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Anthropogenic impact on the shores and the bottom of the Jebriyan bay in the Northwestern part of the Black Sea

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Abstract. The Jebriyan Bay is located in the northern part of the Kiliya Danube Delta, at a junction of the delta cone and the indigenous coast. This is a zone of very high anthropogenic impact on the Danube Biosphere Reserve. The two opposite shores of this bay are fundamentally different. Along the northern shore, the Northwest coastal sand sediment

flows discharge from the Cape of the Great Fontanne to the Jebriyan Bay. That is why the northern coast of the bay is made up of sandy forms of coastal topography (marine accumulative terrace and spit). The southern coast is deltaic; composed of a mixture of muddy, siltstone and sandy sediments. The area of the bay is limited to isobaths –11 m and is about 80 km². The bottom of the bay has a gentle relief, made up of smooth outlines, with an average depth of 6.2 m. The shape of the transverse profile of the underwater slope is mostly convex. The natural system of the bay was affected by fishing, recreation, shipping and industrial sand production on coastal accumulative landforms. Coastal fishing uses a system of fixed bottom seines and small motorized floating equipment. Recreational facilities are designed to serve about 350 thousand people during the warm period each year. The impact of shipping was expressed in the construction and operation of the seaport of Ust-Dunaysk, together with suitable canal and the technical canal between the sea and the branch of the delta breakthrough the system of the large Ochakov branch. The ladle port had an area of about 1.5 km², a maximal depth of 16 m, and an average depth of 13.7 m. The trough was connected to the Ochakov branch of the Danube Delta by a technical canal with a depth of 4 m. Vessels could enter the harbor of Ust-Danube through an access navigation channel with a depth of 11–12 m and a bottom width of 125 m. The port was used for the transshipment of large containers, general forest cargo from ocean vessels (displacement of 60–100 thousand tons) on regular sea lines from the countries of Southeast Asia to the Black Sea, to the Danube and further to the countries of Central Europe and to the ports of the North and the Baltic Seas. But it was unfortunate that the port construction site did not last as expected. Between 1980–2010 the harbor and approach canal of Ust-Dunaysk were filled with Danube river sediments. The example of Jebriyan Bay has shown that when executing any type of sustainable nature management project, it is very important to take into account the natural milieu.

Keywords: Northern Black Sea, Danube Mouth, Jebriyan bay, dynamic, sediment, economy significance.

Вплив антропогенного фактору на берег і дно Жебріянської бухти в північно-західній частині Чорного моря

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Анотація. Жебріянська бухта знаходиться в північній частині Кілійської дельти Дунаю, на стику дельтового конуса і корінного морського берега, в зоні антропогенного впливу Дунайського біосферного заповідника. Два протилежних берега даної бухти докорінно відрізняються. Уздовж північного берега відбувається розвантаження Північно-західного вздовжберегового потоку піщаних наносів, який поширюється від мису Великий Фонтан і до Жебріянської бухти. Тому північний берег бухти представлений піщаними формами берегового рельєфу (морською акумулятивною терасою і кошою). Південний берег є дельтовим, він складається з суміші мулистих, алевритових і піщаних наносів. Площа бухти обмежується ізобатою –11 м і становить близько 80 км². Дно бухти має пологий рельєф, з гладкими контурами, середня глибина 6,2 м, форма поперечного профілю підводного схилу в основному опукла. Природна система бухти підпала під вплив рибальства, рекреації, судноплавства, промислового видобутку піску на берегових акумулятивних формах рельєфу. Прибережний лов риби використовує систему ставних і донних неводів, малі моторні плавучі засоби. Рекреаційне господарство розраховане на обслуговування близько 350 тисяч людей протягом теплого періоду в році. Вплив судноплавства виразилося в будівництві і експлуатації морського порту Усть-Дунайськ, разом з підхідним каналом і технічним каналом між морем і дельтовим рукавом Прорва, в системі великого Очаківського рукава. Портовий ківш мав площу близько 1,5 км², максимальну глибину 16 м, середню 13,7 м. Ківш був з'єднаний з Очаківським рукавом дельти Дунаю технічним каналом, глибиною 4 м. Судна могли заходити в гавань Усть-

Дунайська по підхідному навігаційного каналу з глибинами 11–12 м., шириною по дну 125 м. Порт використовувався для перевалки великих контейнерів, генеральних, лісових вантажів з океанічних суден (водотоннажність 50–90 тисяч тонн) на регулярних лініях з країн Південно-східної Азії на Чорне море, в Дунай і далі в країни Центральної Європи і до портів Північного і Балтійського морів. Місце будівництва порту виявилось вкрай невдалим, і в період 1980–2010 роки гавань і підхідний канал Усть-Дунайська були заповнені дунайськими річковими наносами. Приклад Жебріянської бухти показав, як важливо враховувати природне обґрунтування будь-якого виду раціонального природокористування.

Ключові слова: Північне Причорномор'я, гирло Дунаю, Жебріянська бухта, динаміка, осадові породи, господарське значення.

Introduction.

The Jebryan bay occupies a special geographical place on the northern coast of the Black Sea. Its formation is associated with the development of the Kiliya part of the Danube Delta under the influence of a strong wave-energy with a vector in the south-west direction. During the Holocene era, giant sediments of runoff from the Danube delta led to its rapid extension into the open sea. The demolition of alluvium to the south made the northern part of the delta to form a concavity of the coastline in the form of a small bay at the junction with the indigenous coast of the sea in the Jebriyan section. The southern part of the bay is made up of a delta coast which is composed of sandy-silty and silty deposits washed by the alluvium of the Danube River. It is connected by a canal with one of the largest delta branches – Ochakovsky. Until the mid-90s of the twentieth century, it remained the main shipping port in the Kiliysky branch. Along the northern shores a coastal sandy stream of terrigenous sediment of about 150 km long are deposited. This led to the formation of the sandy embankment of the Sásyk estuary, the accumulative terrace of Volchék and the Jebriyan spit in the Southern part. The Danube silty and terrigenous coastal deposits also fill the bottom of the bay which forms a calm bottom relief with smooth outlines.

The aforementioned features created favourable conditions for vigorous economic activity developed in the bay and on its shores. Fishing remained traditional (Zaitsev *et al.*, 2006) until the end of the twentieth century, 3 large fishing and processing points operated on the shores of the bay with a system of coastal fishing equipments. On the northern shore of the bay the wide sandy beaches on the Volchek terrace began to be massively used for recreational purposes. This gave birth to a sea side resort village in Primorskiy. In 2019 summer there were 123 boarding houses and recreation centres for people with the appropriate infrastructures (rescue station and boat rental, shops, regular transport, pharmacy, bank branch, medical centre, these are just a few of them). Over the past 5 years, about 350 thousand people have been using the recreational services of the Primorsky Recreation Zone. In the southern delta coast of the bay, the Lighter Fleet Base began its work in the southern delta coast of the bay in 1972, and in 1980 the seaport of Ust'-Dunaysk became operational. Floating containers passing through this port to the Danube cargo transported mostly from

the ports of Saigon (Vietnam) and Calcutta (India) to the European countries through the Danube water system on regular navigation routes. A deep suitable canal for ships with a displacement of up to 100 thousand tons was built along the coastal shallow water to the port. In the Danube, containers were carried along the delta branch of the opening which was deep in the 70–80s of the 20th century. It ensured the unhindered passage of Black Sea containers to the Danube right up to the port of Passau (Federal Republic of Deutschland).

Despite this huge economic potential, for several decades now the Jebriyan Bay and its shores have been experiencing high rate of anthropogenic pressures. The natural system is subject to significant stress. It is, therefore, very important to evaluate the natural state of the bay in recent years as shown in the figure 1. Moreover, since 1998 this bay has been included in the zone of traditional permissible anthropogenic activity of the local population. It is also the part of the Danube Biosphere Reserve which requires the sustainable use of natural resources in a fragile natural delta system.

The aim of this manuscript is to identify and study the dynamics and morphological patterns of the Jebriyan bay coasts (northern coast of the Black Sea) in order to minimize the high rate of economic use of natural resources. To achieve this goal, the study set out some basic tasks: a) the physical and geographical conditions for the formation of the bay coast; b) the main features of dynamics of the bay coast; c) the lithodynamic processes in the bay; d) an assessment of the mutual influence of nature in the bay and the economic facilities on the banks and bottom of the bay. This article is prepared basing on the results of the field work carried out in the Jebriyan bay (fig. 1).

Review of previous researches.

Previous researches have shown that within the past decades there have been much concern on the degrading nature of the Danube Delta which is considered to be an economic hub and Europe's largest delta. This study highlights the contribution of some prominent authors by tracing the history of studies already carried out in this Delta. As far back as the ancient times, the Danube Delta remains the economic hub and European largest and most important river transport artery.

Although, in spite of this potential, it is unfortunate, that scientific interest on this delta is usually counted from the middle of the XIX century when scientific

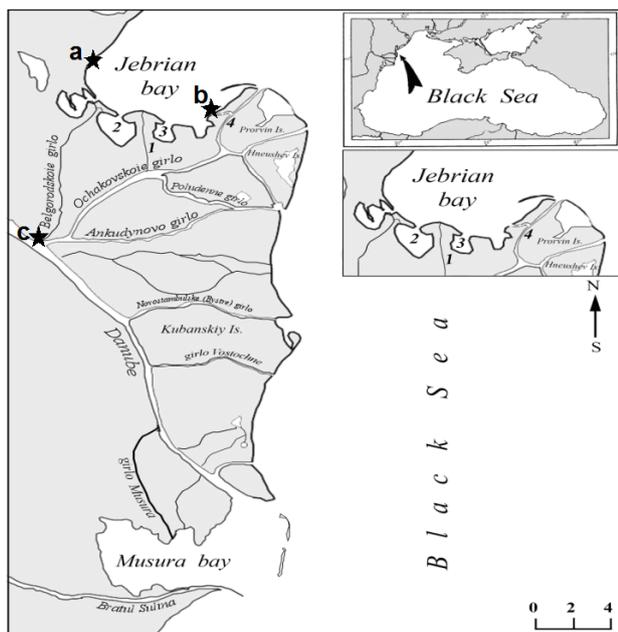


Fig. 1. The location of Jebriyan bay within the boundaries of the Kiliya part of the Danube Delta: A – the arrow indicates the location of the bay; B – the contours of the coast of the bay. Digits: 1 – Belgorodskiy branch; 2 – Soloniy bay; 3 – Polunochniy bay; 4 – Prorva branch. Hydrometeorological Stations: a – Primorske; b – Ust'-Dunaysk; c – Vilkove.

research began with the purpose of developing a permanent shipping line through the Danube Delta to the Black Sea (Nikiforov and Diaconu, 1963). Some detailed research was carried out by the European Danube Commission and the Russian Corps of Railway Engineers as pointed out by Mikhailov & Morozov, 2004. In a similar manner, Lelyavsky, Lishin, Rummel, Chekhovich and a host of other authors were cited in the monograph.

The most famous studies of the Kiliya delta were carried out by the European Danube Commission (1922), the Hydrographic Service of Romania (1930 and 1943), the Hydrographic Service Navy of the USSR (1940, 1956, 1986), the Ukrainian Navy (1998, 2018) and the Danube expedition of the Black Sea Research Institute of the USSR Marine Fleet (1957, 1976, 1989, 2002). In the end of the twentieth century and at the beginning of the twenty-first century, biological and hydrological surveys in the Jebriyan bay were conducted by the Institute of Biology of the South Seas of the National Academy of Sciences of Ukraine and Odessa State Ecological University. A significant amount of research has equally been carried out by Bondar and his staff at the Delta Nature Reserve as cited by Munteianu in 2002.

Zenkovich (1943) was the first to pay a close attention to the nature of the Jebriyan bay. His findings proved that the bay is a facility of close interaction of natural systems in the delta and the adjacent coastal

indigenous systems in accordance with the theory of coastal science (Fig. 1). This phenomenon made it possible to establish finally the processes of the Holocene evolution of the Danube Delta (Petrescu, 1963; Zenkovich, 1958). Its influence led to the emergence and development of the Jebriyan bay. The first research of sediment shore composition were carried out in the early 60s by Shuisky, 1966 and an article specially dedicated to the sediment shore was first published in 1969 by Shuisky. A detailed analysis of the morphology and dynamics was performed in this article with the help of the wind-wave energy flows of sediment distribution. Unfortunately, according to the Romanian researchers (Petrescu, 1963; Gaştescu, 1993) neither the bay, nor its key lithodynamic significance has been given to the adequate attention it deserved from policy makers. The relationship between the structure and dynamics of the entire Danube Delta and its evolution during natural history has been highlighted by (Andrianova *et al.*, 2011; Panin, Jipa, 2002). Researchers also obtained numerical data on the velocities and signs of long-term fluctuations in the Black Sea level over the past century. The coast of the bay is shown in the Fig. 2.

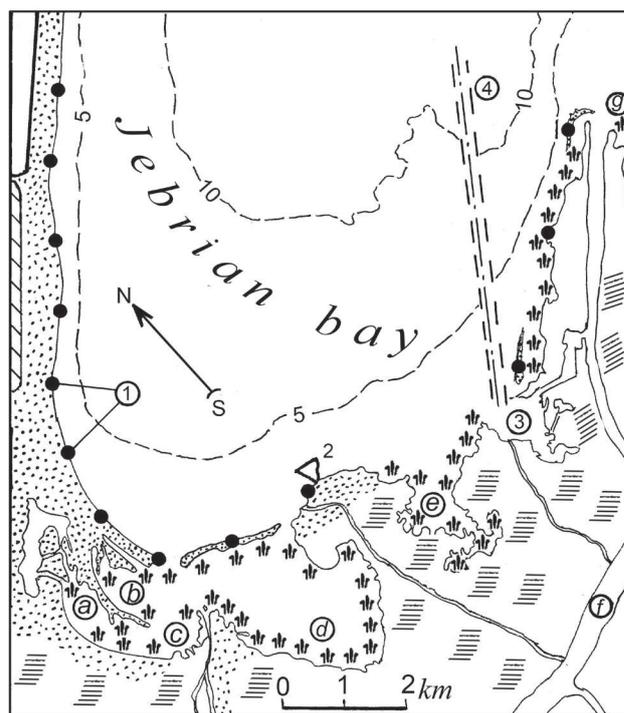


Fig. 2. The structure of the Jebriyan bay as part of the Danube estuary. Secondary "delta bays": a – Durnoy; b – Zebriansky; c – Belgorod; d – Salty; e – Polunochniy; f – Ochakov Branch; g – the mouth of the Prorva. Onshore facilities: 1 – location of coastal surveying and ground tacks; 2 – the average long-term separation point of the lithodynamic section of delta and beach sediments of the root shore; 3 – bucket of the port of Ust'-Dunaysk; 4 – route navigable approach channel; 5 and 10 – isobaths at the bottom of the bay, in meters. North point 1 is still on the Volchek terrace, and the south point is at the root of Jebriyan Spit.

The exploration of the Danube Delta and its environs including the Musura and Jebriyan bays intensified in 2003. The main objective was to create a natural waterway from the Danube to the Black Sea and vice versa. The Institute of River Transport (Kiev), the Institute of Ecological Problems (Kharkov), the Institute of Hydrobiology of the Academy of Sciences of Ukraine, the Institute of Marine Biology of the Academy of Sciences of Ukraine and others participated in these works. Various aspects of the issue were discussed at the 9th scientific conferences under the program “Problems of the Black Sea Ecology”. As a resolution from the conference “The Black Sea – Danube River” waterway along the Bystriy delta branch was chosen as the optimal one. New information was obtained on the morphology and dynamics of the coasts of the Jebriyan Bay and the delta as a whole (Berlinskiy, 2012; Vykhovanets, Organ, 2010; Shuisky, Organ, 2017, 2017a). After several strong storms and intensive elaboration of the shore’s relief and sediment new information regarding the nature of the bay was received from (2007–2019). This made it possible to find and understand the exogenous mechanisms of the formation of the coasts of the Jebriyan bay in particular and the Kiliysky Danube delta as a whole. This made it easier to assess the nature of anthropogenic impact on the natural coast and bottom of the Jebriyan bay.

It is, therefore, evident that many authors have carried out research on the natural coast and bottom of the Jebriyan bay for many years. In this case, a wide range of methods were used by previous authors; like the field work methods of Vykhovanets, 2003; Zenkovich, 1958; Mikhailov, Morozov, 2004; Shuisky, 1969, 1984, 2003 and Gaștescu, 1993. Stationary topographic sections were studied on 13 typical coastal bay sections for repeated Manuel surveys at a scale of 1: 1000; they are shown by large dots in the Figure 2. The length of each section is 500 m. A baseline is fixed along the coast. It is used to capture the coastline and roughness of the coast. Benchmarks are installed at the base of the ground at every 100 m. The shore is leveled and the echo sounder is measured from each reference point towards the sea and at an angle of 90° to the baseline to the depth of 6 m. The bottom samples were taken by the Peterson bottom grab. The authors took the sediment samples of the average width of the beach on the shore, one on each profile. Then, the average value over the entire stationary section was calculated (Shuisky *et al.*, 2017). On the underwater slope, sediment samples were taken on average through each meter of depth. The sediment samples were subjected to water and fractional analysis (*lithological method*) in the Analytical Laboratory of the Department of Physical Geography of Odessa National University (Odessa, Ukraine). Then they were analyzed using mathematical statistics methods.

In order to determine the pattern of sediment distribution along the coast of the Jebriyan Bay, Knaps (1968), developed and verified the natural conditions of the sandy and the pelitic shores of non-tidal seas with the use of *hydrometeorological method*. For decades, this method has been tested in areas of the North-Western part of the Black Sea by comparing the results of the study with different methods. Amongst the methods used were the hydrometeorological, geomorphological and lithological methods. These methods made it possible to identify the direction and intensity of the coastal movement of sediments (Fig. 4). The first calculations according to the observations at the Primorske station were made from 1950–1966 as shown in the Figure 4a and later, for comparisons, during the period of 1984–2016 (Fig. 4 b). Over the past half century, they have shown qualitatively identical result: sediments continue to fill the top of the bay (Vykhovanetz, Organ, 2010). At the same time, at the site of convergence we noticed a shift of sediments east wards, from the distal of the Jebriyan spit to the top of the Polunochny ledge, that is almost 4 km which is approximately 10% of the coastline of the bay, (*analytical method*).

Hundreds of researchers have carried out studies on the Danube Delta, but very few scientific works have attracted the attention of the Jebriyan Bay. The delta has already been fully explored, but as concerns the Jebriyan Bay is very little known. Materials concerning the bay are rare and scarce. There is not enough information about the impact of economic activity on the state of nature of the coast and the bottom of the bay. We hope that this article will improve and deepen our knowledge and understanding of the bay and delta as a whole and will serve as the platform to optimize nature management.

Results and their analysis.

The Jebriyan Bay is located in the northwestern coast of the Black Sea with a continuous extension of the Danube Delta towards the sea. The length of the bay along the center line became wider because of an active filling with sediment from the top of the bay. This filling led to the absorption of the Northwest coastal flow of sand deposits which originated from the northeast near the Cape Big-Fontanne as shown in the Figure 1a, which ignited a new focus on the accumulation of alluvial sediments of delta. The Kiliyskaya part of the Danube Delta was formed in the upper Holocene. Its protrusion created an obstacle for the long shore sediment flow and led to the emergence of the Jebriyan Spit and the Volchek Terrace by adjoining coastal bars to the coast, leading to the formation of a system of rampant storms and dividing the hollows separating them. Over the past decades, they have attained large sizes and represent a new “*grindu*”, which is called Jebriyan *grindu* according to Zenkovich, 1943; Nikiforov &

Diyakonu, 1963. The length of the bay along the center line is about 9 km while the length of the coastline is about 45 km if we take into account the Salt, Jebriyan and Durnoy small delta bays. With such values and an average long-term water level, the bay area does not exceed 80 km². In this area, the maximal depth is 11 m, with an average depth of 6.2 m, and the water volume is about 0.5 km³. Hydrometeorological regime along the shores was studied by current period monitoring in HM-stations “Primorske” and “Ust’-Dunaysk” on the bay-coast (fig. 3), and special geographical literature from (Andrianova *et al.*, 2014; Vykhovanetz, 2003; Il’in, *et al.*, 2012; Panin, Jipa, 2002).

The coasts of the Jebriyan Bay had such coordinates at four points on the coastline: a) the northern point on the adjacent shore of the Sasyk embankment is 45° 32′ 30″ N – 29° 40′ 18″ E; b) the southern point on the Belgorod bar is 45° 28′ 44″ N – 29° 36′ 18″ E; c) the final target of the Delta Channel Prorva is 45° 30′ 45″ N – 29° 45′ 40″ E; d) and the harbor bucket of the seaport of Ust-Dunaysk is 45° 28′ 06″ N – 29° 42′ 18″ E. The difference between the values is small; this confirms the small size of the bay. Coordinates may be needed in the future for comparisons, in order to determine the exact dynamics of the coast and the bottom as shown in the Figure 2. The recreational site in the bay is located in the northern sandy shore, about 8 km long between the middle part of the Sasyk Beach barrier and the distal section of the Jebriyan Spit which is based on the balneological resources of the regions. The medicinal properties of sea water, sand cover of beaches, a mixture of sea and steppe air, local mineral waters, etc. are actively used. Food products are highly valued, in particular, vegetables, fruits, grapes, dairy products, and sea food. The duration of the swimming season is from 130 to 145 days for different years. During fishing, the bottom trawl methods are used often. This leads to disruption of the structure of bottom sediments and the physical destruction of soils, plants and animals. At the same time, the turbidity of the water increases, and this leads to a slowdown in photosynthesis and a decrease in the oxygen content in the water.

The materials we have obtained from the physical and geographical studies of the Jebriyan bay are much more numerous than those presented in the article. This is because we have applied the methods of preliminary selection in accordance with the goals and objectives of the article and used the most significant information necessary for the presentation of the results and conclusions.

The hydrodynamic elements of the near shore waters.

Firstly, we used original datum of direct monitoring on hydrometeorological stations “Ust’-Dunaysk” and “Primorskoye” from current work observation diaries by direct separation. Continuous number of the

observation years were 1984–2015 and near Zmeinyi Island in opened aquathory of the Northern Black Sea (Il’in *et al.*, 2012) (fig. 3). Secondly, for its elaboration was used mathematical and statistics method and hydrometeorological method by R. Knaps [1985], the result shown in the fig. 4.

It is possible to see from the location and contours of the shores of the bay, that its water area is open to the action of winds and wind waves from the N, NE, E and partially the SE, rhombuses (Fig. 2). With the use of a wind rose for the gradation of wind speeds in individual particular points (Fig. 3), the result clearly shows that the coasts are significantly affected by strong and gale winds with speeds of more than 10 m/s. Such winds produce waves with a height of more than 1.5 m depending on the acceleration length and the depth of the water aquatory. At the entrance to the bay, the maximal height of the waves can reach 4–5 m as much as possible, and this leads to a significant abnormal force of the wave flows in different parts of the water area. At the same time, a synoptic wind surge of at least 1.2 m above the ordinary is possible at the top of the bay (Nikiforov and Djakonu, 1963; Mikhailov and Morozov, 2004). Such phenomena lead to the appearance of a surge lens of water, its saturation with suspended sediment, flooding of the low coast, and an increase

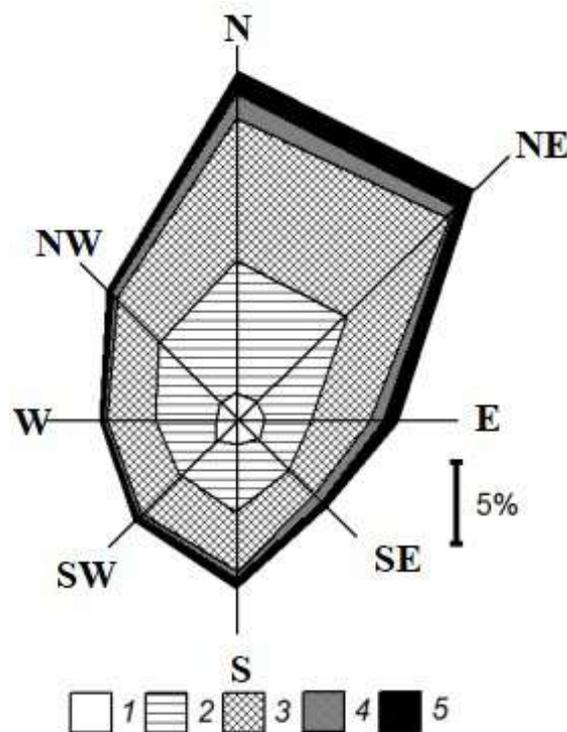


Fig. 3. Wind rose, constructed according to observations in the North-Western Black Sea hydrodistrict from 1923 to 2006. Wind speeds: 1 – ≤ 1 m / s; 2–2–5 m / s; 3–6–10 m / s; 4–11–15 m / s; 5 – ≥ 16 m / s. The circle in the center of the rose is calm, 4.5%.

in the wave effect on it. At this time, the shore most often erodes, but subsequent minor disturbances usually restore the shore. Post-storm water level depletion is accompanied by the removal of a water lens, and its suspended sediment which is usually pelitic fractions. This process can be very powerful, especially with fast denivelation. An injection effect develops, which does not allow sufficient amount of alluvium from Danube to accumulate and fill the Jebriyan bay. Indeed, unusually large sediment with an average size of 204 million tons / year flows from the Danube.

Its main part moves south wards along the sea edge, and only about 6% in suspension might fall into the bay with the corresponding wind directions. However, this quantity is also pumped out by driven currents. There is enough sediment that fills the plains and shallow lakes which lead to the formation of primary accumulative forms, bars and streamers.

The wind regime, the presence of the Jebriyan Bay and the interaction of the Danube and the adjacent part of the sea led to a typical system of currents. The stock stream from the Dnipro and Dniester flows into the northern branch of the Circular current of the Black Sea. On a beam traverse of 15 km from the coast, this branch meets the stream of the Danube runoff. As a result, part of the branch is pressed to the shore and invades the bay, where it takes the form of a clockwise circulation. Such a local Jebriyan circulation is not very stable; its repeatability is about 55%, although it can be up to 85% in some years. Together with the overtaking effect, this circulation prevents strong shallowing and helps to clean the bay from pollutants.

Furthermore, the wind regime, the contours of the coast and depths in the bay led to a high degree of mixing of water and its saturation with oxygen. The mixing of fresh river water and salt water led to the saturation of water with vital substances. All this contributed to a high primary production with a rich forage base. According to hydrobiological and hydrochemical studies (Zaitsev et al., 2006; Mikhailov and Morozov, 2004), the waters of the bay have a high intensity of self-purification. At the same time, the Danube water has a significant influence on the hydrochemical regime of the Jebriyan Bay, which in general is permanently polluted.

The distribution of mass sediment along the shore flow paths is controlled by the wind-wave energy flows (Zenkovich, 1958; Knaps, 1985; Shuisky and Organ, 2017). Taking into consideration the advantage of the natural relationship established between the wind and wave regimes in the sea according to which the dimensions of wind waves become larger, the greater the speed and the duration of the wind, the longer the acceleration of wavelength and the depth of the water area and the lower the viscosity of the water. This connection has a tangential regularity and

makes it possible to calculate the elements of energy triangles (Fig. 4). Integral alongshore nano-motive force T shows the direction of effective sediment movement to the top of the bay along both the northern and the southern coasts (Fig. 4 *A, B*). This means that the accumulation focus has moved to the Belgorod bar, and wave shafts continue to adjoin the Jebriyan spit. The process of coastal buildup in the Volchek and sand spit areas continues, and the reformation of the named bar has intensified. It occurs continuously, intensifying or weakening, under the influence of sediment accumulation from the coastal stream, which begins in the northeast, closed to the Big Fontanne Cape.

The greater the T_{res} , the greater the nanosized ability of the wind-wave energy flow, the greater the amount of sediment that moves along the coast to the accumulation sites in the Jebriyan bay. Along the coastal route, the ability of sediment to constantly change depends on the exposure of the coast with respect to E, the slopes of the underwater slope, the relief of the coastal bottom, the strength of the storm, the shape of energy triangles and the productivity of sediment sources for the coastal zone, etc. Therefore, the change of each component of the coastal zone immediately affects the value of the T_{res} . According to the values of T_{res} , it is possible to see that earlier in the middle of the 20th century (Fig. 4 *A*), sediment freely passed along the Sasyk sandy bar, but actually accumulated on the distal part of the Jebriyan spit. Over the past decade, sediments supply to point T_2 have increased (fig. 4 *B*), to the south on the distal spit. These sediments accumulate and at the same time they increase the size of grindu. The same scheme of the natural process was developed during the Holocene and earlier, when large grindu were formed: Krasnikol, Sereturile, Karaorman, Letia.

The dynamics of the relief and sediments. Based on the results of our field work and stationary studies, the main features of the morphology and dynamics of the coasts of the Jebriyan bay were identified. The shores are generally low; they rise above the ordinary by ≤ 3 m. The southern shore is bordered by low sand and pelitic beaches, peculiar wave shafts that are underlain by sandy-mud strata in the Würm and Holocene ages. As a rule, they are flooded during wind surges. The back side of the coast is overgrown with cattail, a water lily, reed sediment developing everywhere. Mud-silt sediments are actively accumulating inside the delta during floods and strong wind surges. Such conditions are typical for the top of the bay. Wave bars are built up by sediments from the underwater slope, and small bays, which they fence off from the sea, turn into delta lakes. These lakes can be preserved for a long time, but their depth is rarely significant, and most often does not exceed 1 m, hence, it turns into floodplains. Few lakes dry off and their traces are preserved in the form of overgrown clay-silty sections.

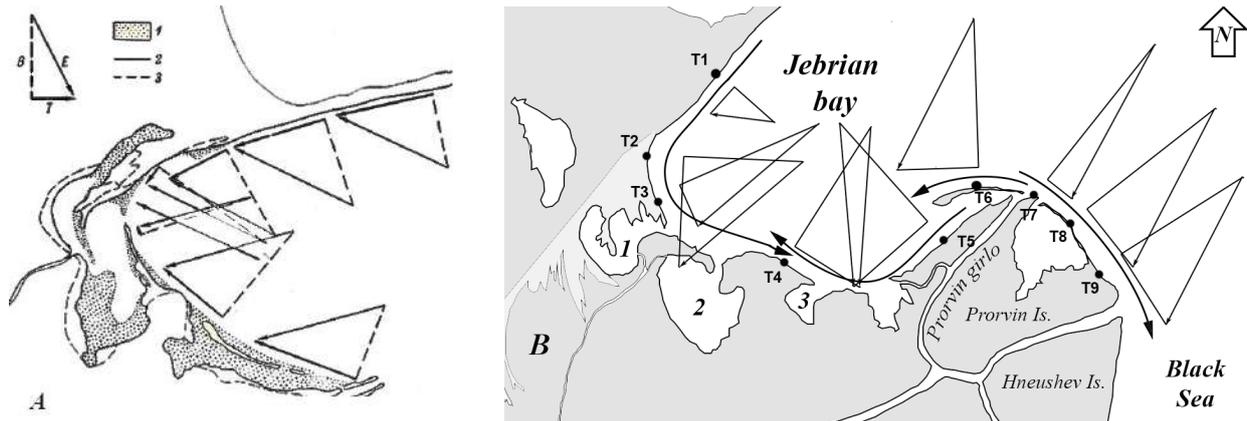


Fig. 4. Wind-Energetic characteristics: *A* – by Yu.D. Shuisky (1969); *B* – average per 1 year by datum for the period of 1984–2016; *E* – wave energy resultant; T_{pes} – alongshore nanomotive force; *B* – a component normal to the coast – “breaking force”; The Deltaic Small Bays (local name is “Kuts”): 1 – Durnoy Kut; 2 – Soloniy Kut; 3 – Polunochniy kut.

The southern coast with its indigenous plot overlooks the sea on a short stretch of about 2.5 km, under the Volchek shore terrace. The extreme part of the Sasyk sandy embankment to the north-east. Its peculiar “continuation” is a sandy terrace adjoining a clay root bank. The Jebriyan spit is to the south-west of it (Fig. 2). All of them form a discharge area of the Northwest alongshore sediment flow. Moreover, the sediments that come to the bay are primarily deposited on the underwater slope (Fig. 5 *A* and *B*). This means that (Fig. 5) during sedimentation drag-fault along the detritus flows and accumulate near the edge. Here they form up to 3–4 submarine shafts that look like a terrace near the sandbank. From the sea, it ends with a dump of depths in the range of 1–4 m and to the bottom of the bay at depths of 4–7 m. During wind waves over the near-sandy terrace, the waves increase the sediment supply to the coastline and the beach.

This phenomenon is continuous, because it is ensured by a continuous flow of sediments from the sandy alongshore sediment flow. Due to the development of wave transformation in the shallow water there is an accelerated formation of submarine shafts which are attached to the coast and influences the growth of the coast and the increase in the width of the beaches.

This is an example of the high dynamics of sand accumulation processes presented for two typical sites: that is in the northern part of the Volchek terrace (Fig. 5 *A*) and in the middle of Jebriyan Bay (Fig. 5 *B*). It shows that shoreline can grow at very significant high speeds which can reach 15 m during a year on the distal section of the Jebriyan spit.

In general, along the northwestern coast, velocities from 2 to 7 m / year are most often found. The average long-term value according to field studies in 9 stationary sites (Fig. 2) was 5.2 m / year during the period of 1982–2019. This trend is clearly traced by the increase in the width of the Volchek sand terrace. Taking into consideration the increment of sediments on the coast

and underwater slope, the average specific accumulation value was 45 m³ / m • year in section *A* and 66 m³ / m • year in section *B*, which is 6.5 km to the south. It is clear that with the advancement from the central part of the Sasyk beach barrier to the Jebriyan Spit distal, the amount of accumulation becomes larger. At the same time, a simple wave sediment deposition is replaced by a massive movement of bottom shafts to the coast and their attachment to the beach. As a result of

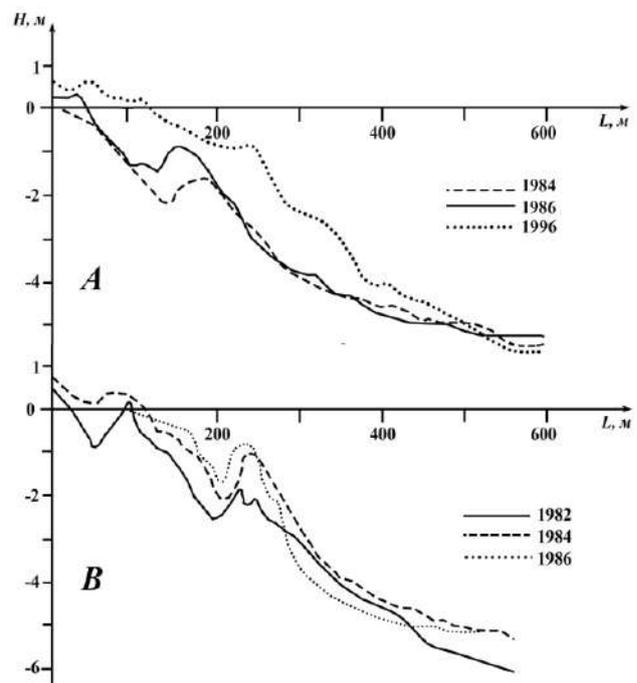


Fig. 5. *A* – Dynamics of submarine slope profiles within the western side of Jebriyan Bay in different dates; *B* – Dynamics of the transverse profile of the beach and the underwater slope in the northwestern part of the Jebriyan bay in the Black Sea coast. Repeated surveys of profiles: *A* – at the northern part of the Volchek terrace in 1984, 1986 and 1996; – In the middle part of the Jebriyan spit in 1982, 1984 and 1986. Height *H* and horizontal layering *L*, in meters.

this, the frontal outer coast of the Jebriyan spit extends towards the sea, and the distal extremity becomes longer, which we consider as the main dynamic feature of the spit. Such phenomena form the values of the slopes of the underwater tilt in the wave energy field. The most common integral slope of the underwater tilt along the central axis of the bay is 0.0011.

With such a slope, the effect of wind waves on the top of the bay is very insignificant. However, at the same time, on the northern (Jebriyan) flank of the bay, slopes range from 0.0143 to 0.0227; and in the southern (pro-Prinian) region, about 0.008–0.010, i.e. 1.5–2.9 times less to a depth of –7 m. This means that the north coast is mainly affected by the wave (bottom stream), and the south coast is mainly affected by the overtaking processes and wave currents. There is a strong overtaking processes at the top of the bay, where today the following delta lakes can be found: Jebriyan Kut, Durnoy Kut, Soleniy Kut, Kut Shábosh. Therefore, using the Jebriyan bay as an example, it is very easy to determine the structure and patterns of formation of sediment discharge areas.

The Beaches and Sediment composition. The beaches of the northwestern coast of the Jebriyan bay took their shapes from the prevailing historical environmental conditions. Their sizes were determined by the wind wave regime action, wave currents and synoptic fluctuations of the sea level with a constant supply of sand deposits from the coastal stream. The usual width of the beach attained about 40–55 m with a height of 1–2 m above the ordinary (Fig. 6, A, B, C). Generally, in a tidal sea condition, it is a fairly large beach, moderate influence of wind waves, a noticeable effect of storm-surges and wind-driven fluctuations in the water level and an abundance of coastal-marine sediments. In addition, an accumulative formation of Aeolian hummocks and rows (Fig. 6, C) takes place from the beginning of the Volchek coastal accumulative terrace and to the south of the distal of the Jebriyan spit. The natural system of the Jebriyan bay is becoming more diverse and requires a particularly careful attitude on the part of human. All sediment datum made by authors during many natural expeditions with direct sampling and elaboration in the Department Laboratory, have decimal enlistment of sieves.

The differences in the structure and development of the southeastern and northwestern shores of the Jebriyan bay gives rise to a different composition of coastal sediments. The removal of the Danube alluvium is accompanied by its hydrogenic separation towards a certain increase in the size of coastal sediments. Concerns to the Danube, since the leading fraction are aleurite and pelitic, ≤ 0.1 mm (Shuisky, Organ, 2017, 2017a), as the authors reported. Its content in pioneer coastal shafts ranges from 79.42% to 91.45%. Although, unlike channel deposits in these forms, there

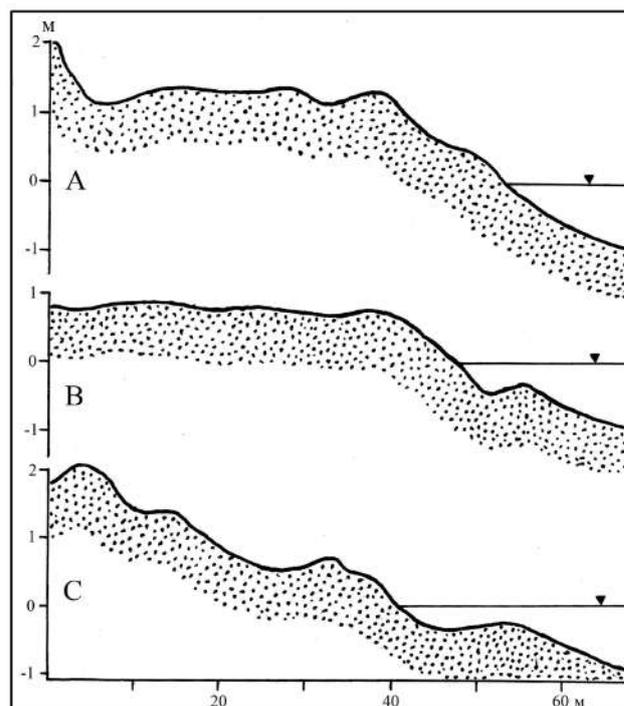


Fig. 6. The different types of transverse profiles of sandy beaches relative to the mean long-term sea level on the northern shore of the Jebriyan bay: A – the southwestern part of the Sasyk liman; B – the central part of the Volchek terrace; C – the middle part of the Jebriyan spit in the area of active accumulation of sediments and the formation of coastal dunes.

is a much larger fraction of 0.1–0.25 mm (from 6.05% to 13.97%). The 0.25–0.5 mm fraction even increased by 2.5 times – from 1.67% to 2.62%. Such indicators of the separation of the river sedimentary materials are typical for the conditions of the delta of a large river flowing into the non-tidal sea and delta coast. The presented ratio of the concentration of fractions remains during the past 50 years of our different observations and measurements in natural conditions.

The study of coastal sediments along the northwestern coast of the Jebriyan Bay showed their significant changes over the same past 50 years. Therefore, on the adjacent part of the Sasyk creek and on the Volchek terrace, the sediments were larger (≥ 10 mm and 7–5 mm) than today, mainly due to the high content of shell and shell detritus (CaCO_3 up to 70%). At the same time, in general, the content of large particles (≥ 1.0 mm) decreased almost 2-fold over the entire northwestern coast of the bay, but along the Sasyk cress, the size of the sediments decreased by 55%. At the same time, on the beaches (Fig. 6 A, B, C), the content of the fraction 0.25–0.5 mm increased from 28.87% to 56.72%. On all sandy form coasts, the amount of the 0.1–0.25 mm fraction decreased from 35% to 22% on average, and the 0.25–0.5 mm fraction remains the leading fraction on the spit and on the terrace, but to the north, on the census Sasyk its amount is 0.1–0.25 mm (up to 57%). All these changes indicate a high

dynamism not only of the topography, but also of the sediment composition in the system of the Jebriyan bay, which is far not always taken into account in the economic practice of nature management. It is necessary to take into account the complexity of the physical and geographical conditions which includes the hydrogenic river and marine, morphological and morphometric, lithogenic and lithodynamical, hydrobiological, in their close genetic and very fast interaction. Original information on beaches and shore sediment was received along the southern deltaic and northern sandy shores of Jebriyan bay within Danube river region.

The Main Impact and Peculiarities of Anthropogenic Activities on the Shores of the Bay

The anthropogenic impact on the nature of the bay. Despite the relatively small size of the Jebriyan bay (Fig. 1, 2), as per its surface area, there are equally centers of significant influence of anthropogenic impact. As it is noted earlier in this article, anthropogenic impacts can be traced from the structures of fisheries, sand production for construction, recreation bases, navigation and most especially the seaport of Ust'-Dunaysk (Fig. 7, 8). These figures are drawn by Yu. Shuisky with the use of the navigation base map with the scale of 1: 50.000. Fisheries structures comprises of three points where fishing boats are

located, rooms for storing and initial processing of fish, warehouses for storing nets, equipment, fuel, rigging, spare parts, and a fisherman's rest house. Fishermen use fixed nets and hooks. These activities do not cause significant harm to the Danube Delta and the shores of the Jebriyan Bay because it is a traditional economy for a small number of indigenous local people.

As postulated by Nikiforov, Diyakonu, 1963; Petrescu, 1963; Shuisky, 1966, 2003, is due to the formation of the "grindu" that large accumulations of sand deposits were created. The new accumulations created the Jebriyan spit, while the old accumulations created the deltaic sand ridge. Moreover, the old ridge of the Jebriyan grindu is used for industrial sand extraction, while it is assigned to the most valuable part of the Danube Biosphere Reserve (according to the conclusions of Ramsar experts). We believe that the active use of grindu sands also violates the European Charter of the ESPOO. Access here by any road transport is free. But modern cars, for the most part, are SUVs and often move along the surface of a rare natural landscape, and, therefore, seriously violate the structure of a unique natural system of various levels of organization. They destroy the protective vegetation cover, intensify the destruction of the Aeolian and coastal-marine relief, and destroy the living conditions of vegetation and

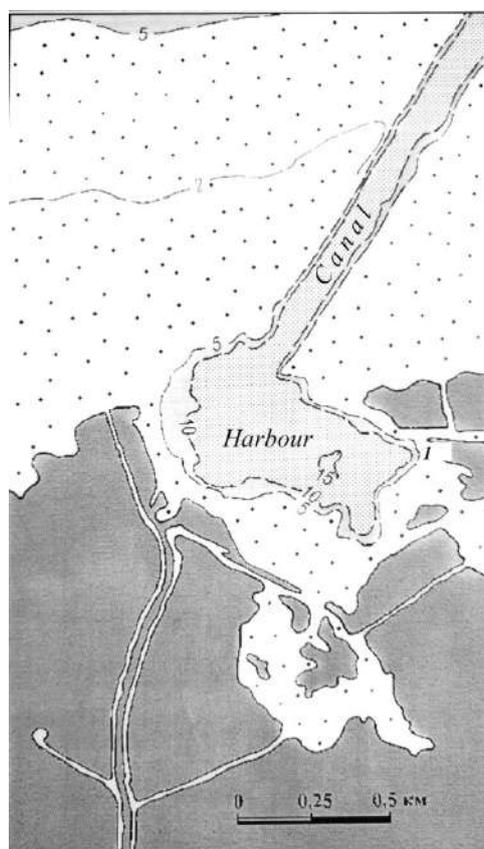


Fig. 7. Scheme of the port harbor of Ust-Danube and the approach channel to it. A dark fill indicates the Danube Delta; 1 – the beginning of the technical channel.

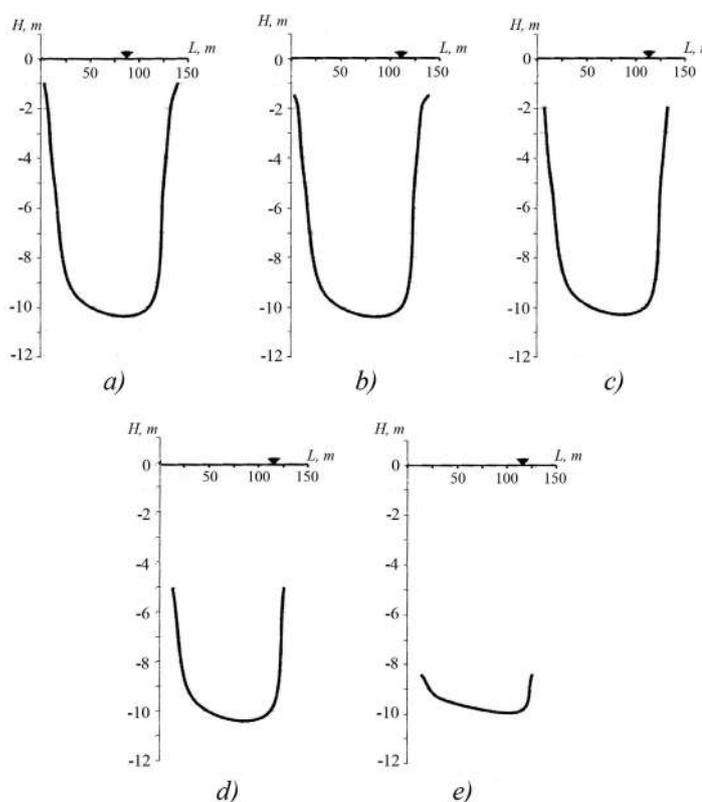


Fig. 8. Curves of transverse profiles on the approach channel of Ust-Danube, located at the bottom of the bay relative to mean sea level.

animals, including those from the Red Book of Europe. The physical and geographical conditions described in this article cannot prevent the negative impact of the anthropogenic factor.

Over the past 25–30 years, a large recreational complex, called Kiliysky was formed on the northwestern coast of the Jebriyan bay. In 2019, 123 large and small recreational facilities were created. In 2017–2019, during each summer, up to 350 thousand people visited it, about 20% of which were on their own off-road vehicles. On the Volchek section, between the residential buildings and the sea, a distance of about 600–800 m is maintained, which is equally tampered by pedestrians on foot or on off-road vehicles. Therefore, the surface of the Volchek terrace is destroyed continuously, and most of the plants and animals died. In addition, our calculations in July 2017, 2018 and 2019 showed that each pedestrian carries along sand with their shoes from the beach, in clothes or in cars in an amount of 5 to 68 grams, an average of 41.6 grams each. Taking into consideration the fact that during 110 days of the swimming season 1 pedestrian takes an average of 4.6 kg of sand from the beach, then the total number of pedestrians estimated at (350 thousand people) directly takes from 1.5% to 3.5% of beach sediments from the terrace and braids (as a). It is important to note that the violation of the structure of the sand surface activates the aeolian removal of sand in the sea or in the floodplains. The size of the surface beach reduces to a much greater extent and slows down the extension of the coastline towards the Jebriyan bay.

The most powerful anthropogenic influence on the the Jebriyan bay shores was the construction of a port. It was caused by the need to build a new port harbor, with a depth of 15 m and an access channel with a depth of 10–12 m. Until late 90s of the XX century, the ships from Ukraine entered the Danube along Bratul (*branch*: in Romanian) Prorva (Fig. 1). However, its considerable channel extension 40–45 years ago led almost to the complete mudding of this Bratul, and it became clear that it was necessary to build a new port and connect it with the deep sleeve of the Danube. Therefore, at first, a technical channel was dug from the deep part of the Breakthrough into the bay and a deep harbor bucket was dug at the exit. This was very sufficient for a large container ship (draft up to 10–11 m). An access navigable canal was built from the bucket in the sea to a depth of 12 m (Fig. 7). Thus, a powerful artificial influence was exerted on the banks and bottom of the Jebriyan Bay which changed the mode of action of the sea waves and wave currents, as well as the movement and accumulation of sediment from the Danube River. As a result of this, the state of plants and animals in the bay, especially benthos were seriously affected. The constant movement of cargo and auxiliary vessels, regular cleansing of the

bottom of the port water area, approach and technical channels from the mass of sediment violates the bottom layer as a living environment for mollusks, arthropods, worms and others, which are food for game animals. Sedimentation work increases the concentration of suspended sediment, which increases the scattering of light in water, reduces the intensity of photosynthesis and the concentration of oxygen in water, and reduces the self-purification of water, especially when water comes from the Danube.

The construction of the port harbor and two channels (technical and approach) created another problem. It includes the storage of mass sediment that is released during excavation. Before designing in the 60–70s of the twentieth century, the researchers predicted that the influence of winds from the northern and northwestern sectors would almost completely carry out the river alluvium from (Prorva) Prorva, (Potapovsky) Potapov and (Gneushev) Gneushev branches to the South towards the southern part of this delta. They did not take into account the long-term changes in the wind regime under the influence of modern climate changes at the end of the 20th century, the frequency of east and south winds (especially storms) over the north-western Black Sea that have increased significantly, in the conditional squares 4, 5, 10, 11 (Andrianova *et al.*, 2014; Il'yin *et al.*, 2012). This led to incorrect long-standing forecasts of the movement of Danube sediments. Calculations of the structure of energy triangles (Fig. 4) showed that about 10% of the alluvium of the Ochakov branch both directly and through the technical channel is carried to the top of the Jebriyan bay.

The consequences of anthropogenic impact.

The presented human actions on the nature of Zhebriyanskaya Bay are characterized by a certain variety. All types of influence, except for transport influence from road and sea transport, are within the permissible limits. Therefore, we made estimates of anthropogenic influence for two reasons.

The sandy natural systems composed of accumulative forms are unique in structure, dynamics, and the ratio between the individual components. These systems are very fragile, able to collapse quickly, but recover very slowly. All over the World they are under protection and are part of national parks and reserves, such as on the coasts of Lietuva, Denmark, the Netherlands, Belgium, and the western shores of France. However, in the north of the Jebriyan bay, sandy beaches are not protected; they are subject to constant violation especially when sand is extracted for construction, during continuous development by road. This activity leads to continuous degradation, loss of landscape diversity, extinction of species from the Red Book of Ukraine and the entire European continent.

Of course, such violations of coastal systems are

seasonal in nature. Since the end of September to the beginning of May, sand forms within the boundaries of the Kiliysk resort zone are partially restored. However, every year they come to a second violation. Based on similar experience on the sandy shores of Latvia, Lithuania and Poland, the aeolian and beach topography is experiencing a reduction of up to 3–5% per year. Only after special protective wooden dams, levees and pavements were arranged that the gradual artificial destruction of the coastal relief forms ceased. It is precisely such ameliorative actions that are also needed on the northwestern shores of the Jebriyan bay of the Black Sea coast.

During the design of the Ust'-Dunaysk port, scientists of Odessa State University named after I.I. Mechnikov (Department of Physical Geography in 1995), led by Prof. Yuriy Shuisky, made a forecast for the port's operating hours. Taking into account the influence of alluvial sediments from the Danube and the mode of their distribution in the Jebriyan Bay, the regularities of the evolution of the Ochakov branch deltaic system, the period of duration of this is port is limited to 25–30 years. Such a short period is caused by the action of extremely dense saturation with river and delta sediments, in which not only artificial, but also natural negative forms of relief are impossible. Even according to research studies of the 60s in the XX century (Shuisky, 1969), including the works of I. Petrescu (1963), the final movement of the Danube sediment along the southeastern coast of the Jebriyan bay towards its peak was clearly established. This trend was confirmed at the beginning of the XXI century (Shuisky, 2003), and also today with the example of Fig 4. However, sufficient funding and powerful dredging equipment in the USSR made it possible to cope with the introduction of negative landforms.

In fact, since the advent of the technical channel, the port bucket and the approach channel, initially for the container terminal in 1972, have started experiencing great difficulties with the insertion of artificial negative landforms (Fig. 7). During the initial period of the creation of artificial negative relief forms, the drift was small, which made it possible to cope with a dredging technique. Although, after the creation of design depths, the fight against alienation became so difficult that it was economically unprofitable. In the USSR, this was not an obstacle, since the issue was political. In the early 90s of the twentieth century, Ukraine abandoned the port of Ust'-Dunaysk, and in order to get out of an unfavorable situation, the port's leadership ordered to extract sand on an ancient grind and sell it to other countries. Nevertheless, by the end of the twentieth century, the excavation was 4.5 million tons / year. All artificial negative landforms, except for the technical channel (Fig. 7, 1), were filled with sediments.

Today and since 2015, the approach channel and

most of the port bucket (depth 4 m) are filled with sediments. The authors used a marine navigational chart with a scale of 1: 25000 and with a bathymetric image of the approach channel. Five typical profiles a – e were chosen with an equidistance of 1 km (Fig. 8). According to the construction of the curves of the transverse profiles, sediment volumes were collected on each segment of the channel. At a distance of 1 km from the port bucket, the excavation was the deepest, and therefore the specific amount of sediment entering it amounted to about 950 thousand m³. In the second 1-km section (Fig. 8, b), 870 thousand m³ of materials have already entered the excavation and in the third segment – about 810 thousand m³, etc. In total, the approach channel was filled with about 4.2 million m³ of sedimentary materials; such is its “sedimentary capacity”. This size of introduction even in the time of the former USSR was not justified from an economic point of view, and even more so during the deliberate destruction of Ukraine's industry and transport. For Ukraine, the port of Ust'-Dunaysk was “too expensive”. The question was raised about the search for another waterway through the Ukrainian part of the Danube Delta. In this difficult struggle, the natural forces of Jebriyan Bay won.

Conclusion.

The creation of a small Jebriyan bay depends on the development of the Kiliya part of the Danube Delta. Today, it is determined by the peculiarities of the location, the influence of the Black Sea, Danube sediments, sediments from the alongshore sediment flow and the underlying delta substrate. Significant anthropogenic impact is expressed in the form of: a) unsystematic creation of a recreational zone; b) incomplete design and construction of the port of Ust-Dunaysk.

According to the structure of the Jebriyan bay, two banks can be clearly distinguished from their dynamics of the waters, their topography and their sediments: a) low, flooded, silty southeast; b) low sand. Their physical and geographical sphere is influenced by a large river that flows into the non-tidal sea. These features determine the types of economic development and the use of natural resources. The main activities include fisheries, the extraction of building sand in the vicinity of the port and the aeolian ridge of the Jebriyan grindu, and recreational activities.

The seaport of Ust-Dunaysk was built to transport river containers from the sea to the ports of the Danube and to load containers from the Danube ports to the sea container ship. Its creation was facilitated by the active influence of many million tons of alluvium, the rapid growth of the size of the Danube Delta and wide coastal shallow water. Although, experts feared its “short life span”, it was still built. After 25 years,

serious difficulties arose to maintain the necessary depths in the harbor and access to the navigation channel. The occupancy of the harbor bucket and the approach channel to the port exceeded the capabilities of Ukraine to ensure a normal navigational situation.

Almost 50 years after the existence of the seaport of Ust'-Dunaysk in the Jebriyan bay, the correctness and reality of forecast made in late 60s, which stated that the port will be sustainable for duration of 25–35 years, became a reality. Approximately 90% of the scientific materials in the article belong to the authors, including the analysis, discussion and results.

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