МІНЕРАЛОГІЯ, ГЕОХІМІЯ ТА ПЕТРОГРАФІЯ

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Viktor NESTEROVSKYI, DSc (Geol.), Prof.
ORCID ID: 0000-0002-7065-8962
e-mail: v.nesterovski@ukr.net
Taras Shevchenko National University of Kyiv, Kyiv, Ukraine

Mykhailo DEIAK, PhD (Geol.), Senior Researcher
ORCID ID: 0000-0002-9330-2766
e-mail: nayk@ukr.net
State Scientific Institution "Marine Geological and Environmental Centrer of the National Academy of Sciences of Ukraine", Kyiv, Ukraine

Andrii TARNOVETSKYI, PhD Student
ORCID ID: 0009-0008-4919-6637
e-mail: youketeroamano22@gmail.com
State Scientific Institution "Marine Geological and Environmental Centrer of the National Academy of Sciences of Ukraine", Kyiv, Ukraine

LITHOLOGICAL AND MINERALOGICAL COMPOSITION OF ACCUMULATIVE BEACH SEDIMENTS OF THE DNIESTER-DNIPRO SEGMENT OF THE BLACK SEA

(Представлено членом редакційної колегії д-ром геол. наук, проф. В.В. Огарем)

The article presents the results of studies of modern beach sediments of the northwestern Black Sea coast from the village of Karolino-Buhaz (Odesa oblast) to the village of Rybakivka (Mykolaiv oblast). The length of the coastal zone is about 110 km. Most of the beaches here are sloping beaches of various morphologies and widths. Using a uniform methodology, 64 samples were collected and processed along the entire profile. The sampling was carried out from the middle part of the beach strip between the water's edge and the shore in the summer in the absence of storms from a depth of 30 cm. The area of the sweep was 30×30 cm. Each sampling point was accompanied by a description of the geological structure, condition of the coastal zone and characteristics of the beach area. The sampling points were georeferenced using a GPS system.

Grain size and mineralogical analyses were carried out, and the main patterns of lithological composition and distribution of mineral fractions along the entire profile were established. Several contrasting areas were identified: 1) Karolino-Buhaz-Chornomorsk, where the medium-grained (0.5–0.25 mm) fraction significantly prevails (67 %). In the sediments of this area, the main mineral of all fractions is quartz (90 %). The dominant heavy minerals are garnet, ilmenite, and magnetite; 2) Chornomorsk – Cape Velykyi Fontan and Lanzheron (Odesa oblast) – Kobleve (Mykolaiv oblast) with a significant content of coarse-grained psamite (2–1 mm) – 29 % and gravel (2–5 mm) – 16 % fractions. The main minerals here in all fractions are quartz and calcite; 3) Cape Velykyi Fontan -Lanzheron is characterised by a variable particle size distribution, with the bulk represented by fractions of 0.25–0.5 mm and 0.25–0.1 mm, which have different proportions on different beaches. The dominant mineral in all fractions is quartz, with calcite detritus present in subordinate amounts. Heavy minerals are represented by single grains of garnet, ilmenite, magnetite, staurolite; 4) Kobleve – Rybakivka (Mykolaiv oblast) with an increase in the content of fractions of 0.25–0.1 mm (up to 42 %). The main mineral in all fractions is quartz (up to 87 %). The secondary component is calcite detritus. Biotite, muscovite and tourmaline are notable impurities in fine-grained fractions. On some beaches located near the seaport of Odesa, numerous glassy spheroidal aggregates of various compositions and ferruginous spheroids have been found in fractions of less than 0.5 mm. In places of concentration of such formations, the colour of the beach sediments becomes grey.

The total content of anthropogenic material in the beach sediments of the studied segment is on average 0.1–0.12 %. It increases significantly (up to 0.23 %) in the vicinity of the port of Odesa and adjacent areas. In addition, in contrast to the Danube-Dniester segment, there is a noticeable increase in the amount of large-sized material of man-made origin (plastic, concrete, bricks, wood fragments, metal, fabric, etc.) in the beach area.

The main factor in the formation of the mineral and particle size distribution of beach sediments in the Dniester-Dnipro segment of the coast is coastal abrasion. The role of terrigenous inputs from the land is minimal and is manifested only in the northern part (Berezan Bay area). The formation of the material and fractional composition is significantly influenced by periodic artificial sand alluviation (beach area of the Odesa agglomeration), strengthening of slopes with concrete blocks, piling up of blocks of igneous and metamorphic rocks, mainly granitoid, breakwaters and other structures that change the direction and influence along the coastal currents.

K e y w o r d s : *Black Sea, Dniester-Dnipro segment, lithological and mineralogical composition, beach sediments.*

Introduction. Beach sediments of the Black Sea within the territorial waters of Ukraine play an extremely important role. They are an integral part of the creation and operation of recreational, health, sanatorium, tourist and sports complexes, as well as mass recreation centres. In the summer, beach sediments are a place of pilgrimage for millions of people, and in many cases the popularity of certain coastal areas of the sea is determined by the condition and nature of their sediments. The main parameters chosen are width, grain size and mineral composition, ecological status and accessibility. The Dniester-Dnipro segment of the coastal zone (Karolino-Buhaz-Rybakivka) is home to a large number of boarding houses, recreation centres, hotels, and entertainment facilities that exploit beach sediments to varying degrees. Odesa is the largest resort agglomeration with a coastal zone of up to 35 km. Over the past 5 years, from 2 to 3.2 million people have had annual holidays here. In total, the coastal resorts of Odesa oblast received more than 6 million tourists in the summer season before the war. The most important centres of active summer recreation here, in addition to Odesa, are: Karolino-Buhaz, Hrybivka, Sanzhiika, Chornomorsk, Kryzhanivka, Fontanka, Vapnyarka, Nova Dofinivka, Chornomorske, Hrygorivka, Yuzhne, Kobleve, Mors'ke, Rybakivka. Everywhere near these settlements, there is active urbanisation of the coastal zone, which is manifested in construction, changes in the original natural landscape, disruption of the natural stability of the coastal rocks and slopes, and an increase in the anthropogenic load on beach sediments.

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Coastal and beach sediments in the study segment are distributed along the entire coastline and are represented by two types: sloping beaches with a total length of about 65 km and alluvial beaches with a total length of up to 45 km.

Coastal zone of this segment of the coast is currently undergoing active development of landslide processes associated with the intensification of neotectonic movements and peculiarities of the lithological composition of rocks.

Beach sediments serve as an important marker for assessing the state of the natural environment at the land-water interface. They reflect geological and anthropogenic factors. That is why monitoring of these sediments is important for understanding the direction of these changes, assessing their quantitative and qualitative parameters, and predicting negative consequences.

Analysis of previous studies and setting the objectives of this publication. The formation of beach sediments is the result of the combined action of three main exogenous factors: coastal abrasion, solid runoff from the land and the hydrodynamics of the marine environment. In different segments of the coast, the importance of each of these factors may vary for objective reasons (shoreline configuration, lithological composition of rocks, landslide development, river runoff activity, direction and activity of coastal currents, sea depth, etc.), which will ultimately affect the volume and distribution of particle size and mineral content of beach sediments.

The coast of the north-western part of the Black Sea is an interesting and accessible scientific object for studying all the above factors influencing the formation of beach sediments and assessing the possibility of accumulating minerals in them. The largest waterways of Central Europe and Ukraine - the Danube River, the Dniester River, and the Dnipro River - discharge into the Black Sea, and there are various types of rocks that make up the coastal zone and numerous estuaries. In the previous report (Nesterovskyi et al., 2022), we provided a general analysis of the work carried out in this area in different periods and focused on their objectives and results. This primarily concerns the classical and generalising publications by M.I. Andrusov (Andrusov, 1890, 1927), A.D. Arkhangelsky (Arkhangelsky and Strakhov, 1938), M.M. Strakhov (Strakhov, 1956, 1965), E.F. Shnyukov (Shnyukov et al., 1981, 1983), V.H. Gevorkyan (Gevorkyan, 1981), O.Y. Mitropol'skii (Mitropol'skii and Moiseeva, 1975), M.G. Barkovskaya (Barkovskaya, 1960, 1963), E.M. Neves'kii (Neves'kii, 1967), Z.T. Novikova (Novikova, 1973), Y.Y. Yurk (Yurk et al., 1973), Y.Y. Shuiskyi (Shuiskyi, 1986; Shuiskyi and Murkalov, 2012; Shuiskyi and Organ, 2017), and others. Most of these works are devoted to the geological structure of the shelf and coastal zone, sediment stratigraphy and minerals. A significant contribution to the understanding and disclosure of the main factors of coastal sediment formation in the study area was made by scientists of Odesa National University supervised by Yurii Shuiskyi (Shuiskyi, 1986; Shuiskyi and Murkalov, 2012; Shuiskyi and Organ, 2017), who have been conducting monitoring expeditions to study the morphology of surface and submerged accumulative formations, the composition of suspended material and the ecology of the coastal environment for more than two decades. In recent years, the staff of State Scientific Institution "Marine Geological and Environmental Centre of the National Academy of Sciences of Ukraine" has been conducting comprehensive lithological and mineralogical studies in the northwestern part of the Black Sea, aimed at obtaining the necessary parameters to build a comprehensive model of the formation of the material and particle size distribution and assessing the importance of each factor. The algorithm of these studies and partial results are presented in (Nesterovskyi et al., 2022, Lomakin et al., 2022). This paper is a continuation of these studies and covers a new segment of the coast from Karolino-Buhaz village (Odesa oblast) to Rybakivka village (Mykolaiv oblast). It focuses on the study of lithological and mineralogical composition, fractional distribution, ecological status and genesis of beach sediments.

Among the most recent works on this topic, it is worth highlighting the publication by Bayram (Bayram et al., 2020), which discusses the peculiarities of the mineral and chemical composition of the coast of the southwestern part of the Black Sea. Also noteworthy are studies of the quantitative indicators of the main provinces that come from the southern coastal area (Dimitrov et. al., 2002, Berkun, Aras, 2012) and the eastern part of the Black Sea (Tătui, Pîrvan et al., 2019, Berkun, Aras, 2012).

Factual material and research methods. The actual material from the Dniester-Dnipro segment of the northwestern part of the Black Sea was collected directly by the authors during the 2021 field season. The sampling was carried out in July in the absence of storm waves at all accessible beach sediment sites. The same methodology was used to collect samples: on sloping beaches – from the middle part, on shoals – at a distance of 5–7 m from the water's edge. The material was collected in standard 1-litre plastic containers from a depth of 30 cm from the surface and a stripping area of 30×30 cm. At each point, a preliminary description of the coastal zone, condition and morphology of beach sediments was carried out. The sampling locations were georeferenced using a GPS system and recorded in a field log along with a description. A total of 64 samples were collected for the study in this segment. The length of the coastline under study is 110 km. The sampling scheme for the study area is shown in Fig 1.

The methodology for preparing and examining samples in the laboratory had a standard scheme and sequence. All fractional groups were studied using an MBS 9 microscope, scanning electron microscope and electron probe microanalysis. Statistical and graphical methods were used to interpret and present the results.

Research results and their interpretation.

Age and lithological composition of the coastal zone rocks in the studied coastal segment. In this segment, the coastal zone sediments that are in direct contact with the marine environment are represented by Neogene and Quaternary sedimentary rocks. A schematic section of these rocks is shown in Fig. 2.

Sediments of the Neogene system that contribute to the structure of the coastal zone and the adjacent part of the water area are represented by rocks of the Sarmatian, Meotian, Pontic, and Kuyalnik stages. The rocks of the Sarmatian Stage are located below the water's edge and are exposed only at the bottom of estuaries (Dniester, Kuyalnik-Khadzhibeyiskyi, Big and Small Adzhalitskyi, Tiligulskyi, Karabuzhskyi and Berezanskyi) (Zelinskyi et al., 1993). Their influence on the formation of the particle size distribution and mineralogical composition of beach sediments is minimal.

The rocks of the Meotian Stage are involved in the structure of the lower part of the coastal zone section above the water's edge. However, they are not widespread, intermittent, and in some fragments of the shore they are partially eroded and underwater. They occur transgressively on Sarmatian sediments and are mostly composed of clay facies. Small layers of limestone-sandy and silt-sandy rocks are recorded in subordinate amounts. The thickness of the Meotian sediments above the water table in the study areas ranges from minimal to 10–12 m. The surface of the Meotian sediments is uneven, eroded, and contains layers of the basal horizon composed of coarse-grained and gravelly material.

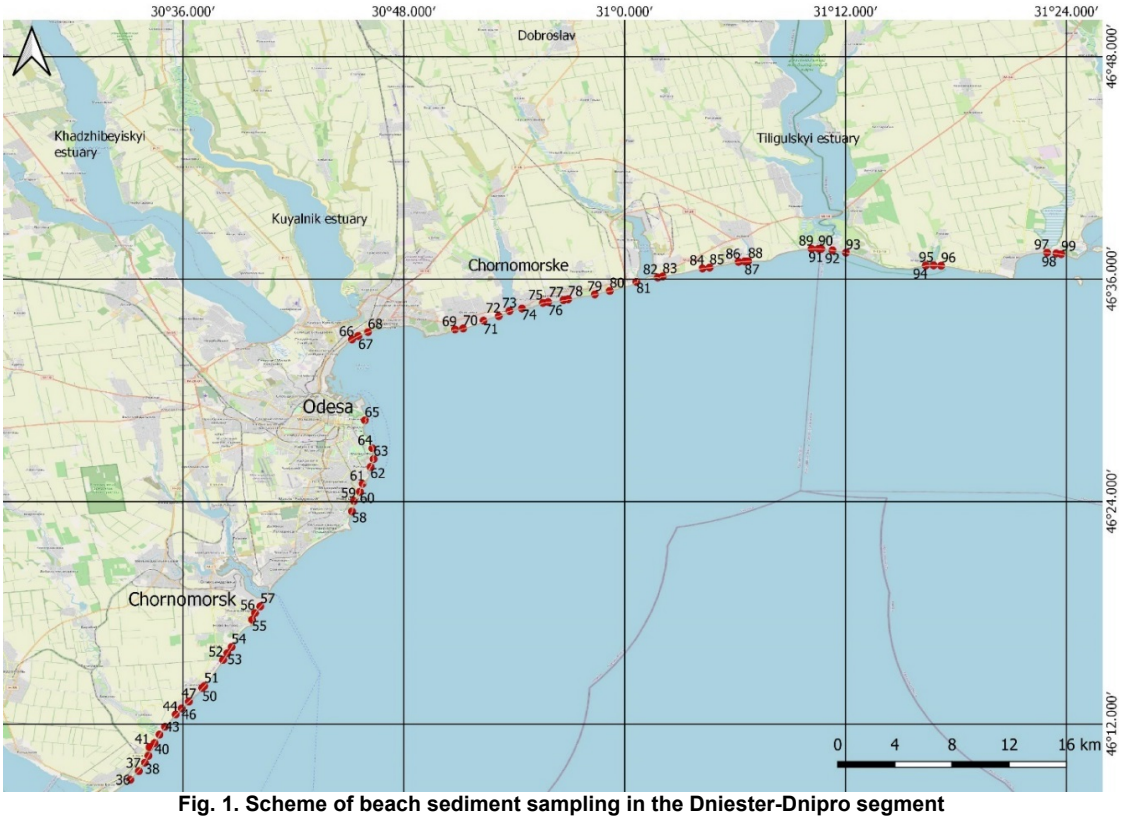

Fig. 1. Scheme of beach sediment sampling in the Dniester-Dnipro segment

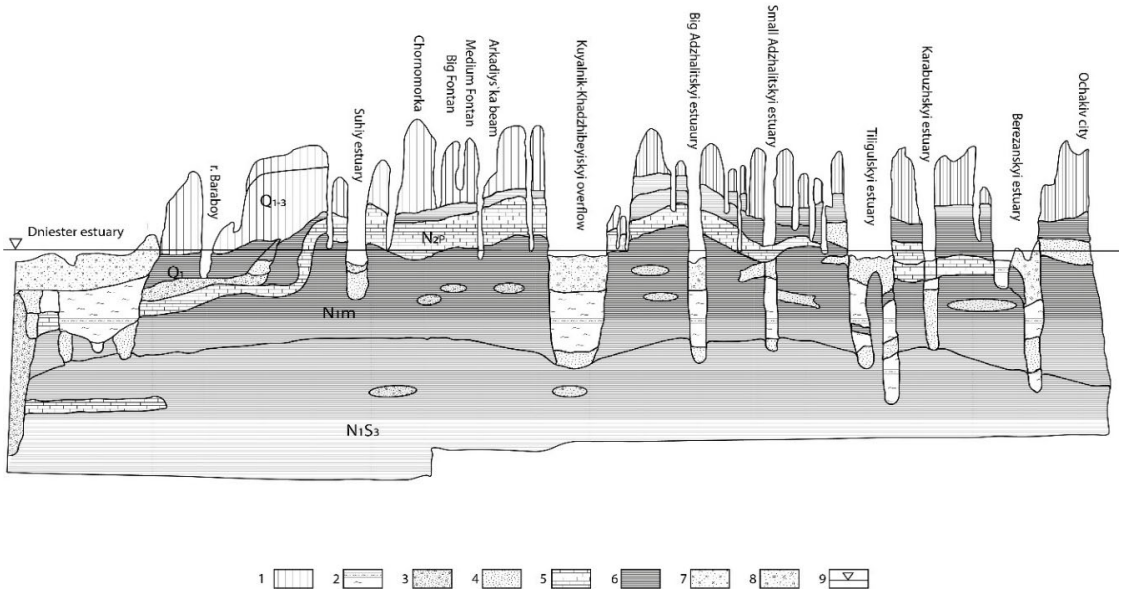

Fig. 2. Schematic geological section along the coastal zone of the Dniester-Dnipro segment
Symbols: 1 – loess loam; 2 – silts; 3, 4 – coarse and fine-grained sands; 5 – limestone; 6 – clays; 7 – sand with shell detritus; 8 – sandy silts; 9 – sea level (Zelinskyi et al., 1993)

The Pontic sediments directly lie on top of the Meotian. They are intermittently present in the coastal section. Above sea level, they are exposed on the coast from the Sukhyi to the Tiligulskyi estuaries. To the southwest of Sanzhiika, they gradually sink and do not come to the surface. They are represented by limestones, clays, siltstones and sandstones belonging to shallow marine and coastal facies. Limestones predominate in the section. The upper and lower parts of the limestone section are stronger, recrystallised, and the middle part is composed of detrital and oolitic limestone with interlayers of sandy clay material. Limestones are poorly dislocated, small anticline folds with slight steepness of their wings are observed. Pliatic and disjunctive faults, as well as landslides at the contact with meotic clays are often observed. Limestones, which are exposed in the zone of active marine abrasion, affect the stability of the shore and prevent its erosion. The thickness of the Pontic sediments above sea level in the coastal study area ranges from the first few metres to 12 metres or more.

Deposits of the Kuyalnik Formation are naturally occurring in the coastal slopes of the Kuyalnik-Khadzhibeyiskyi and Sychavskyi estuaries, and are also

observed on the sea coast between the Tiligulskyi and Berezanskyi estuaries. Their best sections are located near the villages of Fontanka and Rybakivka. They lie on the eroded surface of Meotic and Pontic sediments and are overlain by Quaternary loams. In most of the outcrops studied, they are represented by interbedded sands and clays. The sandy facies is predominantly of fine- to medium-grained, feldspar-quartz composition. To the north-east, the role of clay layers increases significantly (Rybakivka – Ochakiv). The thickness of the Kuyalnyk deposits ranges from 2 to 13 metres. On the coastal area from Small Adzhalitskyi estuary to Rybakivka, undivided Middle and Upper Pliocene sediments lie on top of the Kuyalnik Formation rocks. They are composed of alluvial facies of sands and clays and continental red-brown clays. The latter are distributed only in the watersheds and are not found directly in the coastal zone. The total thickness of these sediments ranges from 2.5 to 15 metres.

Quaternary sediments are widespread in the coastal outcrops of the studied coastal segment. They are represented by different genetic alluvial, estuarine, marine and lagoonal marine facies. They occur on sediments of different ages from the Meotian to the Upper Pliocene. They are mostly represented by loess and loess-like loams, with fossil soils present in the upper part. The thickness of the Quaternary sediments varies from minimal to 25–30 m.

Landslide phenomena are recorded along the entire profile, except for the embayments in estuaries. Landslides develop at the contact of different facies and different ages of sediments. The most active landslide activity is characteristic of the contact between Pontic (limestone) and Meotic (clay) sediments, Pontic (limestone) and Kuyalnik (sandy-clayey) sediments, as well as Quaternary (loam) sediments and Neogene sediments. The activity of landslide processes increases with watering of the section rocks.

Landslide formation processes in the coastal zone are also largely controlled and amplified by neotectonic differential movements, which are quite active in this region and have different amplitudes in different parts of the coast (Lomakin et al., 2022). All of this, together with anthropogenic load, accelerates coastal erosion and increases the total mass of material entering the abrasion zone.

A typical fragment of the coastal zone with active landslide processes is shown in Fig. 3.

Fig. 3. Coastal landslides near Chornomorske

Condition and morphology of modern beach sediments. In the Dniester-Dnipro segment of the coastal zone there are two main types of natural beach deposits: sloping beaches formed directly along the rocky shore and open beaches formed on alluvial deposits. In addition, urban agglomerations have developed beach sediments of artificial and partially artificial origin.

Slope beaches are the longest and most dominant, with a total length of about 65 km in the study area. They are developed on the coastal areas between the settlements of Karolino-Buhaz, Chornomorsk, Kryzhanivka – Rybakivka. Their width in calm sea conditions ranges from 1–2 to 12–15 metres. In stormy weather, these beaches are completely or partially flooded with water and subjected to active overwash. At the same time, the erosion of the shoreline rocks increases. The most actively eroded sediments are those of sandy-aleurite and loess composition. The least vulnerable are dense limestone and clay. The general slope of beach sediments towards the sea is 5–7. After storms, boulders of coastal rocks appear in the beach area, which then gradually break down to the size of the prevailing fractions. In addition, deposits of man-made material appear.

Open-air beaches are fragmented and are associated with the reclaimed areas of the Kuyalnik-Khadzhibeyiskyi, Big and Small Adzhalitskyi, Tiligulskyi, Karabuzhskyi and Berezanskyi estuaries. Their width ranges from several tens to several hundred metres, and their height above sea level is from 0.5 to 2 metres. The slope of the sandbanks' surface towards the sea averages 2–5°. In stormy weather, the beach sediments of the embankments are only partially washed away, with the most active impact being on the area in direct contact with the water. As the shore is not eroded in these areas, beach sediments are replenished or reduced after storms by material redistributed or brought in by the sea.

Beach sediments developed directly within the urban agglomerations of Odesa, Chornomorsk, Fontanka and Yuzhne are of a natural and artificial nature. The bedrock in most of these beaches is protected from sea abrasion, with breakwaters built on the sea side, and in some places the shore is reinforced with concrete and crystalline rocks (Fig. 4). There is also periodic replenishment of beach sediments by adding sandy material from various extraction sites (Fedoronchuk et al., 2015).

Fig. 4. Typical view of the coastal fortifications of the beach area of the Dniester-Dnipro segment (Fontanka village)

Particle size distribution of beach sediments. Based on the results of granulometric studies, it was found that the beach sediments consist of gravel (2–10 mm), psamite (0.1–2 mm), siltstone (0.01–0.1 mm) and pelite (<0.01 mm) fractions. The content and proportion of different fractions varies from site to site, but in general, psamites predominate (up to 81 %) throughout the study area. The content of the gravel fraction is variable, but does not exceed 16 %. The siltstone fraction has a minimum content of up to 5 %. The content of the pelitic component is less than 0.5 % and generally correlates with the siltstone fraction. However, it is distributed sporadically along the profile, with concentrations increasing slightly in areas of active landslide events. If landslides occur infrequently, this fraction is then quickly removed by waves into the sea. The general distribution of the fractional composition of beach sediments along the entire profile is shown in Fig. 5. Four contrasting areas can be distinguished by the peculiarities of its distribution:

1) Karolino-Buhaz – Chornomorsk (Odesa oblast). Here, the beach sediments are represented by the predominance of

medium-grained (0.5–0.25 mm) psamite fraction, the content of which is up to 67%. Secondary fractions are coarse-grained psamite (0.5–1 mm) — 17 % and fine-grained psamite (0.25–0.1 mm) – 10 %. Silty, coarse-grained psamite and gravel fractions are completely absent in this area (Fig. 6).

2) Chornomorsk – Cape Velykyi Fontan and Lanzheron (Odesa oblast) – Kobleve (Mykolaiv oblast). It is characterised by a significant decrease in medium-grained and an increase in coarse-grained psamite fractions. There is also a noticeable increase in coarse-grained psamite (1–2 mm) – 29 % and gravelly (2–10 mm) – 16 % fractions. The content of siltstone fraction is less than 1 % (Fig. 7).

3) Cape Velykyi Fontan Lanzheron is characterised by an unstable particle size distribution, where the bulk of the fractions is represented by medium (0.25–0.5 mm) and fine (0.25–0.1 mm) material, which has different proportions on different beaches (Fig. 8);

4) Kobleve – Rybakivka (Mykolaiv oblast). There is a sharp increase in the content of fine-grained psamite (up to 42 %) due to a decrease in medium-grained psamite (up to 20%) and gravel (up to 11 %) fractions. The content of siltstone fraction also increases (Fig. 9).

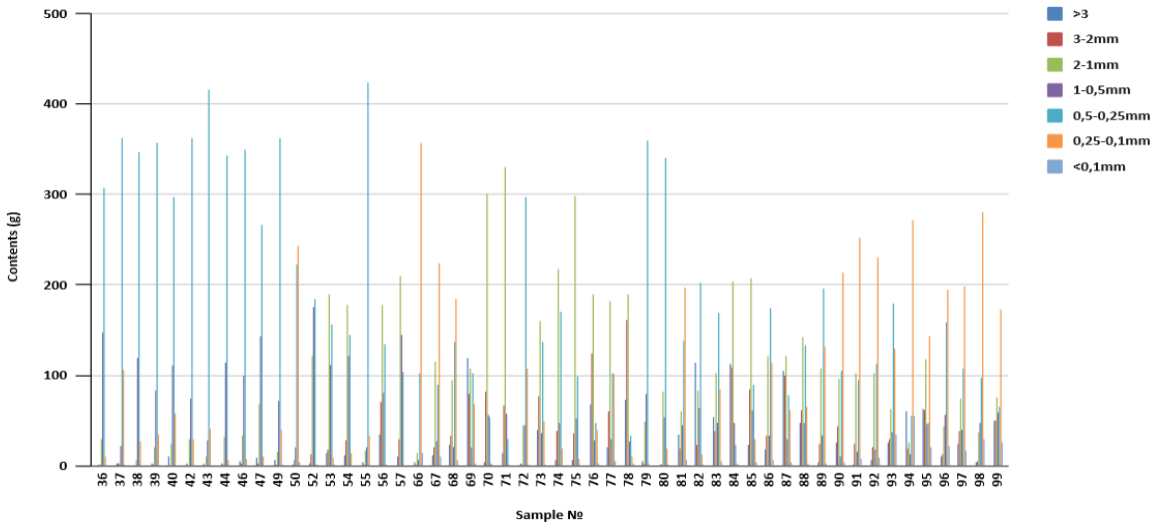

Fig. 5. Generalised particle size distribution of accumulative beach sediments in the Dniester-Dnipro segment

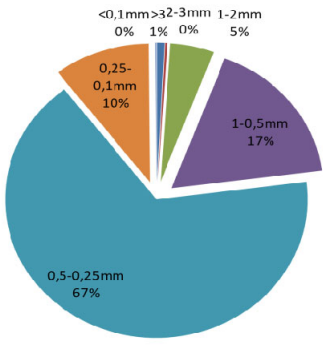

Fig. 6. Average content of beach sediment fractions in the area from Karolino-Buhaz village to the outskirts of Chornomorske

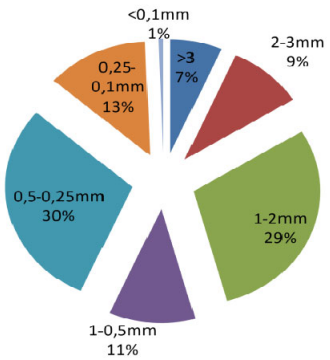

Fig. 7. Average content of beach sediment fractions in the area from the outskirts of Chornomorske (Odesa oblast) to the outskirts of Kobleve (Mykolaiv oblast)

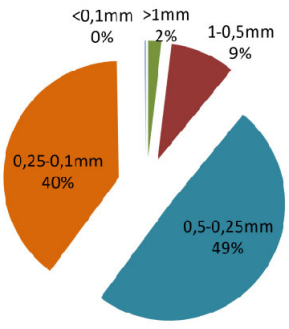

Fig. 8. Average content of beach sediment fractions in the area from Cape Velykyi Fontan – Lanzheron (Odesa)

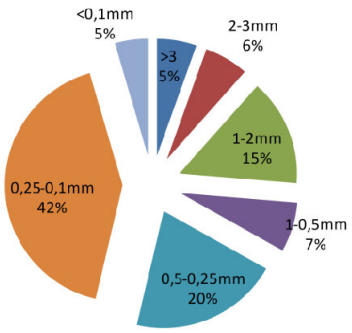

Fig. 9 Average content of beach sediment fractions in the area from the outskirts of Kobleve to Rybakivka village (Mykolaiv oblast)

Mineral composition of beach sediments. The beach sediments of the Dniester-Dnipro segment contain natural minerals: quartz, calcite, garnets, ilmenite, glauconite, tourmaline, mica (phlogopite, muscovite), feldspar, staurolite, magnetite, limestone fragments, detritus, fragments and whole shells and technogenic formations: glass fragments, glass balls, iron balls, shapeless metal alloys, slag.

Natural components. The main rock-forming minerals are quartz and calcite.

Quartz is widespread and predominant in all fractions, except for the Kryzhanivka (Odesa oblast) – Kobleve (Mykolaiv oblast) area, where carbonate formations prevail.

Most of the quartz (up to 97 %) is distributed in fractions of less than 1 mm, but with a sharp predominance in fractions of less than 0.5 mm. It is represented by transparent, medium and poorly rolled grains of colourless, yellowish and white colour (Fig. 10). Some grains contain inclusions of iron oxides – ilmenite and hematite.

Prismatic quartz crystals, which were common in the fraction of less than 0.25 mm in the beach sediments of the Danube-Dniester segment, are almost absent in this segment.

Carbonate formations are represented by weakly rolled fragments of calcite crystals and aggregates, fragments of limestone, oolite, detritus, and individual shells (Figs. 11–13). Limestone fragments and detritus are typical for fractions larger than 0.5 mm, and calcite grains in fractions Smaller than 0.25 mm. Calcite oolites are found in fractions of 0.5–1 and 0.25–0.5 mm. Whole and partially destroyed shells of small fauna are common in fractions larger than 1 mm. As a rule, all carbonate formations are coloured in different shades of yellow and brown.

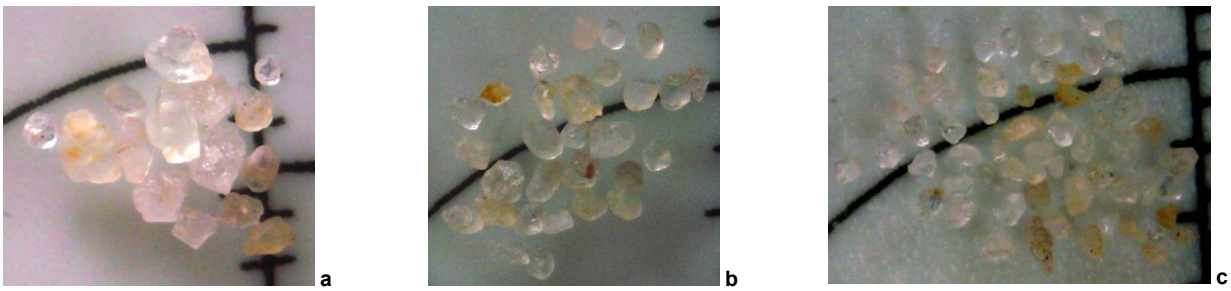

Fig. 10. Morphology of quartz grains:
a – 1–2 mm fraction, b – 0.5-1 mm fraction, c – 0.25–0.5 mm fraction

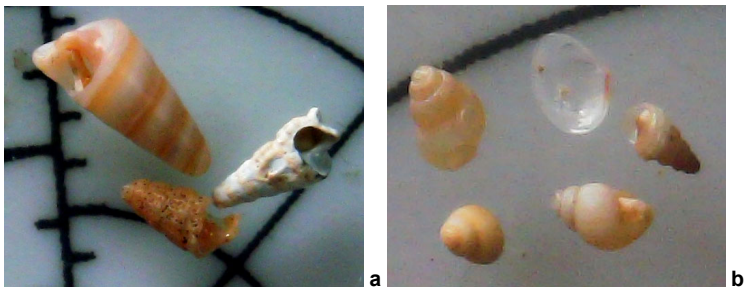

Fig. 11. Whole shells of gastropods and molluscs:
a – fraction 2–3 mm, b – fraction 0.5–1 mm

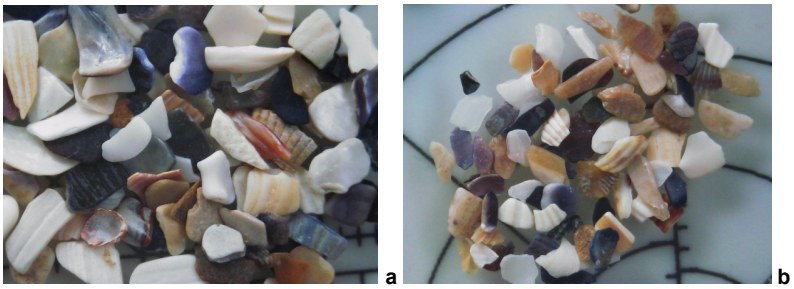

Fig. 12. General view of detritus:
a – 2–3 mm fraction, b – 1–2 mm fraction

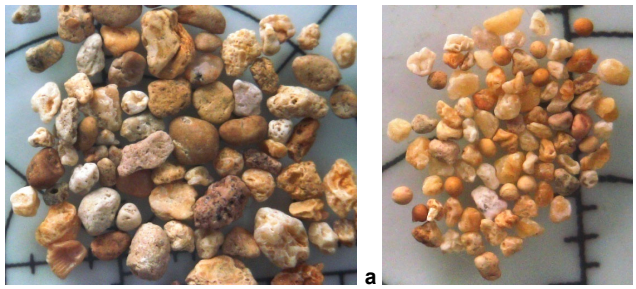

Fig. 13. Carbonate formations (fragments of limestone, calcite crystals, oolites):
a – 2–3 mm fraction, b – 0.5–1 mm fraction

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Secondary and accessory minerals are represented by garnets, ilmenite, mica (phlogopite, muscovite), staurolite, magnetite, glauconite, tourmaline, and feldspars.

Among garnets, almandine and transitional varieties between almandine and spessartine as well as almandine and pyrope have been identified. They are found in fine-grained fractions, but are mostly present in the 0.1–0.25 mm fraction. Almandine grains are more frequent and found in all observation points. They are recorded in minimal quantities within the Odesa agglomeration and are practically absent in places where limestone deposits outcrop into the coastal zone. The garnet grains are semi-coated, corroded, but mostly with a shiny surface (Fig. 14).

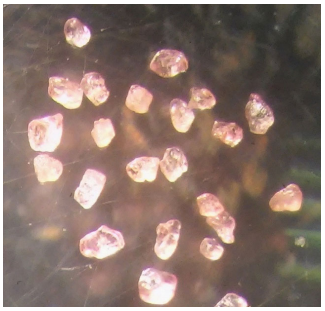

Fig. 14. Almandine grains, fraction 0.1–0.25 mm

Ilmenite occurs in fractions together with garnets and has a correlation with them. However, its content is 2–3 times lower than that of garnets. In the samples, ilmenite is rolled, not transparent with a shiny surface (Fig. 15). The chemical composition of ilmenite is given in Table 1.

Glauconite occurs in all points of observation as single grains of 0.1–0.25 mm fraction. Its aggregates are well rolled, oval and flattened-oval in shape. The colour is light green (Fig. 16). It should be noted that this mineral is absent in the samples of the Danube-Dniester segment.

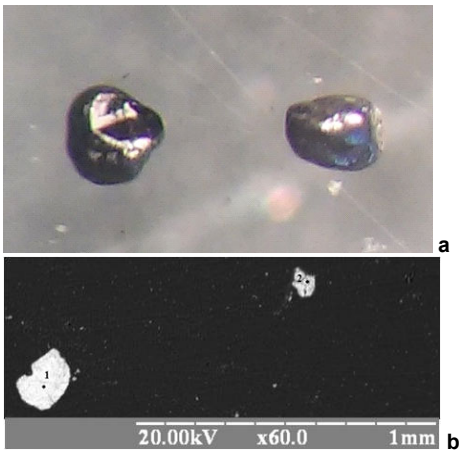

Fig. 15. Ilmenite grains:
a – binocular; b – electron microscope

Table 1

Chemical composition of ilmenite

Sample	TiO_2	V_2O_5	Cr_2O_3	MnO	FeO	Total
1	73.46	0.28	0.41	0.77	25.07	100.00
2	82.60	0.85	0.17	0.13	16.25	100.00

Fig. 16. Glauconite grains, fraction 0.1–0.25 mm

Tourmaline was found in single grains in the Kobleve-Rybakivka beach area (Mykolaiv oblast) in a fraction of less than 0.25 mm. It is a weakly short-prismatic, well-cut crystal with a characteristic vertical hatching on the faces. There are no traces of rolling. The crystals are transparent, green-brown in colour with various shades (Fig. 17). The chemical composition of individual tourmaline crystals varies, but within the limits corresponding to its varieties (Tab. 2).

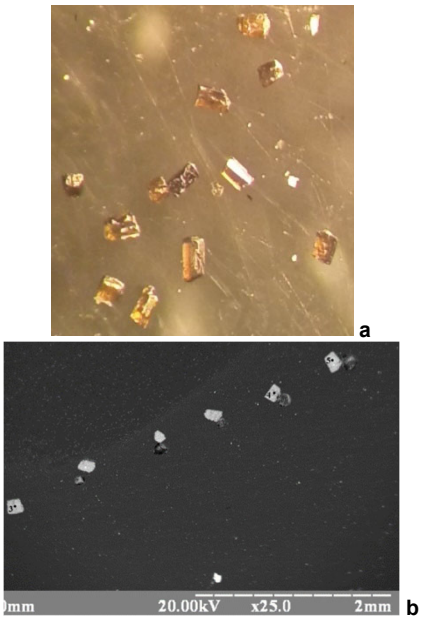

Fig. 17. Tourmaline crystals:
a – binocular, fraction 0.1–0.25 mm; b – electron microscope

Table 2

Chemical composition of tourmaline crystals

Sample	TiO_2	FeO	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	Total
3	1.10	9.76	3.38	9.47	34.36	40.32	0.13	1.48	100.00
4	0.86	7.36	2.59	10.01	37.10	41.04	0.05	0.75	100.00
5	1.30	11.92	3.53	9.08	32.61	41.22	0.06	0.17	100.00
9	1.00	6.87	3.05	11.60	32.76	43.40	0.00	1.16	100.00
11	1.17	15.90	3.04	7.60	31.53	40.04	0.08	0.48	100.00

Mica is represented by muscovite and phlogopite laminae, which occur in fractions of 0.25–0.5 and 0.1–0.25 mm. The highest concentration of mica is observed in the 0.1–0.25 mm fraction. Muscovite is widespread throughout all observation points, while phlogopite is found only from the area of Nova Dofinivka (Big Adzhagilskyi estuary) to Rybakivka village (Berezanskyi estuary). Muscovite laminae are transparent, water-transparent, colourless, rounded and phlogopite laminae are translucent, brown in different shades (Fig. 18).

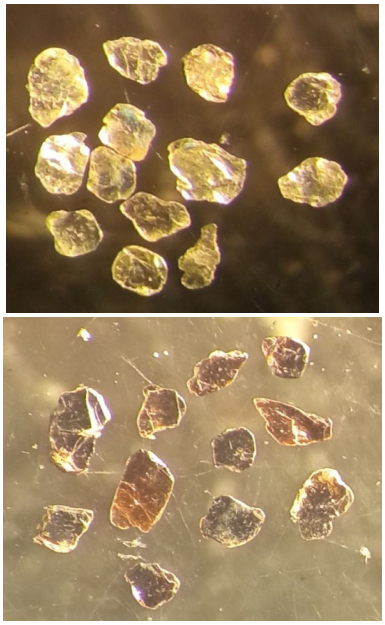

Fig. 18. Mica grains:
a – muscovite; b – phlogopite, 0.25–0.5 mm fraction

Feldspar occurs as rounded, opaque or translucent, more or less prismatic grains of grey-yellow, yellow-brown colour. Its total content is much lower than in the Danube-Dniester sediments and averages about 1.5 % of the total light fraction. Its distribution by size is not regular, but there is still a correlation with quartz, which is concentrated in fractions of less than 0.25 mm.

Staurolite occurs together with garnet and ilmenite in fractions of 0.1–0.25 mm. Its grains are transparent, almost not rolled, and have a yellow-brown colour of various shades (Fig. 19). Some of its grains contain micro-inclusions of ilmenite and magnetite. The chemical composition of staurolite is given in Table 3.

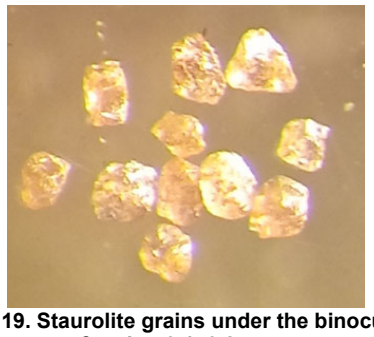

Fig. 19. Staurolite grains under the binocular, fraction 0.1–0.25 mm

Magnetite occurs sporadically in fractions of less than 0.25 mm together with garnets. Its grains have a moderately rolled shape with a rough surface. Some grains have remnants of facets with a shiny surface. The colour is black, resinous black. In contrast to the Danube-Dniester segment magnetite, it has a fresh, non-oxidised character (Fig. 20).

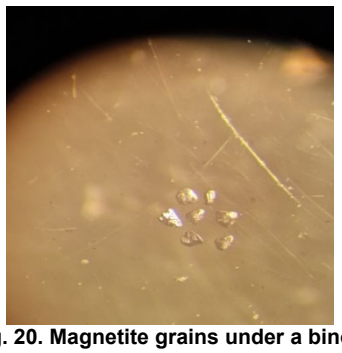

Fig. 20. Magnetite grains under a binocular, fraction 0.1–0.25 mm

Table 3

Chemical composition of staurolite

Sample	Na_2O	MgO	Al_2O_3	SiO_2	TiO_2	FeO	MnO	Total
3	0,42	3,78	50,27	26,73	0,54	17,84	0,41	100
4	0,84	4,29	49,97	26,95	0,6	16,74	0,61	100
5	0,57	3,01	50,92	26,12	0,58	18,35	0,44	100
6	0,63	4,13	50,04	28,06	0,62	16,27	0,24	100
7	0,72	3,69	50,19	26,91	0,73	17,67	0,09	100

Technogenic formations. Technogenic formations are represented by glass, glass balls, iron spheroids, shapeless metal alloys, and slag.

Glass fragments are irregularly shaped, prismatic-elongated, lamellar aggregates and balls (Fig. 21). They come in a wide range of colours: green, brown, black, yellow, blue, etc., and are mostly transparent. Dark-coloured and black ones are translucent and opaque. Their chemical composition is also not homogeneous, and they often exhibit magnetic properties. They contain the following elements in different proportions: Al, Si, Fe, K, Ti, Ca, Na (Tab. 4). The highest concentrations of glass and glass beads are recorded in the beach sediments of the Odesa industrial agglomeration, where they are found mainly in medium- and fine-grained psamites of 0.25–0.5 and 0.1–0.25 mm and make up up to 15 % of their total fractional content.

The iron spheroids are found in fractions of 0.1–0.5 mm. They are of different sizes, spherical in shape with a smooth, shiny and rough surface (Fig. 22). The main component is iron (81.3–96.3 %). The constant impurity components in different proportions are: Si, Al, Mg. Less frequently, Na, Ca, Cu, Zn, Mn are present in them (Tab. 5). Ferrous spheroids in single specimens are present in almost all the samples studied, but their highest concentrations are typical for the beaches of Luzanivka and Odesa agglomeration.

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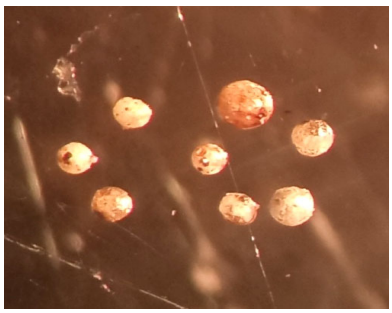
a

b

Fig. 21. Glass fragments of different colours, fraction 0.25–0.5 mm (a); glass beads (b), fraction 0.1–0.25 mm

Table 4

Chemical composition of glass beads

Sample	Na_2O	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	FeO	MgO	Total
1	0,00	18,51	45,13	2,60	1,45	0,83	31,49	0,00	100,00
2	0,31	6,32	84,21	1,69	0,72	0,40	6,34	0,00	100,00
3	0,00	23,84	54,96	3,34	4,04	0,60	13,23	0,00	100,00
4	0,00	52,57	41,51	2,02	0,81	0,68	2,42	0,00	100,00
5	0,00	27,60	55,53	3,59	7,81	0,82	4,65	0,00	100,00
6	0,00	27,78	59,85	4,61	2,71	1,36	3,69	0,00	100,00
7	1,09	16,12	73,38	6,18	0,96	0,66	1,61	0,00	100,00
8	0,00	29,18	54,19	4,52	4,41	1,01	6,68	0,00	100,00
9	0,00	30,31	59,23	4,79	0,14	1,17	4,17	0,00	100,00
10	8,10	22,92	64,71	0,17	3,22	0,27	0,63	0,00	100,00
11	0,00	18,25	68,00	6,33	1,54	0,51	5,37	0,00	100,00
12	0,00	25,64	64,44	5,25	0,20	1,19	3,30	0,00	100,00
18	0,50	27,58	57,73	4,31	7,00	0,00	0,82	2,04	100,00
19	0,00	30,52	56,65	5,94	0,82	0,58	4,25	1,25	100,00
20	0,00	22,42	39,37	0,58	26,36	0,95	8,84	1,47	100,00
21	0,00	14,69	60,19	1,90	7,48	1,41	10,54	3,79	100,00
22	0,00	29,12	54,53	4,78	1,02	1,46	6,63	2,47	100,00

Notes: 1–4 – black opaque; 5–8 – brown translucent; 9–12 – white opaque; 18–22 – colourless transparent.

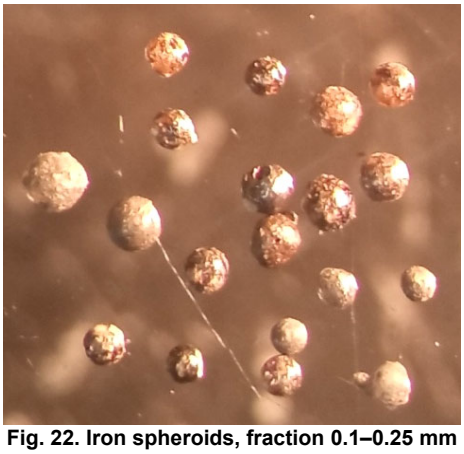


Fig. 22. Iron spheroids, fraction 0.1–0.25 mm

Table 5

Chemical composition of iron spheroids

Sample	Na_2O	MgO	Al_2O_3	SiO_2	TiO_2	MnO	FeO	CaO	Cu_2O	ZnO	Total
1	1,76	0,4	0,33	0,56	2,56	3,11	83,31	0,57	4,29	3,12	100
2	–	0,44	0,26	1,58	–	–	97,73	–	–	–	100
3	–	–	0,61	1,75	1,32	–	96,32	–	–	–	100

Metal alloys. They are metal-like aggregates of acute-angled, lamellar, bizarre shape. Opaque, often covered with a yellow-brown oxidised film on top. On fresh fractures, they have a metallic lustre with a coloured shine (Fig. 23). They have magnetic properties. They were found in all observation points in fractions of 0.25–0.5 and 0.1–0.25 mm, but their highest content is recorded in the area from Chornomorsk to Rybakivka village. Here they make up the medium-grained fraction and reach a concentration of up to 95 %. The chemical composition of these aggregates is given in Table 6.

Slag in single irregularly shaped fragments was found in beach sediments in the area from Odesa to Rybakivka. It is a light porous aggregate, black, black-brown in colour, magnetic. It is concentrated in fractions of 0.25–0.5 and 0.1–0.25 mm.

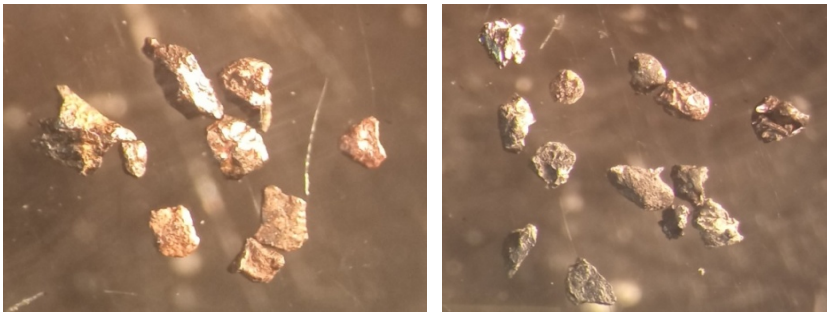


Fig. 23. Metal alloys, fraction 0.25–0.5 mm

Table 6

Chemical composition of iron alloys

Sample	Na_2O	MgO	Al_2O_3	SiO_2	FeO	Total
1	1,4	2,12	5,31	11,62	79,55	100
2	0	0,52	1,6	3,99	93,89	100
3	0	0	0,81	2,77	96,42	100

Conclusions

• Beach sediments in this segment are formed mainly by coastal abrasion. A small part is supplied by benches and longshore transport. Beach sediment material in the Odesa agglomeration area is also replenished by artificial filling. The input of material by river runoff is minimal. The Dniester River, given its direction along the coastal course, discharges on the beaches below the Dniester estuary towards the River Danube, while The Dnipro River discharges into the Dnipro estuary, which is semi-isolated. Smaller rivers such as Serednyi and Velykyi Kuyalnyk and the Tiligul River are completely regulated by estuaries and embankments. The influence of the Berezan River is local.

• The particle size distribution of beach sediments in the study area, unlike the Danube-Dniester segment, is characterised by considerable variability. There are several contrasting areas with a predominance of certain fractions, which is explained by changes in the lithological composition of the shoreline rocks and the peculiarities of sea wave dynamics in local areas. However, in general, there is a gradual increase in the grain size of the material and a decrease in its sorting in the direction from Chornomorsk to Kobleve. The beach sediments of the Odesa agglomeration do not have such a pattern, as they are regularly replenished with artificially produced sandy material from the shelf zone sediments. These sediments are well sorted and dominated by fractions smaller than 0.25 mm.

• The beach sediments of the Dniester-Dnipro segment are generally almost devoid of pelitic fractions. Their content is less than 0.5 %, which indicates a rather active hydrodynamics of the coastal zone. Pelites are washed out of the beach sediments by wave processes and are transported beyond their influence.

• The general trend in the distribution and content of the main rock-forming components of beach sediments in the studied coastal segment, except for the Kryzhanivka-Kobleve area, generally coincides with the Danube-Dniester. The main mineral of the light fraction is quartz, which makes up more than 87%. The heavy fraction includes garnets, ilmenite, magnetite, and staurolite. At the Kryzhanivka-Kobleve area, the main rock-forming mineral of the light fraction is calcite. In the Kobleve-Rybakivka area, tourmaline also appears in the heavy fraction. The occurrence of tourmaline indicates that the material was brought to this site from the land by the Berezan, Pivdennyi Buh and Dnipro rivers.

• In the beach sediments of the Odesa agglomeration, iron spheroids and glass balls of man-made origin are of significant importance in the heavy fraction. The bulk of them is concentrated in the fraction of less than 0.25 mm. Its content gradually decreases to single digits from Odesa towards the Dniester and Dnipro rivers.

• The results obtained can be used to build a genetic model of modern beach sediments and to calculate quantitative indicators of the accumulation of certain mineral components that accumulate on beaches and are transported to other areas of the shelf.

• In general, the content of anthropogenic material in the beach sediments of the studied segment averages 0.1–0.12 % of the total sample weight. However, it increases significantly (up to 0.23 %) in the area of the port of Odesa and adjacent areas.

• The contamination of beach sediments with anthropogenic material, the size of the components of which is much larger than the bulk of the sediments, is significant. This primarily concerns plastic, construction material, wood fragments, metal objects, fabric, etc.

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Віктор НЕСТЕРОВСЬКИЙ, д-р геол. наук, проф.
ORCID ID: 0000-0002-7065-8962
e-mail: v.nesterovski@ukr.net
Київський національний університет імені Тараса Шевченка, Київ, Україна

Михайло ДЕЯК, канд. геол. наук, ст. наук. співроб.
ORCID ID: 0000-0002-9330-2766
e-mail: nayk@ukr.net
ДНУ "МорГеоЕкоЦентр НАН України", Київ, Україна

Андрій ТАРНОВЕЦЬКИЙ, асп.
ORCID ID: 0009-0008-4919-6637
e-mail: youketeroamano22@gmail.com
ДНУ "МорГеоЕкоЦентр НАН України", Київ, Україна

ЛІТОЛОГО-МІНЕРАЛОГІЧНИЙ СКЛАД АКУМУЛЯТИВНО-ПЛЯЖЕВИХ ВІДКЛАДІВ ДНІСТРОВСЬКО-ДНІПРОВСЬКОГО СЕГМЕНТУ ЧОРНОГО МОРЯ

Наведено результати досліджень сучасних пляжевих відкладів північно-західного узбережжя Чорного моря від с. Кароліно-Бугаз (Одеська область) до с. Рибаківка (Миколаївська область). Протяжність берегової зони сягає близько 110 км. Тут здебільшого розвинуті пляжі присхилового типу різної морфології та ширини.

Проведено гранулометричний і мінералогічний аналізи, встановлено основні закономірності літологічного складу і розподілу мінеральних фракцій уздовж усього профілю. Виділяються декілька контрастних ділянок: 1) с. Кароліно-Бугаз – м. Чорноморськ, де суттєво переважає середньозерниста (0,5–0,25 мм) фракція – (67 %). У відкладах цієї ділянки основним мінералом усіх фракцій є кварц (90 %). З важких мінералів домінують гранат, ільменіт, магнетит. 2) м. Чорноморськ – мис Великий Фонтан і Ланжерон (Одеська обл.) – Коблево (Миколаївська обл.) із суттєвим вмістом грубозернистої псамітової (2–1 мм) – 29 % і гравійної (2–5 мм) – 16 % фракцій. Головними мінералами тут у всіх фракціях є кварц та кальцит. 3) мис Великий Фонтан – Ланжерон характеризується мінливим гранулометричним складом, основна маса представлена фракціями 0,25–0,5 мм та 0,25–0,1 мм, які на різних пляжах мають різні співвідношення. Домінує в усіх фракціях кварц, у підпорядкованій кількості є кальцитовий детрит. Важкі мінерали представлені поодинокими зернами гранату, ільменіту, магнетиту, ставроліту. 4) м. Коблево – с. Рибаківка (Миколаївська обл.) зі зростанням вмісту фракцій 0,25–0,1 мм (до 42 %). Основним мінералом усіх фракцій є кварц до 87 %. Другорядним компонентом є кальцитовий детрит. Помітною домішкою у дрібнозернистих фракціях є біотит, мусковіт, турмалін. На деяких пляжах, що розташовані неподалік від морського порту Одеси, у фракціях, менших за 0,5 мм, встановлено численні скляні кулеподібні агрегати різного складу та залізисті сфероїди. У місцях концентрації таких утворень колір пляжевих відкладів стає сірим.

Основним фактором формування мінерального і гранулометричного складу пляжевих відкладів Дністровсько-Дніпровського сегменту узбережжя є берегова абразія. Роль теригенного привносу із суходолу мінімальна і проявляється лише в північній частині (район Березанської затоки). Суттєвий вплив на формування речовинного і фракційного складу оказують періодичні штучні намиви пісків (пляжева зона Одеської агломерації), укріплення схилів бетонними блоками, нагромадженням брил магматичних і метаморфічних порід переважно гранітоїдного складу, хвилерізи та інші споруди, що змінюють напрямок та вплив уздовж берегових течій.

Ключові слова: ***Чорне море, Дністровсько-Дніпровський сегмент, літолого-мінералогічний склад, пляжеві відклади.***

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