ISSN 2413-5577, Ecological Safety of Coastal and Shelf Zones of Sea, 2025, No. 4, pp. 6–32.

Original paper

Current State and Dynamics of the Western Crimean Bay-Bars

Yu. N. Goryachkin [1, 2]

[1] *Marine Hydrophysical Institute of RAS, Sevastopol, Russia*

[2] *Shirshov Institute of Oceanology of RAS, Moscow, Russia*

e-mail: yngor@mhi-ras.ru

Abstract

The bay-bars of Crimean salt lakes are unique natural formations of significant recreational value. Since 2015, the bay-bars have undergone intensive development, with construction projects being planned. This paper analyses and characterizes the current state of the bay-bars in Western Crimea and assesses their dynamics over the past 150 years, based on long-term field monitoring data from Marine Hydrophysical Institute of the Russian Academy of Sciences, satellite imagery, cartographic materials, official reports, and published literature. It was revealed that the condition and dynamics of these bay-bars are determined by the aggregate effect of natural and anthropogenic factors. Key natural processes include storm-induced sediment redistribution along the bay-bar and adjacent coastline, sediment transport from the coastal slope into the lakes across the bay-bars, and aeolian processes. Nevertheless, human activity constitutes the dominant forcing factor. Sand mining was widespread across nearly all bay-bar sites, with industrial-scale extraction occurring at Lakes Sasyk-Sivash, Donuzlav, Sakskoye and Kyzyl-Yar. Consequently, the sediment volume of the bay-bars has been severely diminished, with a reduction in both width and height. This has, in turn, increased the vulnerability of structures to storm damage. Additional anthropogenic pressures include artificial breaching of the bars, extensive construction, removal of dunes and vegetation and beach grading. Collectively, these interventions have degraded the natural landscape and led to loss of the lakes' therapeutic qualities. The intensive development, which entails the physical destruction and transformation of the bay-bars, poses a significant threat to the survival of these unique ecosystems and the vital recreational and ecological services they provide. An urgent shift in management strategy, prioritizing conservation and restoration of the bay-bars, is therefore imperative.

Keywords: Black Sea, Western Crimea, bay-bar, coastal dynamic, anthropogenic impact, coastal area

Acknowledgments: The work with remote sensing data and the assessment of the current state of accumulative forms were supported by Russian Science Foundation grant no. 25-17-00104, https://rscf.ru/project/25-17-00104/, and the analysis of the results of long-term monitoring field work and archival reports of the Marine Hydrophysical Institute was carried out as part of the state assignment of MHI RAS no. FNNN-2024-0016.

For citation: Goryachkin, Yu.N., 2025. Current State and Dynamics of the Western Crimean Bay-Bars. *Ecological Safety of Coastal and Shelf Zones of Sea*, (4), pp. 6–32.

Текущее состояние и динамика пересыпей Западного Крыма

Ю. Н. Горячкин [1, 2]

[1] *Морской гидрофизический институт РАН, Севастополь, Россия*

[2] *Институт океанологии им. П.П. Ширшова РАН, Москва, Россия*

e-mail: yngor@mhi-ras.ru

Аннотация

Пересыпи соленых озер Крыма – это уникальные природные объекты, представляющие собой ценный рекреационный ресурс. С 2015 г. началось их интенсивное освоение, разрабатываются проекты застройки. В статье на основе материалов многолетних мониторинговых полевых работ Морского гидрофизического института РАН, спутниковых снимков, картографических материалов, ведомственных отчетов и литературных источников проанализировано и охарактеризовано современное состояние пересыпей Западного Крыма и дана оценка их динамике за последние 150 лет. Установлено, что состояние и динамика пересыпей Западного Крыма определяются совместным влиянием природных и антропогенных факторов. К природным относятся перераспределение наносов между отдельными участками пересыпи и соседними участками берега при штормовом волнении, перенос наносов с берегового склона в озера через пересыпи и эоловые процессы. Однако доминирующую роль играет антропогенное воздействие. Почти повсеместно на пересыпях добывали песок. В промышленных масштабах отбор проводился на пересыпях озер Сасык-Сиваш, Донузлав, Сакского, Кызыл-Яр. Как результат, объем пересыпей значительно сократился: уменьшилась их ширина и высота, что повысило уязвимость строений на них при штормовом воздействии. Отмечены и другие виды антропогенного воздействия: прорытие пересыпей, капитальное строительство, уничтожение дюн и растительности, планировка пляжей, приведшие к деградации естественных ландшафтов и утрате озерами лечебных свойств. Интенсивное освоение пересыпей, сопровождающееся их физическим уничтожением и трансформацией, создает реальную угрозу для сохранения этих уникальных природных объектов, выполняющих важные рекреационные и экологические функции. Необходим пересмотр подходов к их хозяйственному использованию в сторону сохранения и восстановления.

Ключевые слова: Черное море, Западный Крым, пересыпь, динамика берегов, антропогенное воздействие, береговая зона

Благодарности: работа с данными дистанционного зондирования и оценка современного состояния аккумулятивных форм выполнены за счет гранта Российского научного фонда № 25-17-00104, https://rscf.ru/project/25-17-00104/, анализ результатов многолетних мониторинговых полевых работ и архивных отчетов Морского гидрофизического института выполнен в рамках государственного задания ФГБУН ФИЦ МГИ FNNN-2024-0016.

Для цитирования: *Горячкин Ю. Н.* Текущее состояние и динамика пересыпей Западного Крыма // Экологическая безопасность прибрежной и шельфовой зон моря. 2025. № 4. С. 6–32. EDN AOIMLM.

Introduction

According to generally accepted terminology, a bay-bar is a strip of land formed by sediment accumulation, which separates a lagoon or bay entrance from the open sea. Bay-bars are formed by wave action and wave-driven currents resulting from longshore or cross-shore sediment transport. They are composed of sand, gravel, pebbles or shells [1), 2)]. Morphologically, bay-bars belong to the closing coastal landforms, which are of the accumulative and barrier-type variety [3)]. A coastal bar is what they are genetically. During its growth, an accumulative spit can attach its distal end to the opposite shore of the bay, transforming into a bay-bar. More complex bay-bars also exist, consisting of several systems of coastal ridges of different ages which can include relics of former lagoons. Such bay-bars are typical of Western Crimea.

While accumulative beaches are subject to considerable variability, bay-bars are a relatively stable component of coastal dynamics. Only during rare, extreme storms can waves overtop narrow bay-bars, transferring sediments from the seaward side to the lake side and forming washover channels which are, however, rapidly filled in again [1, 2]. Bay-bars of various lithological compositions, like other large accumulative landforms, shape the typical landscapes of the north-western Black Sea coast, including Western Crimea. These accumulative forms are a result of the Quaternary history of the Black Sea, during which tectonic movements and changes in sea level formed the shallow shelf in the north-west of the sea. The most distinctive features of the Black Sea coastline are lagoons, formed when the lower reaches of gullies and river valleys flooded. Most coastal depressions are currently separated from the open sea by continuous bay-bars formed by sediment transport.

In Western Crimea, bay-bars are typical of the North-Western, Tarkhankut and Evpatoriya sectors [3]. In the North-Western sector, they occupy ~ 10 km of the coastline; in the Tarkhankut sector, they are localised to three bays; and in the Evpatoriya sector, they account for around half of the entire 42 km coastline (Fig. 1).

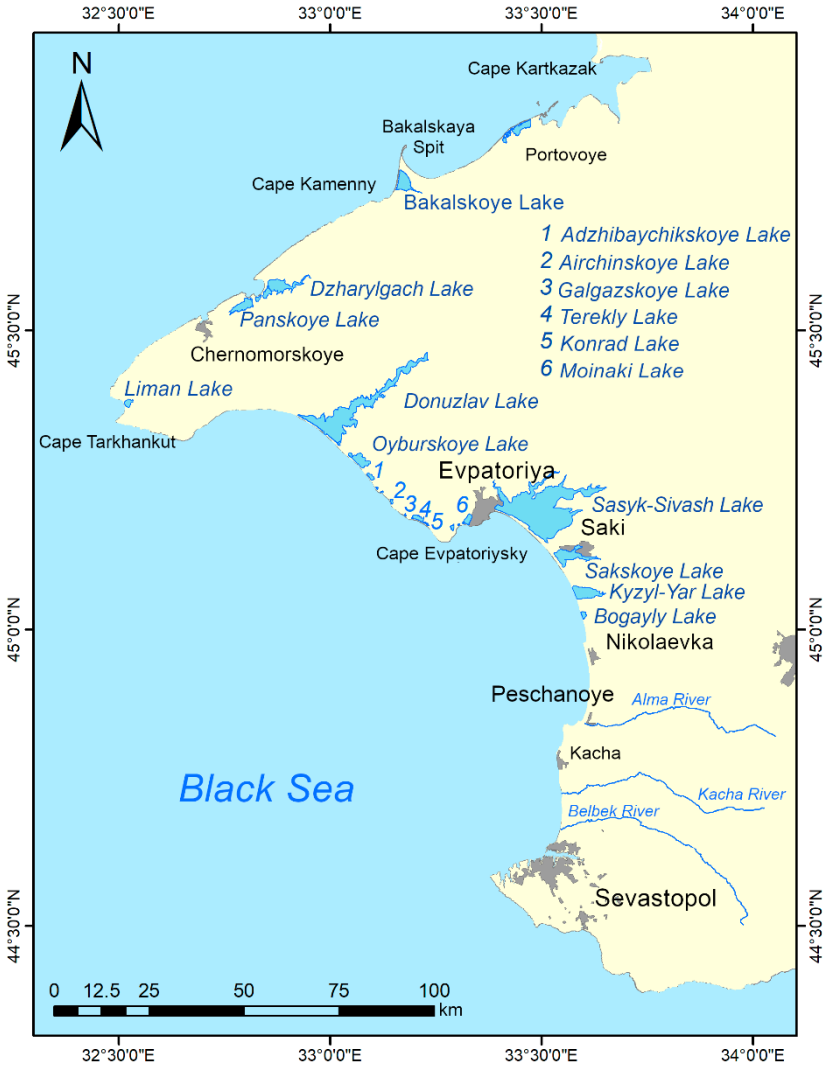
Just a century ago, the study of marine-origin bay-bars was considered important from both scientific and practical perspectives, since their formation was associated with the genesis of valuable minerals such as salt, therapeutic muds and construction materials like gravel, sand and silt [4]. Understanding the formation and structure of bay-bars was also emphasised as important for beach management and grading, afforestation, dune stabilisation, road construction, creating marine canals,

---

1) Zenkovich, V.P. and Popov, B.A., eds., 1980. [*Marine Geomorphology. Terminology Reference Book. Coastal Zone: Processes, Concepts, Definitions*]. Moscow: Mysl, 280 p. (in Russian).

2) Akhromeev, V.N., 2002. [*Geomorphological Reference Dictionary*]. Bryansk: Izdatelstvo BGU, 320 p. (in Russian).

3) Zenkovich, V.P., 1960. [*Morphology and Dynamics of the Soviet Black Sea Coast, Vol. I*]. Moscow: AS USSR Publ., 187 p. (in Russian).



F i g . 1 . Major salt lakes of Western Crimea and their bay-bars

and constructing structures [4]. Study [4)] states that, in the 1920s and 1930s, sand mining was carried out directly on the beaches of bay-bars and in river channels in Crimea where the reserves of this material were considered inexhaustible.

Currently, bay-bars are primarily regarded as valuable recreational resources. These unique natural formations support biodiversity and play an important role in coastal ecosystems. Much of the coastline of Western Crimea still consists of wide, sandy beaches that are ideal for recreation. However, they have been subjected to

[4)] Pavlov, I.S., ed., 1932. [*Reference Book for Construction Materials Industry. Iss. 1. Ukraine and Crimea*]. Moscow, 119 p. (in Russian).

intensive development over the past decade. Construction projects are underway or planned on the bay-bars of lakes Bakalskoye and Karadzha. Plans have been made to build a new city with a population of around 30,000 people on the bay-bars of several lakes between the villages of Shtormovoye and Zaozernoye. The large-scale project "Golden Sands of Russia" is being actively developed and promoted. This involves extensive construction on the bay-bar of Lake Sasyk-Sivash with the aim of accommodating around one million tourists per year. Construction on the bay-bar of Lake Sakskoye is almost complete. Insufficient understanding of coastal dynamics by project developers can lead to unjustified decisions. Such decisions are already having a negative impact on the environment and carry the risk of unnecessary financial costs [5].

The earliest references to the bay-bars in salt lakes, including those in Western Crimea, appear in works primarily devoted to salt lakes and salt extraction [5), 6), 7)]. These studies are valuable because they describe the characteristics of the bay-bars as they were in the last quarter of the 19th century. The first studies to focus specifically on the origin and structure of the Crimean bay-bars were published in the early 1930s by the renowned Soviet geologist A. I. Dzens-Litovsky [4), 8)] [6]. These publications were the outcome of expeditions conducted as part of an extensive study of the hydrogeological features of Crimean salt lakes, undertaken by the Institute of Hydrogeology and Engineering Geology of the All-Union Geological Survey.

The next stage in the study of Crimean bay-bars is associated with V. P. Zenkovich, the founder of Soviet coastal geomorphology. In his generalising monograph [3)], he used the Northern Black Sea region as an example to explain the formation and development of accumulative landforms, including bay-bars. The regional volume of monograph [9)] contains specific data on the bay-bars of Western Crimea, reflecting their state in the late 1940s. More recent information on certain bay-bars from the late 20th century is presented in the works of Yu. D. Shuisky [7–9]. Notable recent studies of the bay-bars of Western Crimea include [1, 2, 10–12].

This study aims to characterise the current state of the bay-bars in Western Crimea and assess their dynamics over the past 150 years. This will be achieved by analysing satellite imagery, cartographic materials and archival data.

---

5) Pershke, L., 1882. [*Salt Lakes of the Northern Black Sea Coast and the Basis for their Rational Development*]. Saint Petersburg: Tipografiya i Khromolitografiya A. Transhelya, 89 p. (in Russian).

6) Mushketov, I.V., 1895. [A Note on the Origin of the Crimean Salt Lakes]. *Gorny Zhurnal*, 2(6), pp. 344–393 (in Russian).

7) Konrady, A.V., 1896. [*Saki Salt Industry of Master of the Hunt I. P. Balashev in Crimea*]. Saint Petersburg: Tip. Trenke i Fyusno, 31 p. (in Russian).

8) Dzens-Litovsky, A.I., Pastak, A.I. and Meyer, R.F., 1934. [*The Resort of Saki and its Suburbs*]. Moscow: Fizkultura i Turizm, 78 p. (in Russian).

9) Zenkovich, V.P., 1960. [*Morphology and Dynamics of the Soviet Black Sea Coast, Vol. 2*]. Moscow: AS USSR Publ., 216 p. (in Russian).

Materials and methods

This study is based on long-term field monitoring data from Marine Hydrophysical Institute of the Russian Academy of Sciences (MHI RAS), as well as satellite imagery, cartographic materials, official reports and published literature. The electronic archive of coastal photographs of the Crimean Peninsula, created at the MHI RAS, was also used. General geographical and cartographic methods were employed, as well as analysis of satellite imagery of the Earth's surface.

Results and discussion

North-Western sector

The sector extends 105 km from the northern border of Crimea to Cape Kamennyy, to the west of the Bakalskaya Spit. The coastline is formed by Quaternary marine and continental deposits, comprising both abrasive and accumulative segments. Some capes and protrusions have eastward-oriented spits, while small attached terraces are found on the side facing away from them. Accumulative landforms have primarily been created as a result of the longshore transport of sand and shell material from west to east. The sector is characterised by sustained land subsidence, as evidenced by drowned ravine mouths, lagoons, and silty deposits in the nearshore zone. According to map [10)] dated 1941, spits in the stage of attachment and bay-bar formation existed in the northern part of the sector at that time. These features currently appear as bay-bars; the area has undergone anthropogenic transformation, with former lakes and lagoons being converted into rice paddies and fish-breeding ponds. Only one segment remains: a complexly configured bay-bar, ~ 1.5 km long, located 2 km north of Cape Kartkazak. Map [10)] dated 1941 shows this bay-bar as a spit in the stage of attachment.

To the southwest of the Lebyazhyi Islands, the coast is low-lying and accumulative, of lagoon type. These accumulative landforms are predominantly composed of whole and fragmented shell material. This coastal segment is characterized by both cross-shore and longshore (northeastward) transport of detrital-shell sediments. The most notable recent event in this area is the formation of a new bay-bar. Historical maps dating back to 1817 clearly show the progressive separation of small lagoons, formation of bar-bays, an increase in the number of Kondzhalayskie islets and the growth of the Sergeevskaya Spit. This spit eventually transformed a marine bay into the Andreevsky Lagoon [11), 12), 13), 14), 15), 16)] (Fig. 2).

[10)] RKKA, 1941. *Northern Crimea*, 1:25000. Moscow: Generalny Shtab RKKA.

[11)] Mukhin, S.A., 1817. *Ordnance Topographic Map of the Crimean Peninsula*, 1:168000. Saint Petersburg: Voenno-Topograficheskoe Depo.

[12)] Kozlovsky, A.N., 1842. *Topographic Map of the Crimean Peninsula*, 1:210000. Saint Petersburg: Voenno-Topograficheskoe Depo.

[13)] VTD, 1865–1876. *Map of Taurida Governorate*, 1:126000. Saint Petersburg: Voenno-Topograficheskoe Depo.

[14)] KSU, 1922. *Map of Crimea*, 1:420000. Krymskoe Statisticheskoe Upravlenie.

[15)] RKKA, 1938. *Map by General Staff of RKKA*, 1:50000, L-36-5234.

F i g . 2 . Andreevsky Lagoon and Sergeevskaya Spit (bay-bar) on a map of 1842 [12] (*top*) and a satellite image (July 2024) (*bottom*)

The growth of the Sergeevskaya Spit was particularly significant during the last two decades of the 20th century. During this period, a new spit, the Zapovednaya Spit, began to grow from the village of Portovoye towards the Lebyazhyi Islands. It is currently attaching itself to one of the islands.

In 1989, the Andreevsky Lagoon had not yet been completely separated from the sea [16]. According to [13], the breach was still ~ 15 m wide in 1998.

The 2006 map shows a fully formed bay-bar [17]. However, analysis of satellite imagery revealed that breaches periodically appeared in the bay-bar until 2017. Since 2018, such breaches have not been recorded (Fig. 2). The current length of the Sergeevskaya Bay-Bar is ~ 10 km, with a width ranging from 5 to 80 m. Its narrowest section is in the east.

---

[16] General Staff, 1993. *Map by General Staff of Armed Forces of the USSR, State of the Territory as of 1989*, 1:100000, L-36-79.

[17] Soyuzkarta, 2006. *Topographic Guide Map of Crimea*, 1:50 000. Simferopol: NPP Soyuzkarta.

Fig. 3. Disappeared villages of Sergeevka and Andreevka on the map [18)]

It is also important to note that the coastline is retreating at a rate of up to 3 m per year, according to work [13]. The former village of Sergeevka, located 15 km northeast of the present-day village of Steregushcheye, has consequently been completely submerged. Although the sea engulfed it at the end of the 1940s, it was still shown on the shoreline on map [18)] (Fig. 3). In the 1980s, the village of Andreevka, situated on the spit separating the lagoon from the sea, was also submerged (Fig. 2). Indeed, modern toponyms such as Andreevsky Lagoon and Sergeevskaya Bay-Bar originate from the names of these vanished settlements. The coastal dynamics of this area are examined in greater detail in [3, 14].

Tarkhankut sector

The Tarkhankut sector extends 138 km from Cape Kamennyy to Lake Donuzlav. Tectonically, it corresponds to the Tarkhankut Rise, which is a raised area dissected by a network of ravines. The largest of these ravines form the wide bays of Yarylgachskaya, Uzkaya (also known as Ak-Mechetskaya) and Karadzhinskaya. Large accumulative landforms known as bay-bars separate the salt lakes in the heads of these ravines. Smaller ravines create concavities along the coastline, in which minor bay-bars also develop. Behind these are topographic depressions. Most of the coastline consists of cliffs formed by abrasion, with Sarmatian and Pontian limestones and clays predominantly exposed. Beaches are formed from abrasion material in coastal concavities and bays, which act as natural sediment traps. More detailed information on the coasts of the sector is presented in work [3] and monograph [9)].

[18)] Ministry of Defense of the USSR, 1947. [*Atlas of Black Sea Soils*]. Ministerstvo Oborony SSSR, 30 p. (in Russian).

Yarylgachskaya Bay has the most complex configuration of marine accumulative landforms, with a shoreline length of ~ 9 km. Here, a sandy bay-bar separates three salt lakes, Dzharylgach, Yarylgach (Karlav) and Panskoye (Sasyk), and the Karlav Lagoon (Maloye Solenoye) from the sea (Fig. 4).

The Dzharylgach and Yarylgach lakes, as well as the Karlav Lagoon, are separated from the sea by a wide, curved bay-bar reaching up to 600 m in width near Lake Dzharylgach and 150 m near the lagoon. The village of Mezhvodnoye (formerly Yarylgach) is located in the northern part of the bay-bar. Lakes Yarylgach and Dzharylgach are divided by a narrow (10–15 m wide) secondary bay-bar, which was reinforced when a road was constructed across it. Secondary accumulative features (spits and bay-bars) are attached to both bay-bars. The Karlav Lagoon still has a connection to the bay through a wide (~ 150 m), though shallow, breach.

According to radiocarbon dating, a marine bay existed at the site of present-day Lake Dzharylgach 5000–5400 years ago, with free water exchange with the sea. Later, during the Black Sea transgression and intensification of abrasion processes, a lagoon formed. The lagoon connection with the sea became increasingly restricted, finally becoming completely separated ~ 4600 years ago [15].

Lake Panskoye, known as Sasyk until the 1940s, lies in the western part of Yarylgachskaya Bay. In 1978, an artificial breach 130 m wide was cut through the bay-bar, dividing the bay into two parts. Between 1979 and 1991, the new port of Chernomorskoye was built on the northern shore of the lake with a quay line extending 1 km. Two concrete groynes (75 m and 150 m long) were constructed at either end of the breach to minimise siltation in the fairway. Consequently, the brine and therapeutic muds of the lake underwent desalination (from 100% to 18%), resulting in the loss of their therapeutic properties. In effect, Lake Panskoye has been transformed into a man-made technogenic bay.

The Yarylgach Bay-Bar is predominantly composed of fine- to medium-grained sands (0.25–0.5 mm), which account for 70–90% of its mass. It also contains admixtures of fragmented and whole shell material (10–30%), as well as oolitic limestone grains. According to drilling data, the vertical thickness of the sands ranges from 3 to 7 m [16]. Coarser sediments are found in the north-eastern part of

Fig. 4. Yarylgachskaya Bay. The numbers denote salt lakes: Panskoye (*1*), Karlav Lagoon (*2*), Yarylgach (*3*) and Dzharylgach (*4*)

the bay-bar, which is most exposed to wave action. In some places, dunes are preserved but they are subject to displacement, particularly in areas without vegetation.

The beach width reaches 40–60 m in the northern part, decreasing to 20 m in the south. A significant portion of the beach is occupied by an oil storage facility and other structures. As it was noted in [9], the volume of sand far exceeds what could have been produced by the erosion of local rocks or the remains of organisms that have lived here. Therefore, it is most probable that the sand was delivered from the open sea during severe storms.

A comparative analysis of cartographic materials from various historical periods, alongside modern satellite imagery, reveals that the configuration of four primary salt lakes has undergone minimal change. According to satellite imagery, the shoreline has remained relatively stable, shifting by 2–5 m depending on the season and severe storm activity. The accumulation of sediment against the eastern groyne of Lake Panskoye suggests that predominant longshore sediment transport in the bay occurs in a clockwise direction. Unfortunately, traces of illegal sand mining are still periodically observed on the bay-bar, which has currently been significantly altered due to defensive works carried out as part of the Special Military Operation.

Uzkaya Bay (also known as Ak-Mechetskaya Bay) is located 10 km southwest of Yarylgachskaya Bay. It was formed by the confluence of two large, wide ravines. From the south, the bay could formerly be approached via a flat interfluve area but this is now densely built up. To the east of this development lies salt Lake Ak-Mechetskoye, which often dries out completely. Over the past decade, the lake has progressively been filled in to make way for residential construction projects. The entire low-lying coastal area is bordered by a 1 km long, 20–50 m wide strip of sandy beach. This beach consists of light grey, medium- to coarse-grained sand containing detritus, whole shells and limestone fragments. According to satellite imagery, the eastern part of the beach eroded by 10–15 m between 2009 and 2018. Immediately behind the entrance cape on the western side of the bay lies small salt Lake Mayakskoye, which is separated from the bay by a sand-and-shingle bay-bar. Unlike Yarylgachskaya Bay, there is probably low-intensity, near-bottom sediment flow along the open coast of Uzkaya Bay, which replenishes the sediment volume [9]. The ruins of the ancient settlement of Kalos Limen, which are located close to the water edge, demonstrate clearly the gradual retreat of the shoreline from ancient times until now.

Karadzhinskaya Bay is located at the westernmost tip of the Crimean Peninsula, between Cape Tarkhankut and Cape Priboynyy (also known as Kara-Mrun). The bay extends inland as salt Lake Liman (Karadzha), which has a wide ravine that extends several kilometres into the land. The southwestern part of the lake is divided by two secondary bay-bars (10–60 m wide), creating small lakes Bolshoy Kipchak and Maly Kipchak, which dry out in summer (Fig. 5). The main bay-bar is ~ 2 km long and up to 200 m wide. Breaches occasionally form in it after severe storms. The width of the bay-bars is highly dependent on the water level of the lakes.

The bay-bar is composed of shell-oolitic sands and gravel sized between 10 and 50 mm. Fractions sized 0.1–1.0 mm (up to 95%) are predominant. Like other bay-bars in the area, it is primarily fed by comminuted limestone fragments resulting from the erosion of the bay cliffs and submarine slopes. The shell content is low at no more than 12%. Drilling has shown that the upper layer is up to 6 m thick and overlies a 2.4 m thick lens of mud containing marine shells. These muds are underlain by Upper Sarmatian limestone, and a layer of lithified sand has been identified at a depth of 3 m [17]. Fragments of this lithified layer are sometimes visible on the surface of the bay-bar, possibly originating from the nearshore bench. The material of the secondary bay-bars is of marine origin.

According to the authors of study [17], as the bay-bar migrated towards the head of the bay, it overrode the muds, which became buried beneath the bay-bar sands. The presence of a dead cliff on the segment adjoining the bay-bar can also suggest that its body was previously more advanced seawards. In [18], the authors propose that the lake was separated from the sea by a sandy bay-bar during the Dzhemetinian phase of the Black Sea transgression (i.e. around 1000 years ago) based on a paleogeographic reconstruction of the ancient shoreline.

Satellite imagery from the last twenty years shows that, despite seasonal fluctuations, the shoreline of the bay-bar has remained stable. This finding is corroborated by direct observations conducted between 1960 and 1994 [19)]. Unlike two bays previously discussed, the sandy dunes on the Karadzhinskaya Bay-Bar remained in relatively good condition until recently. However, under the current intensive development project for the bay, the dunes are scheduled for removal and replacement with tiles. Overall, only one-third (55,000 m^2) of the existing 165,000 m^2 beach

F i g . 5 . Lake Liman (Karadhza) on a quadcopter image

[19)] Shuysky, Yu.D. and Vykhovanets, G.V., 2006. [A Map of Average Rate of Erosion and Accumulation. 1960–1994]. In: L. I. Mitin, 2006. [*Atlas of Nature Protection of the Black Sea and the Sea of Azov*]. Saint Petersburg: GUNiO MO RF, p. 44 (in Russian).

area extending to the foredune line is proposed to be preserved. Local residents of Olenyovka, a village located within the bay, oppose these plans strongly. Notably, they successfully halted a project involving the artificial breaching of the bay-bar and the construction of a yacht marina in Lake Liman in 2012.

Evpatoriya sector

The Evpatoriya coastal sector extends 76 km from the bay-bar of Lake Donuzlav to the bay-bar of Lake Kyzyl-Yar. The coast is low-lying and predominantly accumulative. The typical landscape consists of saline lagoons (waterlogged areas), which are separated from the sea by sand and shell bay-bars. Lagoonal silty deposits usually lie beneath these spits. A continuous strip of beaches runs along the coastline, backed by an undisturbed low coastal ridge that transitions into modest sand dunes or waterlogged areas. The land is weakly dissected by broad, gentle ravines. Morphologically, the coast belongs to the lagoon-estuary type. A significant proportion of the sand on the beaches consists of crushed shell, particularly in the Evpatoriya area. To the east of the city, the proportion of shingle on the beaches increases. Wind processes play an important role in the dynamics of the bay-bars, particularly in areas lacking coastal vegetation. Much of the coastline has already been developed and continues to be built up. In these areas, the original natural landscapes have disappeared. More detailed information on the characteristics of the sector can be found in [3].

Lake Donuzlav extends 30 km inland. Originally, it was separated from the sea by a bay-bar ~ 10 km long and between 200 and 400 m wide. In [5)], the authors report a width of 0.5 versts (~ 500 m) in 1876 while in [19], a width of 200–400 m is indicated (1930). The bay-bar continues underwater towards the lake as a submarine extension, dropping off steeply. The steepness of this slope suggests that the bay-bar migrated towards the lake during its early formation stages. The lake, which is now a man-made bay, can be classified as a tectonic-erosional trough or a ria-type bay, as evidenced by the structure of its basin, its considerable depth of up to 27 m, and other characteristic features.

The bay-bar is composed of medium-grained, well-sorted sand with a significant admixture of quartz. Accumulations of whole shells are commonly found throughout the area, and intact shells and shell detritus (broken-up shell fragments) are present in all samples, often accounting for 100% of their composition. The rock-forming components of the sediments include quartz, feldspar and carbonates.

The submarine slope in front of the bay-bar extends down to a depth of 15 m and is composed of a mixture of sand and shell material. Several underwater shore-parallel bars have been formed in this area. Below this sandy area, the seabed is made up of limestone. At depths greater than 20 m, the seabed transitions to silted shelly sediment. The large sand reserve on the seabed is evidently linked to the main unloading zone for longshore sediment transport being located at the bay-bar of Lake Donuzlav. A substantial volume of material (primarily from seabed abrasion) is supplied from the shallow-water area between the bay-bar and Cape Evpatoriysky. It is also suggested that the accumulation of sediments was facilitated by the historical landward retreat of the bay-bar itself [9].

According to [9], the bay-bar was completely closed off relatively recently, in 1874. Prior to this, a passageway was observed there, which subsequently became blocked by silt. However, other sources [20] state that the inlet was formed in 1874 as a result of a catastrophic storm.

At the end of 1961, a 200 m wide canal was excavated through the bay-bar and two protective groynes were built to guard the entrance. This divided the bay-bar into two spits: a southern one and a northern one (Fig. 6).

The lake was originally intended for use as a civilian port but a small naval base was instead built there and has operated ever since. In the years immediately following the construction of the canal (1961–1966), the shoreline of the bay retreated by 25–60 m in certain exposed sections. By the 1980s, the shoreline had stabilised. Between 1982 and 1987, certain sections of the bay-bar experienced changes to the shoreline involving both advance and retreat as well as vertical deformation of the beach and underwater profiles relative to the mean position. Our analysis of ultra-high-resolution satellite imagery revealed areas of both progradation and retreat of the shoreline between 2003 and 2020. Average rates for this period indicate that retreat predominates: the northern spit retreated at an average rate of 0.2 m per year,

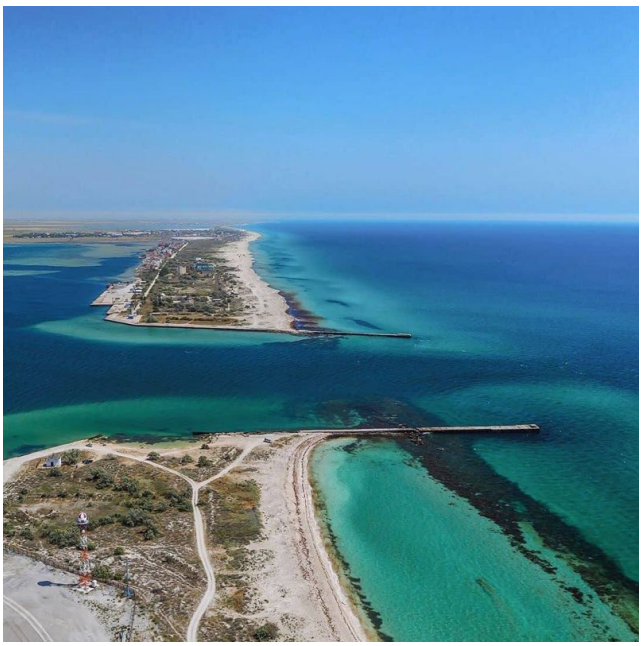


Fig. 6. Quadcopter view of the northern (at the foreground) and southern spits of the Donuzlav Bay-Bar

[20] Kurnakov, N.S., Kuznetsov, V.G., Dzens-Litovsky, A.I. and Ravich, M.I., 1936. [*Saline Lakes of Crimea*]. Moscow, Leningrad: Izdarelstvo AN SSSR, 278 p. (in Russian).

whereas the retreat rate of the southern one was 0.5 m per year. According to an earlier study [21)], the shoreline of the Donuzlav Bay-Bar had slowly retreated at a rate of up to 0.2 m per year over the previous 100 years.

A sand quarry has been operating on the lake, directly adjacent to the bay-bar, for the past 60 years. Additionally, the navigation channel on the seaward side of the bay-bar has been periodically dredged. Between 1963 and 1992, 11.5 million tonnes (5.5 million m^3) of sand were removed from the channel during these operations. Approximately 350,000 tonnes (165,000 m^3) of sand were extracted in a single dredging campaign. According to official data, up to 7.7 million tonnes of sand were mined from the lakeshore immediately adjacent to the bay-bar between 1992 and 2014, with extraction ongoing.

The northern spit remains largely undeveloped for recreational purposes due to its remote location and lack of infrastructure. Nevertheless, a project has been developed to create a world-class resort called the "Crimean Maldives" in the Belyaus area. The southern spit has been intensively developed since the end of the last century. The lakeside is completely built up with cottages, while the seafront is partially developed. During construction, bulldozers have levelled the natural beach relief and destroyed the coastal dunes, removing the shrubs and trees that stabilised them.

A chain of salt lakes stretches along the coast from *Lake Donuzlav to Cape Evpatoriysky*: Oyburskoye, Adzhibaychikskoye, Airchinskoye, Galgaz, Konrad and Terekly, as well as several smaller lakes located between them. A strip of waterlogged areas lies between the bay-bars of the lakes, separated from the sea by a sandy barrier. In spring, these areas fill with water to form shallow ponds. All the lakes lie below sea level. The typical width of the bay-bars separating the salt lakes ranges from 70 to 150 m. The width of the bay-bar decreases where the limestone surface is slightly elevated. Breaches often form in such locations as a result of storm surges. The lakes basins are mostly elongated and run parallel to the seashore, representing lagoons rather than estuarine lakes. Where wide, shallow valleys approach the lakes directly, the bodies of water exhibit features of both types. Examples include lakes Oyburskoye and Konrad.

The profiles of all the bay-bars slope relatively steeply towards the sea while the slope towards the lakes is gentle. These bay-bars extend along almost half the length of the coastline and are typically 1–1.5 m high although study [9] shows heights of up to 2.5 m. The beaches of this coastal section consist of medium-grained sand made up of oolite grains with shell fragments mixed in. Large limestone fragments are also prevalent, particularly after storms. The shoreline is typically marked by beach cusps, or festoons, with their shape and size depending on the characteristics of the preceding wave action.

On this section of coastline, sediments cover not only the beaches, but also the upper part of the underwater slope. This creates an accumulation zone where longshore sediment transport is largely saturated. In the southern part of the section, this zone extends to a depth of 2 m; in the northern part, it widens and extends to

---

[21)] Dolotov, Yu.S., Shadrin, I.F. and Yurkevich, M.G., 1971. [On Dynamics of Relief of a Submerged Coastal Slope Formed by Shells]. In: V. P. Zenkovich, 1971. [*New Studies of Coastal Processes*]. Moscow: Nauka, pp. 110–119 (in Russian).

the 8 m isobath. The offshore extent of sandy bottom deposits is typically 300 m from the waterline near the village of Popovka, compared to just 10–20 m near Cape Evpatoriysky. At the sandbars of the salt lakes, the seaward boundary of the sands increases abruptly to 1.5 km, and satellite images show that this changes very little over time [19]. Beyond the accumulation zone, sediments only accumulate in depressions in the limestone bedrock, controlled by the seabed slope. At slopes of 0.003–0.007 (typical for the section in question), sediments are thrown onto the shore, with accumulation occurring only within a narrow nearshore strip [9]. The same factor explains why the accumulation zone widens near the salt lakes, where depressions in the landscape extend to the seabed.

The shoreline in this area is relatively stable, with a slight overall tendency towards retreat. Typically, retreating segments correspond to headlands while advancing segments correspond to embayments. At the same time, however, the waterline exhibits significant annual and interannual shifts due to fluctuations in sea level and bidirectional sand migration. According to survey data from fixed transects between 2006 and 2017, as well as analysis of satellite imagery, these shifts reach 34 m near Popovka and 18 m near Shtormovoye. After storms, temporary spits and beach ridges can form either parallel or perpendicular to the shore but they are quickly eroded. Assuming the accuracy of data from [9, 20], the width of the bay-bars separating lakes Adzhi-Baychi and Oyburskoye has significantly decreased since 1933, while the width of the bay-bars separating lakes Airchinskoye and Konrad has increased. However, it should be noted that the widths of the bay-bars of all these lakes are currently approximately the same.

We investigated lithodynamic processes in this area based on a statistical analysis of retrospective calculations of wind waves for 1979–2018 and numerical modelling performed in [19]. The study showed that the most intense longshore sediment flows were generated by wave action caused by winds blowing from the west, southwest and south. Under these conditions, longshore sediment transport is directed clockwise towards the northern spit of Lake Donuzlav, where it meets an opposing flow coming from the opposite direction. Along the south-eastern coast, longshore flows diverge, forming convergence zones in the concave embayments of the bay-bars. An increase in the rate of sediment transport on the underwater slope opposite coastal headlands and a decrease opposite embayments result in the redistribution of material and its deposition in the coastal zone of the bay-bars.

The largest lake in this area is *Lake Oyburskoye*. The length of the bay-bar that separates it is ~ 4 km, its height is ~ 1.5 m and its width ranges from 100 to 220 m (according to [20], widths are up to 300 m). Inside the lake, five smaller lakes have been cut off by bay-bars and two artificial dams. Another small lake is being closed off by spits. According to [9], the lake is bordered by extensive waterlogged areas, which are now mostly built up. The bay-bar, which still contains sections of sandy dunes, is used as a recreational area by local residents. However, it is also the subject of ongoing disputes between the residents and commercial entities.

In the 1970s, a canal was dug through the bay-bar to create a mullet farm on the lake. However, it was quickly filled in with sand and the project was abandoned. A similar situation occurred in 2019, when mass protests by local residents ultimately led to the cancellation of a planned shrimp farm.

The pits resulting from illegal sand extraction are visible on the bay-bar; however, this problem affects all bay-bars in the area. One positive development was the creation of a recreational landscape park on the Oyburskaya bay-bar in 2022, achieved through public pressure. Thanks to this, the bay-bars in the area have generally retained their natural state, despite undergoing some localised alterations. Thus, during the construction of a boarding house, the western part of the bay-bar of Lake Airchinskoye was artificially widened by around 50 m with fill material.

Particular concern is raised by the increasing anthropogenic impact on the bay-bar beaches, especially the practice of levelling the beach relief for the purpose of beautification, which involves the destruction of dunes. This results in adverse changes in the composition of the beach sediment and its reduction, which is clearly seen in Fig. 7.

F i g . 7 . A beach near the village of Shtormovoye after grading its natural relief (*top*), the same beach before a storm (*bottom left*) and after the storm (*bottom right*)

Beyond Cape Evpatoriysky, there is small Moinakskaya Bay. A bay-bar forms its shore and separates the lagoon-type lakes known as Bolshoy and Malyy Otar-Moinak (the larger of which is usually simply called Moinaki) and Yaly-Moinak from the sea. The bay-bar is ~ 4 km long, with ~ 1 km of this directly facing Lake Moinaki. According to [20], the sandy bar of Lake Moinaki had a minimum width of ~ 160 m in 1933 and reached 580 m at its widest point. The highest part of the bar rises approximately 1.5 m above the sea level (according to [20], 2.3 m). These parameters remain roughly the same to this day. Originally, smaller secondary lakes were cut off in the inner corners formed by the bay-bar and the shores of the main lakes. However, during the construction of a pioneer camp on the bay-bar in the last quarter of the 20th century, some of these smaller lakes were filled in. The remaining lakes currently accumulate domestic wastewater and floodwater, which has led to strong freshening and loss of their therapeutic value. Currently, only ~ 20% of the bay-bar remains undeveloped and locates temporary structures.

The upper layer of the bay-bar sands is 6–8 m thick. This is underlain by a 3 m thick layer of dense grey silt, beneath which lies another 10 m thick layer of sand. The grey silt extends towards the lake, forming the lake bed beneath a thin layer of black lagoon mud. The presence of an interlayer of grey lagoon silts indicates that the final stage in the bay-bar development was its retreat into the bay and overthrust onto lagoon deposits. Prior to this, during the transgression period, the Otar-Moinakskaya Bay-Bar alternately extended beyond the modern shoreline and occupied its current position [9)]. Work [20] gives slightly different thickness values, based on borehole data but the sequence of layers remains the same.

The Moinakskaya Bay-Bar is made up of oolitic sand mixed with whole and broken shell fragments, as well as small amounts of gravel and limestone clasts. The latter are particularly abundant after storms. The dominant grain size in the samples is 0.25–0.5 mm, while the subordinate fraction is 0.5–1 mm. Together, these two fractions account for 55–90% of the sediment mass.

According to the 1933 survey, the crest of the beach ridge, which was 6–7 m wide, consisted of fine windblown sand [20)]. Newsreel footage from 1943 shows a rather steep beach scarp here. This morphology persisted until the 1970s, as can clearly be seen in photographs from that period. Eyewitness accounts, including the author hereof, also confirm this. Today, the intensively used beach has a significantly gentler slope. Until the mid-1960s, a channel that connected to Lake Moinaki and flooded during storms crossed the eastern end of the bay-bar in the form of a wet log. This feature no longer exists.

It is noted in [20] that in Moinakskaya Bay, limestone is exposed on the seabed at depths of 1–1.5 m, and the rocks underwater are abundantly overgrown with brown branched algae from the Cystoseira genus. However, our observations indicate that the seabed immediately adjacent to the bay-bar consists predominantly of sand, with increasing amounts of gravel, silt and shell fragments present the further one goes out to sea. The description in [20] most likely refers to the seabed to the east and west

of Moinakskaya Bay-Bar (i.e. the bay-bar of Lake Yaly-Moinak). The reason for this discrepancy is unclear but it can reflect multi-decadal changes or, more likely, the limitations of underwater observations conducted over a century ago.

Lake Yaly-Moinak is located next to the sea and is elongated, running parallel to the shoreline. Unlike Lake Moinaki, which is situated in a ravine, Lake Yaly-Moinak occupies a lagoon along a concave stretch of coastline. The lagoon is separated from the sea by a continuous bay-bar, which is ~ 1 km wide. The bay-bar is currently fully developed with recreational facilities. However, construction waste is being dumped into Lake Yaly-Moinak from the east, with buildings then being erected on top of it. Notably, a Greco-Scythian settlement existed on the bay-bar near the lake from the 4th to 1st centuries BC. This was discovered in 1959 during sand extraction.

The shoreline of Moinakskaya Bay-Bar has remained relatively stable, as can be seen by comparing aerial photographs from 1941 with satellite images taken between 2005 and 2020. Direct measurements conducted by us between 2010 and 2015 revealed that the shoreline there exhibited seasonal and inter-annual variability of up to 12 m. Typically, the area of the beach is at its maximum in autumn and at its minimum in early summer, due to seasonal fluctuations in sea level. The shoreline of the bay-bar of Lake Yaly-Moinak has undergone significant modification. Currently, despite an overall slight retreat, it experiences significant inter-annual and seasonal variations due to the presence of cross-shore hydraulic structures. Additionally, a reduction in the vertical thickness of beach sediments has been observed [21].

Old maps show that Lake Karantinnoye was located where central Evpatoriya (Gogolya Street) is today, but it was filled in at some point in the early 20th century. The sandbar that separated the lake from the bay was 150–200 m wide. From the early 5th century BC to the end of the 2nd century BC, the ancient Greek settlement of Kerkinitis was located on this bay-bar.

The coastline *from Evpatoriya to Lake Kyzyl-Yar* consists of a continuous bay-bar. Although it is known by different names in its different areas, it is one unbroken bay-bar in terms of structure and position. Spanning 25 km, the bar separates the largest lake in Crimea, Sasyk-Sivash, as well as lakes Sakskoye and Kyzyl-Yar, from the sea.

The Lake Sasyk-Sivash basin is genetically an estuarine widening of five ravines flowing into the Black Sea, meaning the lake has a lagoon-like origin. Its highly indented shoreline features numerous secondary bays and accumulative landforms.

In 1933, the width of *the bay-bar of Lake Sasyk-Sivash* ranged from 400 m in the narrowest places to 1500 m in the widest places, with elevations above sea level of 1–5 m [20]. The width ranges from 0.9 to 1.62 km in [5]. Currently, the minimum width of the bay-bar is 140 m. Determining the maximum width is almost impossible, as the northern (lake-side) part of the bay-bar has undergone significant alteration due to salt extraction operations, sand mining and filling of certain lake sections with construction waste. Until the early 20th century, a second bay-bar existed alongside the outer one in the west, but it disappeared subsequently due to the construction of salt evaporation ponds.

The upper layer of the bay-bar currently consists of sand, gravel, pebbles and a small quantity of shell fragments. These deposits slope away from the shore towards the lake at an angle of 5–10° beneath the lakebed silt cover where erosion occurs. Drilling into the bay-bar deposits reveals that at a depth of 4 m, the sand transforms into oolitic one, followed by a thick layer of finer-grained sand. At a depth of 16 m, this is replaced by a thick layer of greenish clay of marine origin [20]. Drilling and trenching on the bay-bar indicate that the deposits, across their entire thickness (up to 31 m to the bedrock), are characterised by extreme mottling and compositional variability, both vertically and horizontally.

As noted in [22], the bay-bar is dominated by the 0.1–0.25 mm fraction, reaching up to 45% at most, with boulder-pebble fractions reaching 40% at most. Previously, the surf zone was littered with the shells of modern mollusks. After storms, layers of shells up to 30 cm thick formed in places, mainly consisting of scallops (Pecten) [4]. Currently, the amount of shell material has decreased significantly. Recent studies by MHI RAS [23] have shown that the 0.25–0.5 mm fraction predominates on the bay-bar (39%), with coarse and fine sand inclusions accounting for 24% and 28%, respectively. The proportion of gravel material in beach sediments has significantly reduced (9%), which can indicate weakening of the intensity of the alongshore sediment flow directed from the south. At the water edge, the percentage of the gravel-pebble fraction increases when moving southwards. The decrease in the proportion of fine-grained fractions can be due to material being transported from the beach zone to the sea by wind and then redeposited on the submarine coastal slope.

Aeolian sand deflation plays a significant role in the formation of the bay-bar of Lake Sasyk-Sivash, as strong land-based winds frequently occur here during the winter. Direct studies of the bay-bar have shown that at a wind speed of ~ 15 m per second, ~ 50 kg of sand per hour are transported through a 1 m wide cross-section [24]. The most intensive aeolian transport occurs in the middle part of the beach. Transport is considerably less in the nearshore zone due to the high moisture content of the particles. Vegetation also has a significant impact: experiments have demonstrated that dense herbaceous cover can reduce the movement of sand particles by a factor of 5–10.

As shown in [4], the surf zone and the bay-bar have a similar granulometric composition of pebbles, gravel and sand of the same grain size. Currently, pebbles are primarily found in the swash zone. The same study notes that during storms, a ridge of sand, gravel and pebbles up to 1 m high and 5–10 m wide at the base forms along the shoreline from Lake Kyzyl-Yar to Evpatoriya, extending ~ 20 km. On average, up to 3 m^3 of gravel is deposited per linear metre of shoreline, totalling 30–50 thousand m^3 along the entire coast. No processes of such scale have been observed in the last hundred years.

Following [6], the authors of [20] consider that the bay-bar of Lake Sasyk-Sivash became fully separated at the end of the 19th century. This conclusion is supported by the fact that the sea overflowed into the lake across the lowest and narrowest part of the bay-bar near the city of Evpatoriya during that period and under strong winds. It should be noted that the bay-bar in this area is only ~ 900 m wide and 1.5 m high, and that the crest of the bay-bar is not yet as distinctly pronounced here as it is further east [20].

We find this statement doubtful because, as is the case today, the width of the bay-bar at this location was ~ 150 m at that time [22], and a road had run along the bay-bar since the Greek colonisation period. Additionally, during the Crimean War, the Turks dug a defensive ditch in this location, connecting the sea with the lake. Subsequently, this site was used for sand extraction as it was the closest area to the city.

It should be noted that the bay-bar of Lake Sasyk-Sivash has been subject to significant man-made impact. In addition to the existing highway, the 20th century saw the addition of a railway, gas and water pipelines, and communication lines.

A workers' settlement called "Dneprostroy" was built on the bay near the village of Kara-Tobe (now Pribrezhnoye) in 1929. A 1934 publication reported: "During the intense days of the First Five-Year Plan, thousands of workers laboured day and night in gravel pits here, extracting gravel and sand for the concrete structures of the giant [Dnieper Hydroelectric Station – *Yu. G.*] under construction... Around the workers' settlement, vast and deep excavations now extend, the layered structure of the bay-bar clearly visible in their walls" [23]. Later, high dunes were replaced by waterlogged areas, which fill with seawater during storms. They are currently gradually being built over.

Work [24] states that the Evpatoriya deposit encompasses the beaches and adjacent bay-bars of lakes Sasyk, Sakskoye and Kyzyl-Yar. It also states that the sand from this deposit is the best on the peninsula for concrete production.

In the second half of the 20th century, the bay was used by unorganised tourists for car camping. By the end of the century, temporary recreational infrastructure had been built there. Gradual development of the bay-bar began in the 21st century, and the western and eastern parts are currently under development. Built-up areas now extend 3 km along the shoreline to the west and slightly further to the east. A project is now being implemented to develop the entire bay, creating a world-class resort called "Golden Sands of Russia". However, the construction volumes envisaged by the project threaten the preservation of the bay unique beaches, which are currently among the cleanest and best preserved in Crimea. An additional threat comes from beach leaseholders levelling and destroying dunes and vegetation that were previously planted to protect against wind erosion (Fig. 8).

Analysis of data from contact measurements, aerial and satellite imagery indicates that, despite interannual and seasonal fluctuations, most of the coastline has remained relatively stable in recent decades. Study [25] shows that the maximum range of interannual fluctuations is ~ 7 m, whereas seasonal fluctuations can reach 26 m. At the same time, signs of coastline retreat have been noted in the east,

---

[22] Totleben, E.I., 1863. [*Sheet IX of Evpatoriya Case as of 5(17) February 1855. Atlas of Plans and Blueprints to Description of Defence of Sevastopol*]. Voenno-Topograficheskoe Depo.

[23] Dzens-Litovsky, A.I., Pastak, A.I. and Meyer, R.F., 1934. [*The Resort of Saki and its Suburbs*]. Moscow: Fizkultura i Turizm, p. 61–62 (in Russian).

[24] Muratov, N.V. and Oginsky, I.M., 1938. [*Resources of Mineral Construction Materials of the USSR*]. Moscow, Leningrad: GONTI NKTP SSSR, 76 p. Vol. 2: Crimean ASSR (in Russian).

Fig. 8. Grading of the full-profile beach relief at the Sasyk-Sivash Lake's bay-bar

in areas of intensive construction and beach exploitation. This is evident in satellite images and in the erosion of the coastal scarp, which consists of sandy loam deposits containing gravel and pebbles. Currently, undeveloped sections of the bay-bar are occupied by anti-landing obstacles.

The bay-bar of Lake Sakskoye is narrower (~ 500 m wide) than that of Lake Sasyk-Sivash, which is 500–600 m wide according to [8]. Lake Sakskoye was once a single body of water but it has now been divided into a series of small and large basins as a result of economic activity. Its bay-bar is characterised by a coarser sediment composition than that of Sasyk-Sivash; its deposits consist of sand mixed with gravel and pebbles. Overall, sand is the dominant component of the bay-bar deposits while gravel and pebbles play a subordinate role.

The bay-bar was previously dominated by limestone and green Cretaceous sandstone pebbles, as well as clay shales, granites, diabases, porphyrites and andesites according to [20]. The same study noted that the seaward slopes of the bar descend steeply into the water and are 10–20 m wide, and that the surf zone is littered with the shells of modern mollusks. However, this description no longer corresponds to reality, as the bay-bar is now completely built up, the beaches have been flattened and mollusk shells are extremely scarce.

The bay-bar deposits are up to 31 m thick throughout their entire depth (down to bedrock), with sands accounting for ~ 24 m of this. These deposits are underlain by a 8 m thick layer of grey silt, with red-brown clays forming the lake shores below that [9]. However, these data are not confirmed by [20], which reports a 9.5 m thick layer of sand underlain by 3 m of grey silt, with red-brown clays beneath.

Data from individual boreholes and test pits generally indicate significant variation in the structure of the bay-bar, both vertically and horizontally. Currently, the beach sediments are predominantly medium-grained sand (0.5–0.25 mm in size). A notable trend is the decrease in the proportion of medium-grained sand and the increase in fine-grained material from the south to the north [23]. In cross-sections, sands typically alternate with gravel and pebble interlayers. The main source of sediment is alongshore flow originating from the south, where an active conglomerate cliff is being eroded between lakes Kyzyl-Yar and Bogayly.

Dating and lithostratigraphic analysis of bottom sediments in Lake Sakskoye revealed a transition from marine to lacustrine conditions 5430–4960 years ago, indicating that the bay-bar of Lake Sakskoye is approximately of the same age as the bay-bar of Lake Dzharylgach [15].

Of all the bay-bars in Crimea, the bay-bar of Lake Sakskoye has been subjected to the longest period of intensive man-made impact.

In 1885, a canal was dug through the bay-bar of Lake Sakskoye, connecting the sea and the lake. Between 1950 and 1964, a sand and gravel deposit on the bay-bar was exploited. During this time, the barrier separating the quarry from the sea narrowed and deformed towards the quarry due to storms. During this period, a reduction in the width of the beach was observed in areas adjacent to the barrier. The quarry was closed due to concerns that it would alter the salinity of the brine in Lake Sakskoye. However, shortly thereafter, underwater sand extraction began in the same area. During operation of the quarry, almost all alongshore sediment flows were intercepted, resulting in a sediment deficit and subsequent coastline retreat. Once the negative impact of the quarry had become apparent, it was closed by the Crimean Region Executive Committee. The shoreline remained stabilised until the early 1980s.

In 1982, a hydraulic structure perpendicular to the shore was constructed to the south of the bay-bar of Lake Sakskoye. This structure intercepted the sediment flow coming from the south along the coast. A classic case of downdrift erosion, intensive coastline retreat, began north of the structure, reaching 18–33 m in some areas. Subsequently, the rate of erosion decreased. To protect the resort facilities from destruction, considerable financial resources were invested in the construction of groins designed to retain the beach, seawalls with wave-dissipating chambers, PVC structures, and other protective measures.

In 2016, a project was developed to build a 5600 m long promenade along the bay and expand the beach by adding material to create a 35 m wide stretch of sand. This would replace the existing sand-pebble mixture with a gravel and boulder mixture (70–80 mm), significantly reducing the recreational value of the beach. Despite criticism of the design solutions by MHI RAS (see [5]), construction was started. The negative consequences soon became apparent. Between 2020 and 2021, the beach almost completely disappeared in some areas, while in others, its width decreased and its elevation marks dropped. Construction was therefore suspended, with MHI RAS commissioned to revise the project. Following recommendations of the institute's experts, any structures that could cause significant negative changes to the morphodynamics of the coastal zone were removed from the project. Construction remains frozen at present.

The bay-bar of Lake Kyzyl-Yar is located to the south of the bay-bar of Lake Sakskoye. Genetically, the lake basin forms part of the Kyzyl-Yar ravine, which was flooded by the sea before becoming cut off by a sand and gravel bar. According to drilling data, the spit and the entire lake basin consist of red-brown clays which occur at a depth of 17 m in the middle part of the bay-bar [20)].

According to historical data, the width of the bay-bar was 180–200 sazhens (414–460 m) in 1880 [5)]. By 1934, the minimum width of the bay-bar had decreased to 170 m in the south and 380 m in the centre [8)]. Report [25)] by Institute of Mineral Resources dated 1986 indicated a width of 200–300 m, which is approximately of the same value as that determined from a satellite image taken in 1985. However, a more detailed analysis reveals that the width of the bay-bar is closely related to the water level in the lake. Currently, the bay-bar is 2.5 km long and ranges in width from 100 m at the northern end to 30 m at the southern end, excluding the reed overgrowth on the lakeside.

The southern end of the bay-bar is adjacent to a ~ 20 m high steep bank known as Krasnaya Gorka. An actively retreating cliff composed of red-brown clays and gravel-pebble conglomerates extends southwards from there for 2.5 km. The erosion of this cliff provides material that replenishes the beaches to the north. Previously, the bay-bar was the highest of the surrounding ones at 3.1 m, a height explained by the huge accumulation of pebbles near Krasnaya Gorka [8)]. Currently, the height of the bay-bar is 1–2 m.

Previous studies reported that the bay-bar of Lake Kyzyl-Yar was predominantly composed of pebbles with interlayers of sand [9)]. In [22], the dominant fraction is shown to be 0.25–0.5 mm (~ 40%), with significant gravel content (up to 39%). Investigations by MHI RAS revealed that, except for the waterline zone, most of the beach surface consisted of medium-grained (54.9%) and fine-grained (27.7%) sands. At the waterline, fine gravel predominates (39.1%), with inclusions of coarse- and medium-grained sand (28.8%) [23]. After storms, bands of a thin layer of fine- to medium-sized pebbles are observed on the surface.

At the end of the 19th century, a canal was dug through the bay-bar to facilitate salt extraction, but it was swiftly replenished by the sea [8)]. In the early 1980s, seepage losses from the Mezhgornoye Reservoir resulted in a permanent stream flowing into the lake. Consequently, the lake water level rose sharply, causing the width of the bay-bar to decrease. The lake itself became significantly desalinated and the therapeutic properties of the bottom muds were lost.

The aforementioned cross-shore structure at the northern edge of the bay-bar of Lake Kyzyl-Yar caused the shoreline to advance 30 m seawards over a distance of about 1 km between 1984 and 2017. In contrast, the southern part retreated by 30–40 m towards the lake. At present, the bay-bar is popular with tourists travelling by car.

The bay-bar of Lake Bogayly (also known as Kaptugan or Kichik-Bel) lies 2.5 km south of Lake Kyzyl-Yar, beyond Krasnaya Gorka. It is the southernmost lake of the Evpatoriya group. The lake is a lagoon formed at the confluence of two ravines.

[25)] Romanyuk, O.S., 1988. [*Report on Topic "To Draw Up the Cadastral Register of the Above-Water Part of the Crimean Coasts with Regard to 1:200 000 Scale"*]. Simferopol, 497 p.

The bay-bar is 1.4 km long and 50–70 m wide, with a full-profile beach crest reaching heights of 1.2–1.5 m. According to [19], the bay-bar was formerly 150 m wide and 3.2 m high, due to the accumulation of large quantities of pebbles.

Unlike the neighbouring bay-bars described above, the beach here consists of pebbles for the first 10–15 m from the shoreline, with medium-grained sand mixed with pebbles found farther out to sea. At the waterline, the dominant fraction is fine gravel (up to 40%), with inclusions of coarse- and medium-grained sand (up to 30%) [23]. Granulometric analysis of samples from the seabed shows that the zone of migration of beach-forming sediments near the bay-bar of Lake Bogayly is limited to the 2–2.5 m isobaths. Deeper than that, fine-grained silty fractions predominate.

The two ends of the bay-bar are both supported by abrasive cliffs composed of red-brown and yellowish-brown clays interbedded with layers of sandstone and conglomerate. These conglomerates occur as cemented pebble beds or lenses exposed at elevations ranging from 2 to 6 m. The typical height of the cliffs is 8–10 m.

The dynamics of the bay-bar are largely controlled by those of the adjacent cliffs. According to our data, the cliff adjoining the bay-bar from the west has receded by 45 m between 1975 and 2014, which corresponds to an average retreat rate of 1.2 m per year. The highest rate was observed between 1980 and 1985 (up to 2.2 m per year). Most of our benchmark markers were destroyed by the retreating shoreline. Analysis of satellite imagery showed that the cliff retreated 42 m between 1984 and 2016. According to satellite data from 1984 to 2018, the bay-bar itself retreated 30–35 m landward. Higher-resolution satellite imagery indicated an average retreat of 8–10 m between 2005 and 2016. The retreating shoreline has completely destroyed the promenade, boat shed and hangar at the western end of the bay-bar, and the buildings of the nearby recreation facility are now at risk.

It should be noted that during strong storms, water overflows the bay-bar and sediments are transported into the lake via topographic lows, forming overflow cones that are clearly visible on modern satellite images. Further information on the structure and dynamics of the bay-bar of Lake Bogayly can be found in [2]. Currently, the western end of the bay-bar is primarily used for recreational purposes.

In [20], the presence of the Kherson group of nine lakes was reported in the Sevastopol area of Western Crimea. Currently, only one of these lakes remains (Mayachnoye). The lakes have either been filled in or their bay-bars dismantled to extract sand (e. g. Kamyshovoye, Krugloye). This is discussed in detail in [26].

Conclusion

Based on the above, it can be concluded that the state and development of the bay-bars in Western Crimea have been influenced by a combination of natural and man-made factors since the late 19th century.

The most obvious manifestation of natural factors is the increase in the number of Kondzhalayskie islets and the formation of the Sergeevskaya Spit in the northwestern area. This led to the Andreevsky lagoon being closed off by the Sergeevskaya Bay-Bar. This process is noteworthy for being well documented. Growth of spits has also been observed in the same area.

In the remaining areas, the primary influence of natural factors is the redistribution of sediments between the individual segments of the bay-bar and the adjacent shoreline, caused by storm waves. As beach width can vary significantly (by up to 30 m), measurements taken at a single point in time can lead to erroneous conclusions about long-term dynamics. For this reason, it is preferable to use high-resolution satellite imagery with precise georeferencing, for which data has been collected for most areas over at least two decades.

It is also necessary to take into account the transfer of sediments from the foreshore to the lakes via the bay-bars during strong storms (e.g. lakes Karadzha and Bogayly), as well as aeolian transport. These processes are occurring against the backdrop of the current rise in the level of the Black Sea.

The impact of man-made activity on bay-bars is of greater importance. Material has been extracted from bay-bars in varying volumes almost everywhere. Large-scale industrial sand mining has taken place on the bay-bars of lakes Sasyk-Sivash, Donuzlav, Sakskoye and Kyzyl-Yar.

In the 1950s, V. P. Zenkovich observed that large-scale extraction of beach sediments was only occurring on the bay-bars of lakes Kyzyl-Yar and Sakskoye. However, these are constantly replenished by longshore sediment transport from the south. Meanwhile, removals in the lower reaches of the Belbek and Kacha rivers are compensated for during floods and do not endanger shoreline stability.

However, the rivers were later regulated, and the natural erosion of the cliffs, which supplied material to the beaches, was protected by various structures. Together with the construction of structures perpendicular to the shore, this resulted in a significant decrease in the supply of sediment along the coast. Consequently, the volume of beaches, including bay-bars, has decreased significantly. This is evident in the changes to the width and height of the bay-bars, which makes them far more susceptible to wave action. Lower-than-natural elevations therefore result in the flooding of buildings on the bay-bars of lakes Sasyk-Sivash and Sakskoye. The composition of the sediment on the bay-bars has also changed.

The following forms of man-made impact should be noted: cutting of channels through bay-bars (lakes Panskoye, Donuzlav, Oyburskoye, Sasyk-Sivash and Kyzyl-Yar); beach surface levelling, which has resulted in the destruction of dunes and vegetation; infilling of lakes; use of bay-bars as sources of construction material in the Sevastopol and Evpatoriya areas at different times. The use of bay-bars as roads has decreased (Donuzlav, Kyzyl-Yar and Bogayly). Most of the lakes have lost their therapeutic value, which is an irreparable loss, particularly given the development of the resort industry in Western Crimea.

Almost all of the bay-bars in Western Crimea are currently used for recreational purposes. Plans are in place for the full development of the bay-bars of lakes Sasyk-Sivash and Karadzha, and the bay-bar of Lake Sakskoye has already been developed. Currently, only the bay-bar of Lake Oyburskoye has low-level protected status. In view of this situation, preserving the natural uniqueness of the bay-bars is of the utmost importance, as is preventing the loss of unique ecosystems and landscapes, reducing the decline in biodiversity and minimising the risk of flooding in coastal areas.

REFERENCES

1. Krylenko, V.V., Goryachkin, Yu.N., Krylenko, M.V. and Divinsky, B.V., 2025. Transformation of the Western Branch of the Bakalskaya Spit (Northwestern Crimea) as a Result of the Storm on 26–27 November 2023. *Ecological Safety of Coastal and Shelf Zones of Sea*, (1), pp. 51–71.
2. Krylenko, V.V., Goryachkin, Yu.N., Krylenko, M.V. and Divinsky, B.V., 2024. Transformation of the Lake Bogaily Barrier Beach (Western Crimea) under the Influence of an Extreme Storm. *Ecological Safety of Coastal and Shelf Zones of Sea*, (3), pp. 59–78.
3. Goryachkin, Yu.N. and Dolotov, V.V., 2019. *Sea Coasts of Crimea*. Sevastopol: Colorit, 256 p. (in Russian).
4. Dzens-Litovskij, A.I., 1933. [The Bay-Bars and Spits of the Crimean Salt Lakes]. *Izvestiia Gosudarstvennogo Geograficheskogo Obshchestva = Izvestia de la Société Russe de Géographie*, 65(6), pp. 585–595 (in Russian).
5. Fomin, V.V. and Goryachkin, Yu.N., 2022. Accounting for the Local Wave and Morphodynamic Processes in Coastal Hydraulic Engineering. *Physical Oceanography*, 29(3), pp. 271–290.
6. Dzens-Litovski, A.I., 1938. “Peresyps” (Bars) and “Limans” (Estuaries) of the Azof-Black Sea Coast and the Steppe Crimea. *Priroda*, (6), pp. 22–36 (in Russian).
7. Shuysky, Yu.D., 2002. [Main Patterns in Sediment Distribution at the Underwater Slope of the Donuzlav Bay-Bar]. In: SCSEIO, 2002. *The Black Sea Ecological Problems: Collected Papers* / SCSEIO. Odessa: SCSEIO, pp. 287–295 (in Russian).
8. Shuisky, Yu.D., 2005. Basic Peculiarities of Morphology and Dynamic of the Western Crimea Peninsula Coast. *Ekologicheskaya Bezopasnost' Pribrezhnykh i Shel'fovykh Zon i Kompleksnoe Ispol'zovanie Resursov Shel'fa* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: ECOSI-Gidrofizika. Iss. 13, pp. 62–72 (in Russian).
9. Shuisky, Yu.D., 2007. Mechanical Composition of Beach Alluvium on West Coast of the Crimea. *Ekologicheskaya Bezopasnost' Pribrezhnykh i Shel'fovykh Zon i Kompleksnoe Ispol'zovanie Resursov Shel'fa* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: ECOSI-Gidrofizika. Iss. 15, pp. 370–385 (in Russian).
10. Agarkova, I.V., 1999. [Economic Activity Influence on the Dynamics of the Saki Coast]. *Scientific Notes of Taurida National V. I. Vernadsky University. Series: Geography*, 12(1), pp. 35–38 (in Russian).
11. Goryachkin, Yu.N. and Kosyan, R.D., 2018. The Bakalskaya Spit is a Unique Natural Object of the Crimean Peninsula (Review). *Ecological Safety of Coastal and Shelf Zones of Sea*, (4), pp. 5–14. https://doi.org/10.22449/2413-5577-2018-4-5-14 (in Russian).
12. Rudnev, V.I., Divinskiy, B.V. and Kosyan, R.D., 2020. Changes in Topography of the Coastal Zone of the Bakalskaya Spit from 2018 to 2019. *Ecological Safety of Coastal and Shelf Zones of Sea*, (1), pp. 22–35. https://doi.org/10.22449/2413-5577-2020-1-22-35 (in Russian).
13. Klyukin, A.A., 2005. Extreme Manifestations of the Unfavourable and Dangerous Exogenous Processes in the XX Century in Crimea. *Geopolitics and Ecogeodynamics of regions*, 1(1), pp. 27–38 (in Russian).
14. Goryachkin, Y.N. and Kosyan, R.D., 2020. Formation of a New Island of the Coast of Crimea. *Oceanology*, 60(2), pp. 286–292. https://doi.org/10.1134/S0001437020020034

15. Subetto, D.A., Sapelko, T.V., Stolba, V.F., Kuznetsov, D.D., Ludikova, A.V. and Neustrueva, I.Yu., 2023. Paleolimnology of Lakes of Western Crimea. *Doklady Earth Sciences*, 510(1), pp. 329–334. https://doi.org/10.1134/S1028334X23600184
16. Longinov, V.V., 1955. [Yarylgach Bay]. In: V. V. Longinov, ed., 1955. [*Dynamics and Morphology of Marine Coasts*]. Collection of Papers of Academy of Sciences of the USSR, Institute of Oceanology, Vol. 4. Moscow: AN SSSR, pp. 152–166 (in Russian).
17. Zenkovich, V.P., 1955. [Karadzhinskaya Bay]. In: V. V. Longinov, ed., 1955. [*Dynamics and Morphology of Marine Coasts*]. Collection of Papers of Academy of Sciences of the USSR, Institute of Oceanology, Vol. 4. Moscow: AN SSSR, pp. 100–109 (in Russian).
18. Pospelov, D.V., 2013. The Black Sea Coastline in the Classical Period and the Middle Ages as the Navigation Factor. *Science Prospects*, (10), pp. 118–120 (in Russian).
19. Goryachkin, Yu.N. and Fomin, V.V., 2020. Wave Regime and Lithodynamics in the Region of the Western Crimea Accumulative Coasts. *Physical Oceanography*, 27(4), pp. 415-429. https://doi.org/10.22449/1573-160X-2020-4-415-429
20. Ilinsky, V.P., ed., 1936. Moinakskoye Lake and its Muds. In: V. P. Ilinsky, ed., 1936. *Trudy Solyanoy Laboratorii*. Moscow, Leningrad: Izdatelstvo AN SSSR, 213 p. Iss. VIII (in Russian).
21. Goryachkin, Yu.N., 2020. Changes in the Yevpatoria Coastal Zone in the Last 100 Years. *Ecological Safety of Coastal and Shelf Zones of Sea*, (1), pp. 5–21. https://doi.org/10.22449/2413-5577-2020-1-5-21 (in Russian).
22. Shuisky, Yu.D., 2007. Mechanical Composition of Beach Alluvium on West Coast of the Crimea. *Ekologicheskaya Bezopasnost' Pribrezhnykh i Shel'fovykh Zon i Kompleksnoe Ispol'zovanie Resursov Shel'fa* [Ecological Safety of Coastal and Shelf Zones and Comprehensive Use of Shelf Resources]. Sevastopol: ECOSI-Gidrofizika. Iss. 15, pp. 370–385 (in Russian).
23. Gurov, K.I., 2018. Results of Sediment Granulometric Composition Monitoring in Coastal Zone of the Kalamitsky Bay. *Ecological Safety of Coastal and Shelf Zones of Sea*, (3), pp. 56–63. https://doi.org/10.22449/2413-5577-2018-3-56-63 (in Russian).
24. Vykhovanets, G.V., 2003. [*Aeolian Process on the Sea Shore*]. Odessa: Astroprint, 368 p. (in Russian).
25. Goryachkin, Yu.N., Lazorenko, D.I. and Fomin, V.V., 2024. Dynamics of Accumulative Coast under the Influence of Transverse Hydraulic Structure. *Physical Oceanography*, 31(4), pp. 486–506.
26. Efremova, T.V. and Goryachkin, Yu.N., 2023. Morphodynamics of the Sevastopol Bays under Anthropogenic Impact. *Ecological Safety of Coastal and Shelf Zones of Sea*, (1), pp. 31–47.

Submitted 08.08.2025; accepted after review 02.09.2025;
revised 17.09.2025; published 30.12.2025

About the author:

Yuri N. Goryachkin, Chief Research Associate, Marine Hydrophysical Institute of RAS (2 Kapitanskaya St., Sevastopol, 299011, Russian Federation), DSc (Geogr.), **ORCID ID: 0000-0002-2807-201X, ResearcherID: I-3062-2015**, *yngor@mhi-ras.ru*

The author has read and approved the final manuscript.