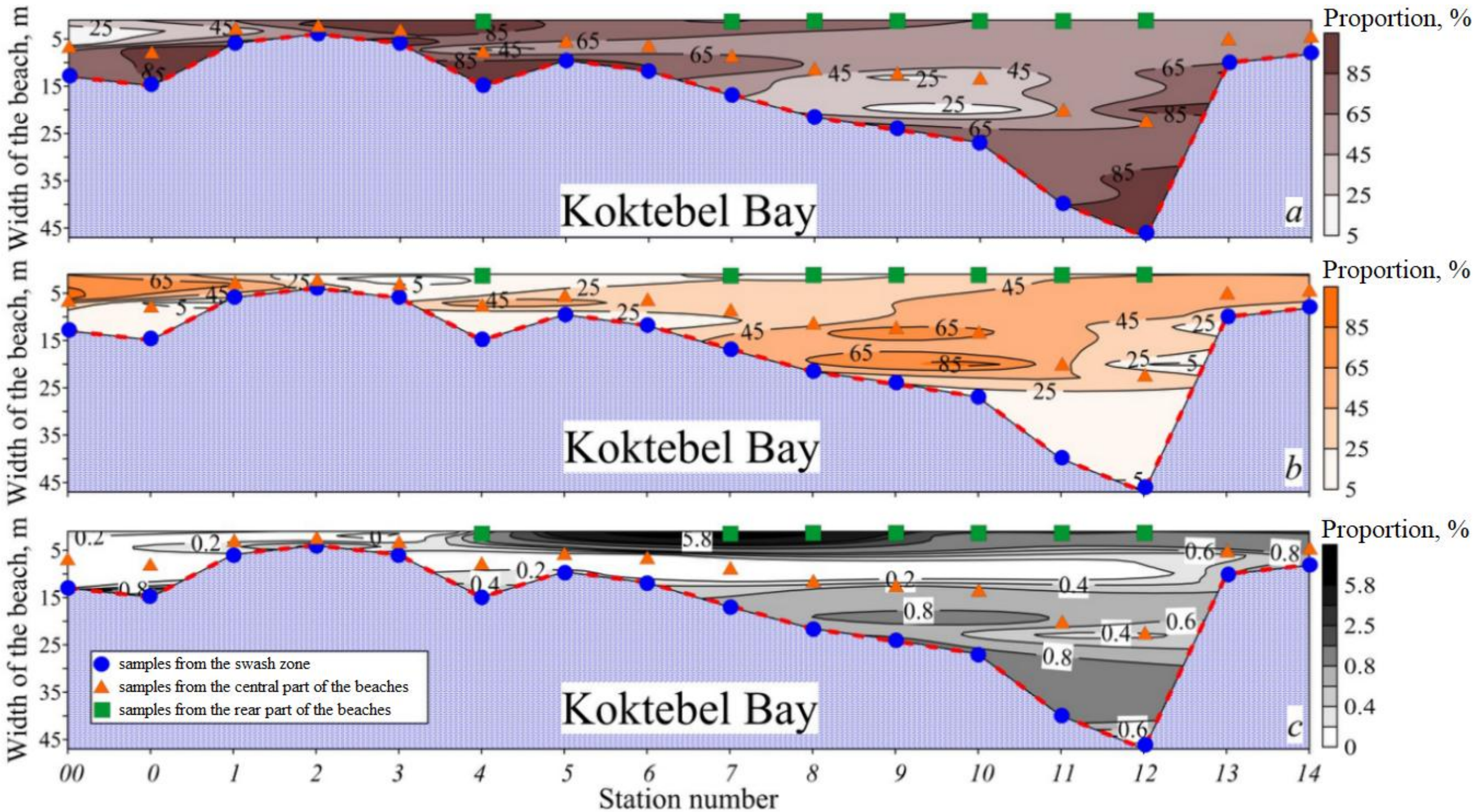
With $S_k > 1$, fine fraction prevails in the sediment; with $S_k < 1$, large fraction prevails.

Results and discussion

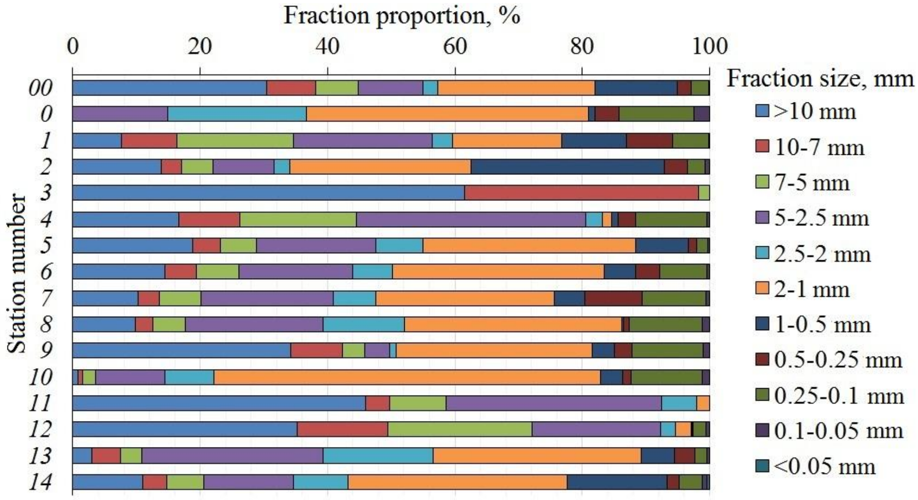
The features of the spatial distribution of granulometric fractions in the Koktebel Bay coastal zone are shown in Fig. 2.

It has been established that, according to the granulometric composition, sediments in the Koktebel Bay coastal zone are quite diverse. It is noted that on the shoreline the coarse-grained pebble-gravel material prevails.

[2)] Parmuzina, L.V., 2011. [*Granulometric Analysis of Sandy-Aleuritic Rocks: Guidelines for Performance of Laboratory Work under discipline Lithology of Natural Gas and Oil Reservoir for Students with Major in Oil and Gas Geology*]. Ukhta: UGTU, 23 p. (in Russian).



F i g. 2. Spatial distribution of the gravel (*a*), sand (*b*), and silt (*c*) fractions in the sediments of the Koktebel Bay shoreline. The dashed curve denotes the shoreline

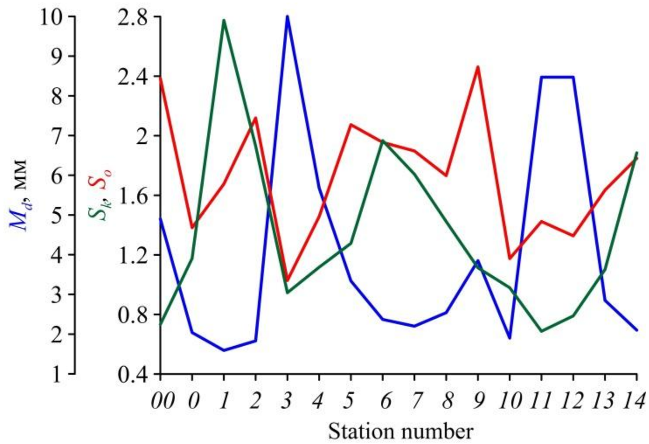


F i g. 3. Spatial distribution of the bottom sediment fractions at the shoreline in the swash zone of Koktebel Bay coast

Its share averages 84% and increases within the study area from west to east. The proportion of sand material in the coastal zone is insignificant (on average 15%) and is represented by coarse and fine-grained fractions. The proportion of fine-grained fraction does not exceed 1%. An analysis of the features of the spatial distribution of sediment material by size in the coastal zone made it possible to single out several characteristic areas (Fig. 3).

The first area (stations *00–2*) is characterized by dense anthropogenic development including a cascade of coastal protection structures (groynes), as well as dwelling houses and recreational facilities located close to the shoreline. It resulted in a limitation of the flow of sediment coming from the shore abrasion in the western part of the bay and a decrease in the proportion of gravel material in this area. The groyne in the area between stations *2* and *3* seems to prevent the sediment flow from east to west. For this area, the maximum proportion of the sand fraction in the coastal zone sediments is noted (on average 24%), which is reflected in the increased values of S_k (Fig. 4).

The second area (stations *3–11*) is characterized by the material that is heterogeneous in its granulometric composition, which is reflected in the values of the grading coefficient: in the area between stations *4* and *9*, it is 1.9 on average (Fig. 4). On the stretch of coastline between stations *3* and *7*, a decrease in both the proportion of gravel material and its size is observed. This is stipulated by the filling of beaches in this area, as well as the location of hydraulic structures intercepting sediment material moving along the shoreline. In addition, an increase in the width of the beaches from west to east leads to the movement of sand material into the coastal zone. Thus, the amount of coarse-grained material



F i g. 4. Spatial distribution of granulometric coefficients for the samples taken at the shoreline in the swash zone

moving from west to east decreases, and the proportion of sand material coming from the beach to the shoreline increases.

As for the third area (stations *12–14*), an increase in the content of sand (from 2 to 21%) and silty (0.4 to 1.2%) material is observed, on the one hand, and a decrease in the proportion of gravel material (from 97 to 78%), on the other. In this area, the increase in the proportion of sand and silty fractions is determined by the structure of cliffs formed by clay-sand material. Since the cliffs in the eastern part of the Koktebel Bay coastal zone are not developed, the clay-sand material entering the coastal zone as a result of wave abrasion is the main source of terrigenous matter for beach sediments. This is also reflected in the S_k coefficient increase (Fig. 4).

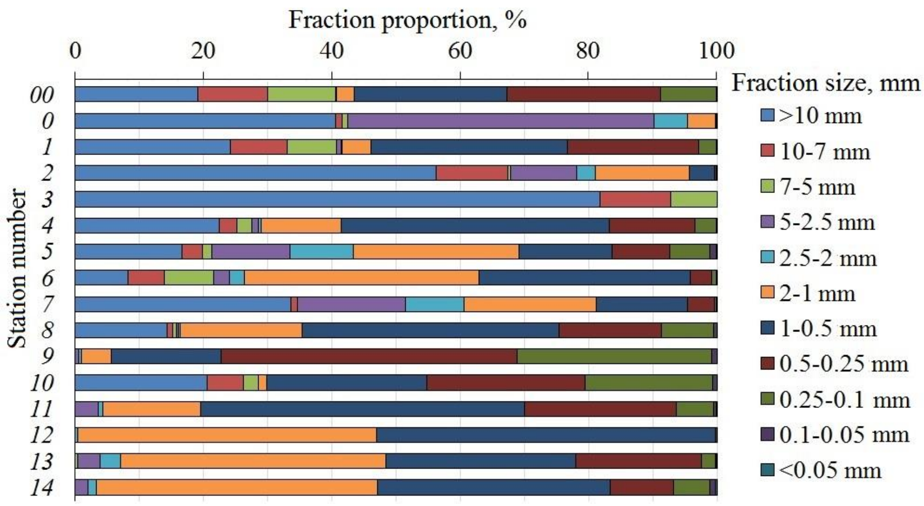
The samples taken on the shoreline were characterized by varying degrees of grading. The material in the first and second areas is medium and poorly graded, and in the third one it is well graded (Fig. 4). Rather weak, though obvious, correlation dependence of the grading coefficient on the size of the material was obtained. The correlation of S_o with the gravel fraction was −0.5, and with the sand fraction it was 0.5. Another dependence, more explicit one, was obtained when comparing the values of M_d and the proportion of sand and gravel material. It was found that the correlation of M_d with the gravel fraction was 0.8, and with the sand fraction it was −0.8.

Since the width of the beaches of the Koktebel Bay coastal zone varies significantly, the granulometric composition of sediments in the central and rear sections of the beaches is quite diverse.

It was found that sediments in the central section of beaches were mainly represented by fractions of coarse gravel (27%) and coarse sand (26%) with inclusions of fine gravel (18%) and medium sand (14%). The proportion of coarse-grained gravel is maximum in the sediments of beaches in the western part of the study area, which is explained by its accumulation in the groyne spacing. From west to east, the proportion of coarse and medium-grained gravel decreases, while the proportion of fine-grained gravel increases. The proportion of coarse (1–0.5 mm) and medium (0.5–0.25 mm) sand fractions, on the contrary, increases from the western part of the area to the eastern one. The features of the spatial distribution of gravel and sand material in the central section of beaches are determined by the morphometric parameters of the beaches themselves (width, angle of inclination), the nature of development in the coastal zone, as well as the type of cliff rocks in the areas not affected anthropogenically.

The heterogeneity of the spatial distribution of granulometric composition fractions in beach sediments made it possible to identify several characteristic areas (Fig. 5).

The first area (stations *00–4*) is characterized by the greatest heterogeneity of the beach material, alternating zones of accumulation of gravel and sand fractions. First of all, this is stipulated by the minimum width of the beaches and the maximum level of anthropogenic impact on the section of the coastal zone in this area. Zones of accumulation of gravel material (stations *0*, *2*, *3*) are located between coastal protection structures (groynes) and in areas with a minimum width of the beach (up to 5 m), near the buildings located close to the shoreline. The maximum concentration of sand material at station *00* is explained by its moving as a result of the natural cliff abrasion. Spatial heterogeneity of the material affected the M_d values, which vary in a wide range from 0.7 for medium and coarse-grained sand sediments to 10 for coarse-grained gravel sediments. The maximum values of the M_d parameter at stations *2*, *3* are explained by the minimum width of the beaches and the movement of coarse-grained gravel material from the coastal zone.

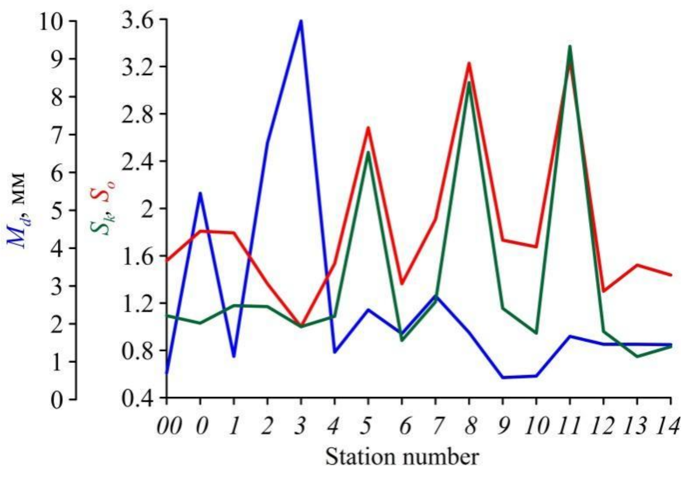


F i g. 5. Spatial distribution of bottom sediment fractions in the central section of the beaches

In the second area (stations *5–10*), a decrease in the proportion of gravel material from west to east (from 77 to 2%) is observed with an increase in the proportion of sand material (from 22 to 97%). Increased proportion of coarse-grained fraction (62–78%) at the beginning of this area (stations *5–7*) is explained by the fact that there are two piers with extensions located close to the shoreline, and the width of the beaches does not exceed 15 m. In the second half of this area (stations *9–10*), an increase in the width of the beaches (up to 40 m) and the absence of structures near the shoreline seem to result in the absence of the sand material in the longshore sediment flow in the central section of the beaches and to its accumulation. The maximum proportion of fine-grained sand fraction (27%) and the minimum value of M_d equal to 0.6 for the entire coastal zone under study are noted in this area.

The third area (stations *11–14*) is characterized by a gradual decrease in the width of the beaches from 43 to 5 m. As a result, the amount of sand material decreases, and the amount of gravel one increases. A slight increase in the proportion of silty material is explained by its moving from the cliffs composed of clay-sand sediments in the rear section of the beach.

In general, the material in the central section of beaches is medium graded (1.8). The material of gravel-sand beaches in the eastern part of this section and gravel beaches in its western part is well graded, and in the central part the material of beaches is poorly graded (Fig. 6). At stations *5*, *8*, *11*, the bicomponent structure of sediments formed as coarse-grained gravel, as well as coarse and medium-grained sand, leads to the fact that at these stations the sediment material is not graded as much as possible (S_o is 2.7, 3.2 and 3.3, respectively). The average median diameter was 2.6, which is significantly higher than the values obtained in [9].



F i g. 6. Spatial distribution of granulometric coefficients for the samples taken in the central section of the beaches

Additionally selected material in the rear section of the beaches at stations *4*, *7–12* showed that the sediments are composed mainly of coarse gravel (on average 60%). The ratio of gravel and sand material at these stations is diametrically different from the composition of sediments in the central section of beaches. In some areas, sediments are sprinkled with a 5–12 cm layer consisting of small pebbles and coarse gravel, followed by mixed gravel-sand sediments with the inclusion of detritus and plant residues. Apparently, this is stipulated by the supply of coarse-grained gravel material into the rear section of the beach during severe storms and its accumulation there. The increased proportion of silty material (up to 13%) in the sediments of the beaches rear section due to the absence of natural cliffs and total development of the coastal zone may be explained by the moving of these sediments with stormwater runoff from nearby sites.

Conclusions

Significant anthropogenic impact on the Koktebel Bay coastal zone (coastline concreting, construction of dams, piers, dwelling, recreational and technical buildings located close to the shoreline) resulted in the disruption of natural processes of sediment material supply and its transport. As a result, the granulometric composition of sediments in the coastal zone (in the swash zone) and in the central and rear sections of beaches differs significantly.

Sediments on the shoreline are represented by gravel material of various sizes. The proportion of sand material in the sediments of the coastal zone averaged 15%, and the proportion of silty ones is less than 1%. The degree of grading of the material is average with minimum values in the eastern part of the coastal zone and with maximum values in its central part. The features of the fractional composition of sediments on the shoreline are determined by two factors: 1) interception and retention of coarse and medium-grained material by numerous structures located directly in the coastal zone; and 2) increase of the beach width and movement of sand material.

According to the granulometric composition, the material of the beaches in the central and rear sections differs. The central section of the beaches is characterized by sediments consisting of coarse and fine-grained gravel with the inclusion of coarse and medium-grained sand. The median diameter of beach sediments decreases from the western part of the coastal zone to the eastern one, and the degree of grading increases from the periphery to the central part of the coastal zone. Sediments in the rear section of the beaches are poorly graded and formed by coarse gravel with inclusions of silty material, which comes with stormwater runoff from nearby sites and accumulates with no material dynamics.

REFERENCES

1. Gurov, K.I. and Fomin, V.V., 2021. Influence of Storm Conditions on Changes in the Granulometric Composition of Bottom Sediments in the Coastal Zone of the Western Crimea. *Ecological Safety of Coastal and Shelf Zones of Sea*, (2), pp. 30–46. doi:10.22449/2413-5577-2021-2-30-46 (in Russian).
2. Gurov, K.I., 2018. Results of Sediment Granulometric Composition Monitoring in Coastal Zone of the Kalamitsky Bay. *Ecological Safety of Coastal and Shelf Zones of Sea*, (3), pp. 56–63. doi:10.22449/2413-5577-2018-3-56-63
3. Gurov, K.I., 2020. Results of Coastal Zone Dynamics and Beach Sediment Granulometric Composition Monitoring in the Central Part of the Kalamitsky Gulf. *Ecological Safety of Coastal and Shelf Zones of Sea*, (1), pp. 36–46. doi:10.22449/2413-5577-2020-1-36-46 (in Russian).
4. Goryachkin, Yu.N., ed., 2015. *The Current State of the Coastal Zone of Crimea.* Sevastopol: ECOSI-Gidrofizika, 252 p. (in Russian).
5. Goryachkin, Yu.N. and Dolotov, V.V., 2019. *Sea Coasts of Crimea*. Sevastopol: Colorit, 256 p. (in Russian).
6. Vronskiy, A.A., Krivobokov, E.M., Kostenko, N.S., Baranov, I.A., Beskaravaynyy, M.M., Budashkin, Yu.I., Vladimirov, E.I., Klyukin, A.A., P'yanykh, S.V. [et al.], 1997. [*Health Resort Koktebel*]. Kiev: Naukova Dumka, 134 p. (in Russian).
7. Trask, P.D., 1932. *Origin and Environment of Source Sediments of Petroleum.* Houston, USA: Gulf Publishing Co., 323 p.
8. Krumbein, W.C., 1936. Application of Logarithmic Moments to Size-Frequency Distribution of Sediments. *Journal of Sedimentary Research*, 6(1), pp. 35–47. https://doi.org/10.1306/D4268F59-2B26-11D7-8648000102C1865D
9. Bratus, O.S., 1965. [Granulometric Composition of Arenaceous Beach-Deposits of Crimea]. *Doklady Akademii Nauk SSSR*, 163(2), pp. 431–434 (in Russian).

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The author has read and approved the final manuscript.