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Dynamics of Sediments Grainsize in Limensky Gulf

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Abstract

The coastal zone dynamics is especially interesting for the researchers from different fields of science. In shallow waters and coastal zones, waves and currents support redistribution of clastic material and subsoils presented in the form of suspended load and bed load. This confirms the need for monitoring morphodynamic processes in the region with the aim of the qualitative and quantitative assessments of the modern transformation of the coastal zone, as well as the formation of forecasts its future development. The features of the granulometric composition dynamics, as well as the processes of erosion and sedimentation in the surface layer of the bottom sediments of the Limensky Gulf were studied by using the XBeach numerical mode. As sediments in the coastal area are presented by a variety of coarse and fine fractions, we used data from actual studies of sediments from the Limensky Gulf. According to the results of the study, it was found that coastal zone sediments are composed of medium sands with the inclusions of shell material and limestone gravel. A feature of the simulation is to use three fractions of bottom sediments surface layer. Analysis of the numerical modeling results showed that the main morphodynamic processes occur within a zone limited by a 20 m isobath. It is shown that the main determining factor governing the

movement of the material is the depth and slope of the bottom. It is shown that the coarse-grained material is concentrated in the coastal zone around the capes, medium-grained fractions accumulate in the central shallow part of the gulf, and the fine-grained material moves during the storm impact into the seaward part of the water area and accumulates here due to the weakening of the hydrodynamic activity.

Introduction

Coastal zone relief dynamics is especially interesting for interdisciplinary researchers. First of all, this is explained by such factors as a general retreat of the coast, an instantaneous reformation of the coastal zone relief and the influence of landslide processes. This confirms the need for monitoring the morphodynamic processes in the coastal zone with the aim of qualitative and quantitative assessments of modern coastal transformation, as well as forecasting its development in the future.

One of the main physical characteristics of bottom sediments is the granulometric composition. The features of the granulometric composition of the sediment allows investigating the types of deposits, their genesis, structure, sedimentation conditions, etc. The study of the fractional composition helps to establish the features of the structure of the sediment, formed in a different time and physiographic situation, as well as to assess the impact of anthropogenic load. The study of mass transport processes in shallow water under the influence of hydrodynamic conditions is determined by the possibility to predict the effect on the ecosystem of various meteorological changes and anthropogenic influences. The features of exogeodynamic processes dynamics can be used in planning measures aimed at the rational use of coastal zone resources. In addition, the study of the mechanical composition allows investigating the processes of absorption, retention and accumulation of pollutants.

The testing ground is ~1.5 × 2.5 km water area, including Limensky Gulf (Blue Gulf) and part of the coastal zone of the Southern coast of Crimea (Fig.1).

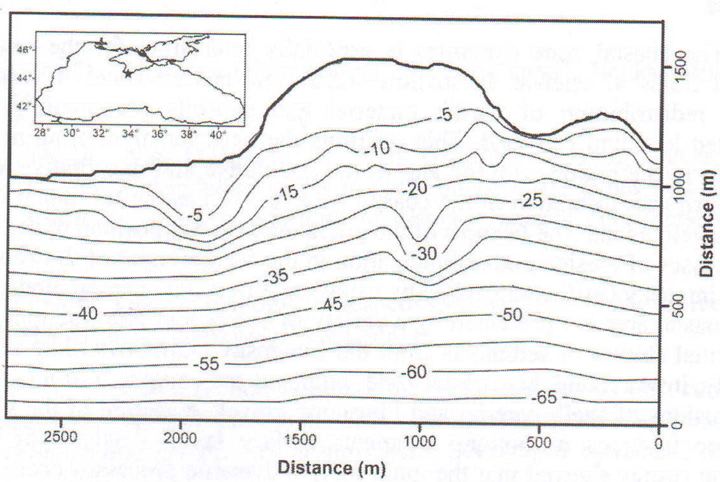

Fig. 1: Location of the study water area and the bottom relief of the Limensky Gulf

Coastal zone in the testing ground area is composed of the Taurian Series deposits. Limensky Gulf is bounded from the East by the spurs of Mount Koshka, from the West – by Cape Kikineiz. The Gulf is stretched in the latitudinal direction and is characterized by high shores. The West coast is composed of series of clay and loam sediments with inclusions of Jurassic limestone detrital material. The shores in the central part of the Gulf are steep, clayey and with an active abrasion zone. Rocky shores of the eastern part consist of the Upper Jurassic limestone blocks (Shestopalov et al. 2005). The Limenka River (temporary watercourse with seasonal flooding regime) discharges the Gulf in its eastern part. The sounding, carried out in 2002, showed that the bottom of the Gulf is flat and rather smooth, with 10 – 12° slope (Kondrat'ev et al. 2003). The average Gulf depth is about 20 m. Average annual sedimentation rate at the testing ground, determined by sediment trap method, makes up 0.84 g/cm2 /year Mitropol'skiy et al. (2005). The results of bottom sediment accumulation measurements previously obtained by radiocarbon dating method also indicate high sediment accumulation rate in the Limensky Gulf (40 – 50 cm/1000 years), which is due to coast abrasion and features of hydrological regime (Shnyukov et al. 1984). Main allochthonous components of modern sediments in the water area under study are the products of abrasion, eolian transport, Limenka river solid runoff and slope runoff. Bottom sediment autochthonous components are the products of biogenic sedimentation. Prevailing winds are the ones of north-eastern and western directions, southern winds blow from the open sea.

The purpose of this paper is to apply the XBeach model (2D) for study the features of the redistribution of sand fractions along the underwater coastal slope in conditions of heterogeneous fractional composition of bottom sediments and different hydrodynamic conditions.

Grainsize Distribution of Bottom Sediments

The composition of sediments in the coastal part of the southern coast of the Crimea is very diverse (Geologiya shel'fa USSR. Litologiya, 1985). They are represented by aleurite-pelitic muds, which are replaced by silty sands near the shore. Terrigenous noncarbonated sands lie a narrow strip along the entire coast of the Southern coast of the Crimea from Cape Sarych to Cape Meganom. As a rule, the sands lie at depths of up to 20-25 meters, in the zone of wave action. Sand material is characterized by poor and medium sorting.

Zenkovich studied features of the Limensky Bay bottom relief and some information on the cross-shore sediment transport in (Zenkovich, 1958). The bottom of the water area continues a steep coastal slope, formed by large blocks. For the blocks begins a flat bottom. Ridges formed by large pebbles and shells of various sizes complicate sandy material. Slides between the ridges are filled with sand. Opposite the mouth of the Limenka river blocks and boulders pushed into the sea. In the western part of the gulf, the pebble layer extends along the shore far beyond the water area.

Modern features of the bottom sediments upper layer spatial structure of the Limensky Gulf are shown in (Ovsyany and Gurov, 2016). The results of study of bottom sediments at the Black Sea hydrophysical ground indicate their inhomogeneity by particle-size distribution. Bottom sediments here are represented mainly by silty sands (0.25 – 0.1 mm fraction) with pebbles and limestone and, to a smaller extent, by aleurite-pelitic silts (0.25 – 0.1 mm fraction). In the coastal zone, bounded by 10 m isobath, sediments are composed mainly of medium sands (0.5 – 0.25 fraction) with the inclusions of shell materials and limestone gravel. Testing ground seaward part has aleurite-pelitic silts. It was determined that two-peak diagram of fraction content, formed both by coarse and fine-grained particles, is characteristic of all sediment samples. The greatest share falls on gravel and sand fractions represented by particles with ≥10 – 1 mm and ≤1 – 0.1 mm, respectively. Aleurite-pelitic suspension (formed as a result of intensive erosion of local clayey shores and sediment surface layer wave reworking) is transported to the deep-water zone. Model experiment revealed the fact that the transport of fine-grained sediment part to the greater depths (in the seaward direction) occurs during the predominance of south-western winds (Alekseev, 2013).

Model Implementation

The XBeach model (XBeach Manual, 2015) is applied in a 2D setting with a constant grid size 1m. All calculations carried out for the storm period of about 12 hours. The grid setup for XBeach requires that the x-axis is orientated approximately normal to the shoreline and the offshore boundary must be far enough offshore to allow space and time to generate the bound long waves.

Wave boundary conditions were implemented as time series of sea state (*instant=jonswap*) with perpendicular direction to the coast. The significant wave height H_s was set at 3,7; 4,6; 5,1 m. The wave peak period T_p = 12 s. Further, default settings were applied, except from the avalanching parameters. The critical slope for avalanching above water (*dryslp*) and the critical slope for avalanching below water (*wetslp*) had values 0.1. The three sediment classes (*ngd* = 3) were considered.

Results and Discussion

The height of the wave and the direction of the wave action were used as two input parameters, which changed in numerical experiments. The features of sand fractions redistribution in the coastal zone under the influence of multidirectional waves of different intensity were considered.

The results of the studies showed that the main determining factor governing the movement of the material is the depth and slope of the bottom. Redistribution of the sediment granulometric fractions begins immediately with the activation of the wave action. More details will be given to the dynamics of the sand material after 6 and 12 hours of storm impact.

It is shown that from the selected hydrodynamic parameters, only the change in wave height is influenced on the nature of the sediment redistribution. With the change in the direction of the wave, the maximum and minimum values of individual fractions vary insignificantly. The main results will be analyzed for wind waves, directed at an angle of 270°.

The modelling study comprised two related parts. In the first case, a homogeneous combination of granulometric fractions was taken as initial parameters. The content of coarse material was 22%, medium-grained - 27% and fine-grained -

51%. The selected values satisfied the average across the entire water area for each fraction.

The simulation results show that coarse and medium-grained material is concentrated in the coastal zone and in the areas adjacent to the capes. The maximum values are noted between the isobaths of 5 and 7.5 m. Deeper the content of coarse-grained fractions is reduced, reaching its minimum values within the isobaths of 10-15 m. As the storm develops, the band of coarse sand expands, varying from 30 m in 6 hours to 50 after 12 at Hs = 3.7 m. With increasing duration of the wave action, the amount of transported material changes. This leads to the fact that the zone of accumulation of coarse-grained fractions also increases, reaching 68 hours at Hs = 4.6 m and 78 m at Hs = 5.1 m after 12 hours (Fig 2). The spatial transformation of coarse and medium-grained material slows down after 6 hours, and the fractional ratio of sand fractions does not change significantly.

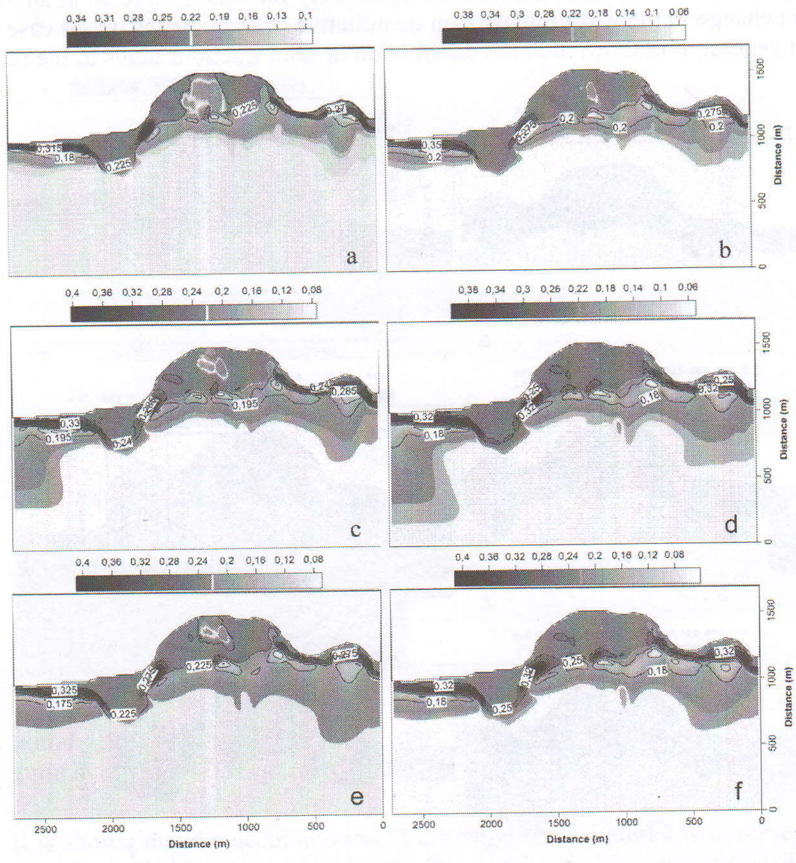

Fig. 2: Spatial distribution of the coarse-grained sand fraction (1.5-0.5 mm) volume concentrations under the action of waves directed at an angle of 270°, for Hs = 3.7 m after 6 h (a), at 12 H (b); for Hs = 4.6 m after 6 h (c), after 12 h (d); for Hs = 5.1 m after 6 h (e), after 12 H (f).

The maximum values of the coarse fraction content do not vary significantly - from 0.39 at Hs = 3.6 m to 0.41 at Hs = 5.1 m. For waves with Hs = 3.7 m, the accumulation of coarse-grained sand fractions is noted as local maxima in the coastal zone. With increasing of wave intensity, the material is distributed evenly between the isobaths of 4-10 m.

In the first hours of the storm impact in the central shallow part of the gulf, an insignificant increase in the finely dispersed material is observed. Subsequently, the fine-grained fraction in the process of storm impact is carried to the sea part of the water area and accumulates here due to the weakening of the hydrodynamic activity.

The maximum concentrations of fine-grained material for the central part of the water area are noted between the isobaths 10-13 m, for the eastern part within the isobaths 7-10 m, and in the western part within the depths of 9-11 m (Fig 3). In addition, for the extreme western and eastern parts of the investigated region, the increase in the fine-grained fraction continues up to a depth of 30-35 m. The increase in the fine-grained material is observed most intensively for waves directed at an angle of 293°. The change in the wave intensity on quantitative characteristics in this case has no effect. In general, it is shown that the distribution of sand fractions tends to the real.

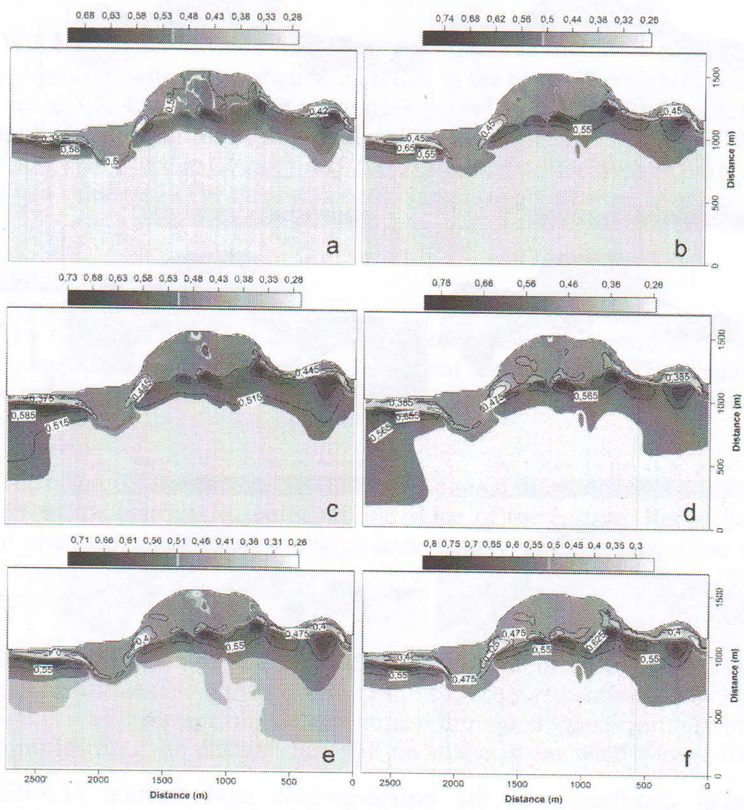

Fig. 3: Spatial distribution of the fine-grained sand fraction (0.25-0.1 mm) volume concentrations under the action of waves directed at an angle of 270°, for Hs = 3.7 m after 6 h (a), at 12 H (b); for Hs = 4.6 m after 6 h (c), after 12 h (d); for Hs = 5.1 m after 6 h (e), after 12 H (f).

In the second case, a combination of three fractions was taken as initial parameters. The initial distribution of volume concentrations of each fraction was based on the results obtained during the monitoring work. The initial distribution of sand fractions is shown in Fig. 4

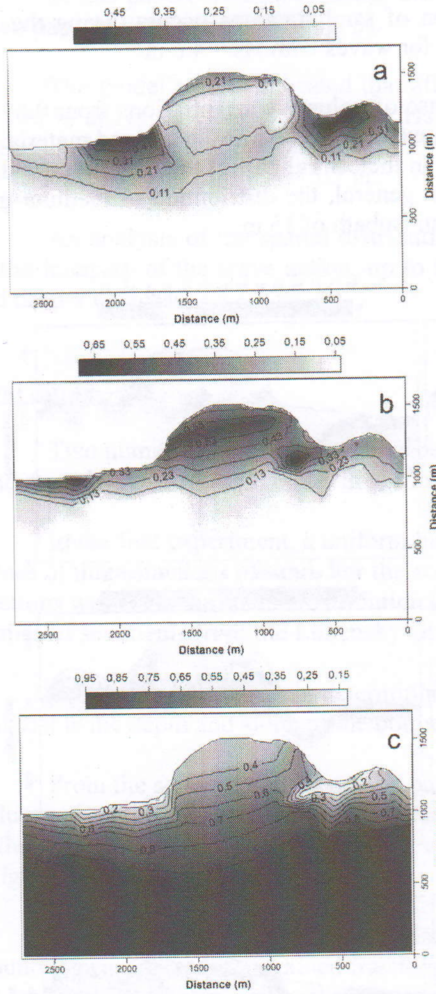

Fig. 4: Initial distribution of sediment fractions: a) coarse-grain material, b) middle-grain material, c) fine-grained material

It is shown that the accumulation of coarse-grained material is observed around the extremities of the capes. However, the band of this distribution increased significantly. The width of the coarse-grained sand accumulation band after 12 hours of wave action in the region of the western cape varies from 114 m at Hs = 3.7 m to 137 m at Hs = 4.6 m and 142 m at Hs = 5.1 m. In addition, the accumulation of coarse material is observed over a greater depth interval - from 3 to 11 m. Deeper isobaths of 13 m in the eastern part of the investigated water area and 20 m in the western part of the volume concentrations of coarse-grained material are reduced. This is largely determined by the selected initial conditions.

In the central part of the gulf between isobaths 6-10 m with increasing values of Hs, redeposition of coarse material is noted. Volume concentrations vary from 0.18 at Hs = 3.7 m to 0.34 at Hs = 4.6 m and 0.42 at Hs = 5.1 m.

In general, the main redistribution of sand fractions occurs during the first 6 hours. The greatest accumulation is noted for waves with Hs = 4.6 m.

For medium-material noted decrease of volume concentrations from 0.69 at the initial time to 0.66 after 12 hours of storm exposure. The transfer of sand material in the north-west direction and its accumulation in the central part of the water area and in the western part of the study area is noted. In general, the distribution of medium-grained sands in the Limensky Gulf is limited by an isobath of 15 m.

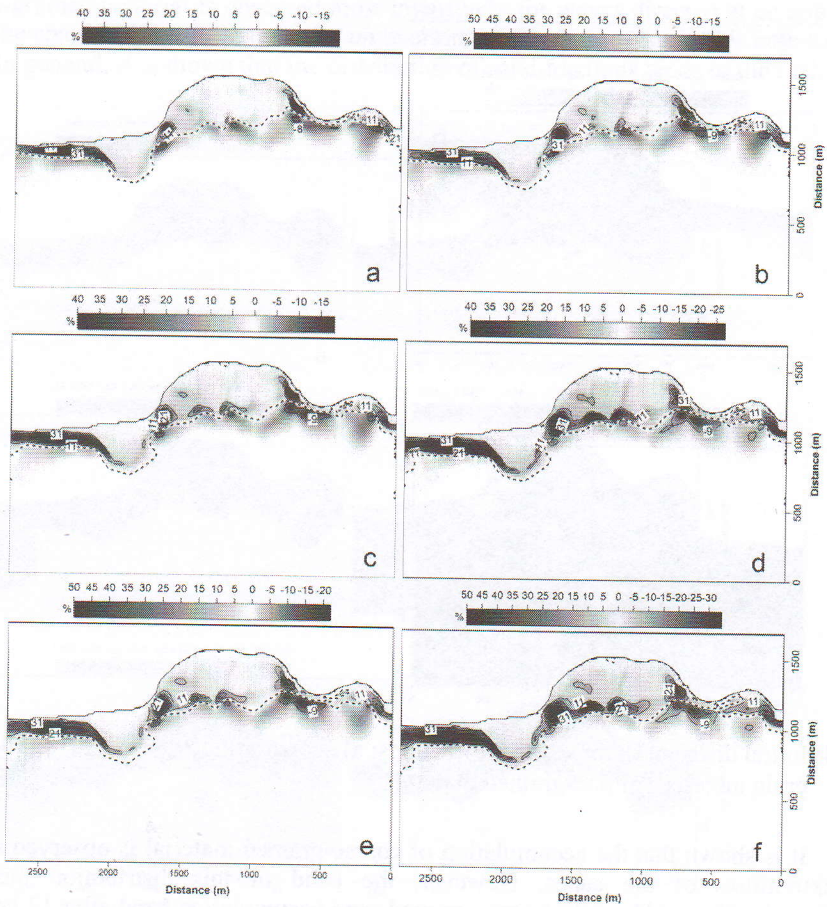

Fig. 5: Distribution of mean grain size (D_{50}) under the action of waves directed at an angle of 270°, for Hs = 3.7 m after 6 h (a), at 12 H (b); for Hs = 4.6 m after 6 h (c), after 12 h (d); for Hs = 5.1 m after 6 h (e), after 12 H (f). Dash curve – boundary between the zones of increasing and decreasing values of D_{50}

Fine-grained material is located mainly in the deep-water part of the investigated water area. During the 12 hours of storm impact, the main part of material is carried outside the isobath 10 m. The boundary of a uniform increase in the volume concentrations of the silty material varies from 11 m for the central part of the water area to 13 m in its extreme western and 14-20 m in the extreme eastern parts.

In this paper, we also consider the qualitative and quantitative dynamics of the mean particle diameter (D50) (Fig. 5).

The model results indicated that after 12 hours of storm impact, D50 decreased on 19.5% at Hs = 3.7 m on 27.2% at Hs = 4.6 m and on 35.2% at Hs = 5.1 m The maximum increase in the mean diameter value (81.9%) was noted for Hs = 4,6 m, and the minimum (78.9%) for Hs = 3.7 m.

An analysis of the spatial distribution of the D50 value showed that, regardless of the intensity of the wave action, up to the isobaths of 11-12 m, the values increase and deeper decrease.

Conclusion

Two numerical experiments have been carried out to study the features of the sand material redistribution under the influence of wind waves of varying intensity.

In the first experiment, a uniform bottom was used, which consisted of averaged values of three fractions of sand. For the second experiment, a combination of three fractions was used, the spatial distribution of which is based on the results from actual studies of sediments from the Limensky Gulf

It is shown that the main determining factor governing the movement of the material is the depth and slope of the bottom.

From the selected hydrodynamic parameters, only the change in wave height is influenced on the nature of the sediment redistribution. With the change in the direction of the wave, the maximum and minimum values of individual fractions vary insignificantly.

It is shown that the coarse-grained material is concentrated in the coastal zone around the capes, medium-grained fractions accumulate in the central shallow part of the bay, and the fine-grained material moves during the storm impact into the seaward part of the water area and accumulates here due to the weakening of the hydrodynamic activity.

In general, the main redistribution of sand fractions occurs during the first 6 hours, and is limited to an isobath of 20 m.

Acknowledgements

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