AGENCY FOR STATE SUPPORT TO
NON-GOVERNMENTAL ORGANIZATIONS
OF THE REPUBLIC OF AZERBAIJAN

ASSISTANCE TO DEVELOPMENT
OF PUBLIC RELATIONS

THE CASPIAN SEA: HISTORICAL PRECONDITIONS OF CONTEMPORARY ENVIRONMENTAL ISSUES

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This collection aims to highlight the distinctive features and current ecological conditions of the Caspian Sea, while considering the historical factors that have led to present-day challenges. Several of these factors are discussed in articles authored by notable Azerbaijani scholars over the years, who have significantly advanced the understanding of the Caspian Sea. The theoretical and empirical insights provided in these writings indicate that it is essential to take into account the elements that have disturbed the ecological equilibrium, which has evolved over millions of years due to the utilization of natural resources, when devising strategies to address the issues facing the Caspian.

The articles included also illustrate the effects of Global Climate Change on the physical, chemical, and biological characteristics of the Caspian Sea.

We believe that the key points derived from these studies will engage Academic Communities, Policymakers, Environmental Advocates, Civil Society Members, Youth Organizations, and a wider audience, as they showcase the unique attributes of different regions and the Caspian Sea as a whole.

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INTRODUCTION

The Caspian Sea is a distinctive and resource-abundant inland body of water on our Planet, representing more than 40% of the total freshwater reserves found in the World’s lakes. Spanning an area of 392,000 km² and bordered by five nations – Azerbaijan, Iran, Kazakhstan, Russia, and Turkmenistan – the Caspian serves as a Climatic and Ecological Benchmark for a significant part of the Earth’s surface.

The effects of Global Climate Change are evident in the water levels and ecosystems of the Caspian Sea, which is leading to a progressively deteriorating Ecological Condition in the Caspian region.

Moreover, recent scientific studies indicate that the sea is experiencing significant Human-Induced Stress, resulting in various adverse Environmental impacts. Certain regions of the Caspian have already become "dead zones," where fish and invertebrate populations are nearly nonexistent, and some areas of the Sea have lost their natural self-purification capabilities. Consequently, a stark contrast has developed between the Ecological Potential of the sea and the severity of its pollution.

Considering the development of strategies to tackle the Ecological challenges of the Caspian, it is crucial to recognize the enduring efforts of both governmental and non-governmental organizations (NGOs) in the Caspian Five nations. These initiatives aim to enhance Environmental Awareness, promote Civil Society involvement in policies designed to improve the Ecological conditions in the Caspian region, and execute the provisions of the Tehran Convention, the Caspian Environmental Program, nine intergovernmental five-party agreements along with their protocols, as well as other related agreements.

Simultaneously, practical experience indicates that the relevant governmental and socio-political institutions across all Caspian states need to establish the Theoretical underpinnings for eco-economic strategies aimed at preventing the irreversible destruction or degradation of the Ecological Balance in the Caspian Sea due to anthropogenic influences. A significant resource in this regard could be the foundational scientific literature from both the Soviet and post-Soviet eras, which focuses on the history of Caspian fluctuations and the factors that have disturbed the Ecological Balance that had been established over centuries through the exploitation of Natural Resources.

A review of the scientific literature on this subject from recent decades indicates a strong prevalence of articles oriented towards Political Science and Sociology. Most of these works concentrate on the legal status of the Caspian Sea, Environmental Security, the impact of Human activities on the Region's Economic Development, the Cultivation of Environmental Culture and National Environmental Policies, Critical Challenges in Environmental Protection efforts in the Caspian, the creation of a Cohesive Environmental Monitoring System, among other topics.

In essence, issues related to Ecology and Environmental Protection in the Caspian Sea have increasingly been integrated into the realm of practical Geopolitics and the domestic policies of Nation-States, thereby assuming a more prominent role in the framework of modern International Relations. At the same time, within the broader context of Global Environmental

Discussions, essential scientific arguments that elucidate the root causes of the Caspian's current Ecological Challenges and offer a Basis for precise forecasting are gradually being eclipsed.

Simultaneously, science should remain integrated within the framework of Practical Ecopolitics and Environmental Culture. Effective political decisions and the development of an Environmental Culture cannot occur without a solid scientific Theoretical Basis. It is important to recognize that a Culture of Environmental Protection encompasses not only Accountability and Ecological Awareness but also a framework of scientific concepts pertinent to current Ecological Challenges.

Moreover, the unification of ecological efforts among the Caspian states, along with focused initiatives to create a Cohesive Environmental Monitoring System, will yield positive results if a Shared Scientific Information Database is established for the Caspian Five Nations.

Therefore, the significance of this collection is clear, as it features articles from various years authored by distinguished Azerbaijani scholars who have made notable contributions to understanding the characteristics and challenges of the Caspian Sea.

We have curated articles that highlight the distinctive traits and present Ecological Conditions of the Caspian Sea, considering the underlying causes of contemporary issues. The Theoretical and Empirical Groundwork provided in these writings indicates that, when tackling the challenges facing the Caspian, it is crucial to take into account the elements that have disturbed the Ecological Equilibrium, which has evolved over millions of years due to the exploitation of Natural Resources. The articles offered to the audience also demonstrate the effects of Global Climate Change on the Physical, Chemical, and Biological characteristics of the Caspian Sea.

We are confident that the core ideas presented in these works will capture the attention of academic communities, policymakers, environmental advocates, civil society representatives, youth organizations, and a broader audience, as they showcase the distinctive features of different regions and the Caspian Sea in its entirety.

PART I. NATURAL FEATURES OF THE SEA

1.1. THE NATURAL ENVIRONMENT OF THE CASPIAN SEA

Historically, the Earth was surrounded by the primordial Tethys Ocean. The contemporary Aral–Caspian depression is essentially a remnant of the floor of that ancient Tethys.

The evolution of the Caspian Sea is characterized by continuous alterations in its basin, linked to tectonic activities and the development of the oceanic crust. Throughout its extensive geological history, the configuration of the basin has undergone numerous transformations. The latest phase in this narrative was defined by the division of the Caspian and Black seas, leading to the Caspian's disconnection from the World Ocean.

In the most recent geological epoch - spanning several hundred thousand years - four distinct basins, each differing in form and dimensions, have occupied the area of the present-day Caspian

Sea. The initial of these basins, known as the Pontic Sea, spread across the Hungarian Lowland and the lower segments of the Danube River. During this era, the climate of the Earth was frigid, resulting in a scarcity of marine life. The flora of that period was also significantly limited. These deductions are based on evidence of extinct species - fossils embedded in the geological layers, various shells or exoskeletons, remains of extinct fauna, and charred plant material. At that time, the Volga and Kura rivers were already discharging into the Caspian Sea, and to the east, in the region where the arid bed of the Uzboy is currently found, the Syr Darya and Amu Darya rivers also flowed into it.

The subsequent phase in the geological timeline of the Caspian Sea was characterized by a heightened intensity of mountain-building activities. Consequently, the sea experienced a contraction in the west, where the Caucasus was elevating, while it expanded towards the east, into the Central Asian steppes. This body of water is known as the Cimmerian Sea.

In the following epoch, the sea once more broadened its reach, encompassing the vast areas of the Pre-Caspian steppes and the Samara Bend to the north, covering most of the right bank of the Volga (up to the mouth of the Kama River), and, while washing the Caucasus, it extended through a wide gulf into the Kura Lowland.

During this timeframe, mountain-building activities persisted both in the Caucasus and along the eastern shores of the sea. Layers of ash embedded within the earth's strata signify a surge in volcanic activity. This period is marked by a rich presence of animal and plant remains within the sea's sediments, which undoubtedly indicates a general warming trend in the climate.

Throughout the remainder of its historical journey, the sea gradually reduced in size, ultimately adopting its contemporary contours. However, even during this latest phase, its shape underwent continuous alterations: the sea would recede, revealing extensive portions of its seabed, only to advance onto the land, inundating forests, steppes, and ancient human settlements.

Over the span of its extensive history, the Caspian Sea has been known by more than 70 names (with variations), reflecting the rich diversity of cultures that have frequented its shores. Due to both natural and historical factors, the western and southern coasts of the Caspian were the most densely populated and often visited. As a result, the names attributed to the sea were frequently linked to the names of these regions and their inhabitants. The contemporary designation, “Caspian Sea,” is derived from the Caspians—a group that once resided along its southwestern coast—and from the Khazars, who inhabited the northwestern coast. The latter name was particularly prevalent among the peoples of the Muslim East.

The Caspian Sea Basin. The physical and geographical characteristics of the Caspian Sea, being a closed water body, are influenced by the flow patterns of the rivers that run through its basin. This basin is remarkably large: it encompasses approximately 40% of the total area of the European section of Russia, the majority of Transcaucasia, the northern region of Iran, and extensive territories of the Kazakh and Turkmen Soviet Socialist Republics. Figure 1 offers a clear depiction of the vastness of the Caspian Sea basin.

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Figure 1 The Caspian Sea Basin.

As stated by A. A. Tillo and Yu. M. Shokalsky (1905), the Caspian basin covers an area of 3,733,000 km². In contrast, B. A. Apollov (1956) reports a slightly smaller area of 3,698,000 km². This discrepancy of approximately 1% can be attributed to the ambiguity surrounding watershed boundaries, especially in the Trans-Caspian area.

The total area of the Caspian Sea basin encompasses both drainage and endorheic (non-draining) regions, along with the surface area of the sea itself. Among the most significant components of the Caspian basin territory are the river basins located in the northern and northwestern sections of the Caspian -specifically, those of the Volga, Ural, Emba, Kuma, and Manych rivers. The cumulative area of these river basins is 1,822,461 km^2, with the Volga River basin - the largest in Europe - accounting for 1,402,010 km^2. Following in size are the river basins of the western Caspian - those of the Terek, Sulak, Samur, and Kura rivers - totaling only 322,312 km^2. The Iranian river basins are even smaller, covering an area of 166,823 km^2. All these river basins are part of the drainage region, which has a total area of 2,311,595 km^2.

The endorheic (non-draining) areas are situated between the Terek and Kuma rivers, the Manych and the Volga, the Volga and the Ural, the Ural and the Emba, and the Emba and the Atrek. The total area of the endorheic region is 965,824 km^2, while the overall area of the entire basin, excluding the Caspian Sea itself, is 3,277,419 km^2.

In the upper reaches of the Volga and Kama rivers, various industries are concentrated, including machine-building, automobile manufacturing, shipbuilding, textiles, rubber, paper, and chemicals. The Kama and Vetluga rivers traverse some of the most affluent forested regions in the country. In the middle course of the Volga, agricultural areas thrive with well-developed grain farming, horticulture, and animal husbandry, whereas in its lower course, the fishing and food industries dominate.

The landscape of the basin and the coastline of the sea are remarkably varied. This area features towering snow-capped mountains and glaciers, deep valleys, vast steppes, and lush subtropical forests. The western slopes of the Ural Mountains are particularly stunning, adorned with either dense forests or exposed rock, and they provide water to two of the largest rivers in the Caspian basin, the Kama and the Ural. The region also encompasses uplands such as the Smolensk–Moscow Upland, the Northern and Vyatka Ridges, the Obshchy Syrt and Ufa Plateau, the Volga Upland, and the Ergeni Hills, along with the Stavropol Plateau and Ustyurt Plateau, as well as the mountain ranges of the Caucasus and Urals, the Mugodzhar Hills, and the Kopet Dag Mountains. Additionally, there are extensive lowlands including the Caspian Lowland, Kura–Araz Lowland, Kuma–Manych Depression, Oka-Don Lowland, and Meshchera Lowland, along with deserts like the Karakum sands. The elevation across the entire basin varies by nearly 6,000 meters. The relief diversity in the Caspian basin and the Aral–Caspian depression - where peaks soar 4–5 km above sea level and depressions plunge more than a kilometer below ocean level - is complemented by a well-established river system and notable variations in climate, soil types, and biodiversity.

Thousands of rivers flow into the Caspian Sea. The Volga River basin alone, which stretches 3,694 km, is nourished by approximately 1,080 rivers, streams, tributaries, and lakes.

Main Morphometric Characteristics of the Sea. The morphometric features of the Caspian Sea differ among various authors. Due to its level fluctuations, these characteristics are not fixed and are therefore provided for a specific elevation—specifically for the mean long-term (centennial) level, as measured by the Baku tide gauge (reference mark: 326 cm). The level recorded by the Baku tide gauge is representative of the Caspian Sea. Similarly, the levels of seas connected to the

World Ocean are also variable, but their fluctuations are relatively minor, oscillating within narrow limits around their long-term average.

The level changes of the Caspian Sea are markedly different from those of other seas linked to the World Ocean. Over its extensive history, the Caspian Sea has experienced continuous changes in its level: it has advanced onto its shores, inundating them, deepening, and altering its contours; subsequently, it has receded, with its level dropping - sometimes by several meters.

The level variations of the Caspian Sea can be categorized into three types: centennial (long-term), seasonal, and wind-driven surges (seiches). The most significant of these, which have the greatest economic impact, are the centennial fluctuations.

The shores of the Caspian Sea bear numerous signs indicating that its level has experienced substantial changes even in historical times. This is evidenced by coastal deposits and terraces. Some of these terraces are situated above the current sea level, indicating that during certain distant periods in its history, the sea level was higher than it is today; others are presently submerged, confirming the existence of lower levels in the past. Off the coast of Dagestan, underwater terraces have been discovered at depths of 20–22 meters, which also suggest higher former sea levels.

Evidence of low levels of the Caspian Sea during its early geological history is supported by the finding of an ancient mouth of the Volga River in the northern region of the sea, which is now underwater, along with the submerged mouth of the ancient Uzboy River. Additional evidence is provided by the so-called abrasion niches - depressions in bedrock that were once shaped by wave action - located in Alexander-Bay Gulf at depths of 4–8 and 12–13 meters.

Details regarding the Caspian Sea's level throughout the historical period are also illustrated by structures such as the ancient Derbent Fortress, which was constructed in the 7th century and referenced by Arab historians. The stone used for building the fortress was sourced from quarries situated near its walls. Currently, these quarries are underwater, resting at a depth of approximately 2 meters.

A map created by Voynovich's expedition in 1782 indicates that Peschany Island, found at the entrance to Baku Bay, is represented as a submerged shoal (bank).

Numerous other pieces of evidence also indicate that sea levels were higher during historical times. The Iranian author Najati (1304) noted that the port of Abeskun was submerged by the sea during his era. This city was situated where present-day Gyumushtepe is, on the southeastern coast of the Caspian Sea. Marino Sanuto's map from 1320 features an inscription along the western Caspian coast stating: "The sea rises by one palm each year, and many fine cities have already been submerged." The Azerbaijani geographer and writer Bakuvi reported that in 1400, the sea inundated parts of the towers and walls of the ancient Baku Fortress. A handwritten pilot guide for marine navigation by Larin mentions that in 1804, the water reached the walls and gates of the Baku Fortress.

The fluctuations in the Caspian Sea level have long piqued the interest of both Russian and international scholars. These changes did not escape the notice of the communities living along its shores, as they influenced the strategic positions of fortress cities and ports, thereby impacting the economies of coastal nations. People sought to understand the reasons behind this enigmatic phenomenon, which led to the creation of many legends: for instance, the idea of an invisible link between the Caspian and the Aral and Black seas, and even the Persian Gulf, through underground channels that allowed Caspian waters to flow away; the tale of the “Black Mouth” - the Kara-Bogaz-Gol Bay, from which water mysteriously disappears into the earth; and the theory of underwater volcanoes that alternately draw in and expel water.

At the start of the 19^{th} century, efforts were initiated to offer a scientific rationale for the variations in the Caspian Sea level. From the very beginning of its examination, there were differing opinions regarding the reasons behind these fluctuations. Some scholars posited that geological factors, such as the uplift or subsidence of the sea floor, influenced the changes in level, while others attributed the phenomenon to climatic conditions.

Advocates of the geological explanation contended that the Caspian Sea is situated in an area where movements of the Earth’s crust have been recorded both historically and currently. Nevertheless, these movements have only occurred in one direction thus far: the subsidence of the sea floor, which could solely lead to a decrease in sea level. Furthermore, tectonic movements in the Caspian region have been exceedingly gradual, occurring at a rate of no more than 0.05 cm annually.

It has been determined that the sediment deposition rate on the Caspian Sea floor is roughly 0.05 cm per year. If the sea floor experiences slight subsidence, resulting in a decrease in sea level, this is somewhat offset by sediment accumulation.

Consequently, tectonic factors can only account for a minimal reduction in level and cannot explain any increase.

The majority of scientists concur that climatic factors are the primary drivers of the changes in the Caspian Sea's level. When precipitation in a particular year surpasses the water loss due to evaporation, the water level of the Caspian rises; conversely, if precipitation is lower than evaporation, the level declines.

The timeframe from 1930 to 1962 was the warmest in the Northern Hemisphere over the past two centuries, signifying a climate shift that impacted river discharge.

The pioneer of Russian climatology, A. I. Voyeykov, asserted that "rivers are a product of climate." Given that the water balance of the Caspian Sea is largely influenced by river runoff, it follows that the overall water balance of the Caspian is also a "product of climate" and is directly affected by climatic changes throughout the entire watershed of the Caspian basin. The level of the Caspian Sea is primarily reliant on the volume of water contributed by the Volga River. It is recognized that approximately 81% of all river water flowing into the Caspian originates from the Volga, which mainly receives its water from snowmelt. The air temperature and precipitation in the Volga basin are dictated by purely climatic processes occurring over the Eurasian continent and the Arctic region.

Some scholars associate shifts in global climatic conditions with heightened solar activity and the emergence of sunspots. Research has shown that fluctuations in solar activity affect atmospheric circulation, resulting in climate change; specifically, the winter temperature in the upper Volga region has risen by an average of 1°C compared to the average winter temperatures of the previous century, which has led to a decrease in river runoff. This trend is corroborated by data from hydrometeorological stations in Moscow, Leningrad, and Yaroslavl.

In recent decades, human activities have increasingly impacted the level of the Caspian Sea, generally resulting in a decline. This impact became particularly pronounced after 1930. The expansion of agricultural reclamation and irrigation projects has significantly increased, necessitating large amounts of Volga water to irrigate the Zavolzhye lands, enhance livestock production in the Caspian Lowland, and sustain soil moisture.

Water usage in industry has risen significantly. Throughout the extensive area of the Caspian basin, numerous reservoirs and ponds have been established, and substantial reservoirs have been developed on the Volga River - Rybinsk, Moscow, Uglich, Ivankovo, Kuybyshev, Volgograd, and Gorky - on the Kura River – Mingachevir - and on the Kama River - Perm. The filling of these artificial lakes, ponds, and reservoirs, along with evaporation from their surfaces, results in considerable water consumption from the Caspian basin. Additionally, once the anticipated water management reconstruction projects for the basin are finalized, the inflow component of the Caspian's water balance will further diminish compared to the current state, leading to a corresponding decline in its level.

Fluctuations in sea level can sometimes enhance transportation conditions but may also impede the functioning of offshore oil fields; in other instances, they can either aid or obstruct fish spawning and reproduction; and they frequently incur significant expenses for the reconstruction and development of quays, navigation channels, and other port facilities.

The Caspian Sea holds the title of the largest lake on the planet. Based on the latest refined data (B. A. Apollov, E. I. Fedorova, 1956, and others), its morphometric features, referenced to the mean level for 1830–1929, are as follows: the total area of the sea, excluding the Kara-Bogaz-Gol Bay, is 401,000 km², with the northern section comprising 111,000 km². Its meridional length measures 1,280 km. The sea's shape resembles the Latin letter S. As a result, its length along the median line (axis of symmetry) surpasses the meridional extent by 160 km; the average width, determined by the ratio of the area (excluding Kara-Bogaz-Gol Bay) to the median line, is 278 km. The total length of the coastline, including Kara-Bogaz-Gol Bay and islands, is 7,550 km.

Due to the significant decline in sea level that commenced in 1930, the morphometric data mentioned earlier have certainly been altered. Primarily, the surface area of the sea has contracted.

The shallow northern section of the sea has notably reduced in size. Numerous bays have either vanished or diminished, including Kaydak, Komsomolets, Mertvy Kultuk, Hasan-Kuli, and Kyzylagach Bay. Conversely, the size of certain islands has expanded nearly two to three times - these include Tyuleniy, Chechen, Kulaly, Novy, and Podgorny. Other islands, such as Cheleken, Dolgiy, Orlov, Sara, and others, have evolved into peninsulas.

Geographically, the Caspian Sea is typically categorized into three sections: northern, middle, and southern. The traditional boundaries that distinguish these three sections are as follows: in the north—from Chechen Island to Cape Tyub-Karagan (Mangyshlak Peninsula), and in the south—from Zhiloy Island to Cape Kuuli. The northern section of the sea is the shallowest, with average depths not exceeding 5 meters. In the middle section of the Caspian, maximum depths reach 790 meters, while in the southernmost and deepest section of the sea, depths can reach up to 1,020 meters. Overall, the mean depth of the Caspian is approximately 180 meters, and the total water volume is around 76,000 km³.

Coasts and Bays. The coasts of the Caspian Sea are distinguished by a diversity of landscapes unusual for other seas: the high mountains of the Greater Caucasus (with Bazardyuzi Peak, 4,480 m); the Bagrodaga and Elburz ranges (with Demavend Peak, 5,654 m); the subtropical greenery of the southern shores; the semi-desert Kura-Araks lowland, where Caspian waves once roared over treeless spaces; the vast Caspian Lowland, whose coastal strip is periodically submerged by Caspian waters; the rocky, centuries-old barren cliffs of Mangyshlak; the sands of the waterless deserts of Central Asia; marshy lowlands overgrown with reeds; a narrow strip of loose sand dunes with whimsical forms along the northern shores of the Middle Caspian alternating with barriers of high mountain ranges; an endless labyrinth of mountain chains, cliffs, and gorges with fragmented and isolated sections, which in turn give way to steep screes on the mountain slopes of Dagestan. All of this illustrates the remarkable diversity and vivid contrasts of the Caspian Sea’s coastal landscapes.

The coastlines of the Caspian Sea showcase a wide variety of landscapes. A brief overview is most effectively structured by examining the natural physico-geographical regions of the Caspian, specifically by sequentially analyzing the northern, central, and southern sections of the sea.

As previously mentioned, the Northern Caspian is delineated by a straight line that connects Chechen Island to Cape Tyub-Karagan. The coastal area extending from Chechen Island to the mouth of the Volga River, which constitutes the western half of the shoreline in this region, is characterized by the Caspian Lowland (comprising the Ischetsk and Kizlyar steppes). The topography of the western Caspian Lowland is influenced by its recent geological history, as it was once the seabed.

Throughout the entire stretch from Chechen Island to the Volga Delta, the shores are composed of shallow waters. The ancient features of the seabed relief remain intact to this day, including coastal ridges that extend the landscape typical of the Volga Delta.

Morphologically, the Volga Delta region is intricately linked to the Caspian Lowland, yet it possesses numerous unique characteristics. The relief of the delta has been influenced by erosional activities and the substantial amounts of sediment transported by the Volga. In the Volga Delta region, the shores are low, consistent, and predominantly covered with reeds. The extensive network of river branches results in a highly winding coastline, dotted with many islands and spits. The Volga splits into over 500 distributaries. In terms of its branching and the complexity of its relief, the Volga Delta is the most intricate in the world. It creates a vast plain that gradually inclines towards the Caspian Sea, covering a total area of 13,370 km^2. Currently, the delta is advancing mainly due to the falling sea level. Because of the gentle inclines of the Northern Caspian shores, a 1 cm drop in sea level leads to a shoreline retreat of about 100 -120 meters. During years of high water, the situation reverses -the sea level rises, and water intrudes onto the land. In years when the discharge of the Volga remains relatively stable, the growth of the delta primarily occurs through sediments carried by the river. In recent decades, the rate of sea-level decline has occasionally reached 30 cm annually. In such instances, the delta has extended into the sea by 3 - 4 km. Consequently, due to this decline, the shoreline in the Volga Delta region has moved seaward by 30 - 40 km in recent years.

Alterations in the shoreline's location and the depths of the sea surrounding the delta pose significant challenges to cargo transport. The Port of Astrakhan is linked to the sea through an artificial navigation channel. As the Caspian Sea level has decreased, various shoals and islands have surfaced in the pre-delta waters, including the Ukatnaya Shoal, Zhyostkiy Island, and the Dzhamibayskaya Shoal, among others.

In the northeastern region of the Caspian, the Ural River empties into the sea. Its delta consists of multiple distributary channels, with the Zolotoy Channel being the deepest. Currently, the Bolshoy Yaitskiy and Peretaska channels are nearly impossible to navigate due to sediment buildup and reduced depths. While not as pronounced as the Volga Delta, the Ural Delta is also experiencing significant progradation, driven by the discharge of fluvial sediments and the falling sea level. The shoreline near the Ural River delta is shallow, prompting river fleet vessels to access the sea via the Ural–Caspian Canal, where depths are artificially sustained.

The coastal area between the Ural Delta and Mangyshlak Bay is notably shallow. Similar to the northwestern Caspian coast, the shoreline here is in a state of constant change, attributed to the shoal-like structure of the coast and the effects of wind-driven water movements. The displacement of the shoreline can reach distances of 12–15 km.

To the east of the Ural River, the Emba River flows into the Caspian Sea. Its waters only reach the sea during significant flooding events; otherwise, they dissipate into the surrounding sands.

The vast expanse between the Emba and Ural rivers features the Tenteksor saline flat, which is interrupted by the Berovskie Ridges - slightly saline elevated landforms. In its lower sections, the Emba River divides into distributaries that, during the summer months, due to low water flow, turn into a series of shallow lakes.

The Buzachi Peninsula features a low-lying saline shoreline that gradually bends to the east, creating the now-dry Komsomolets Bay, which was previously called Dead Kultuk. A southern extension of this bay, which once nearly divided the Buzachi Peninsula from the Ustyurt Plateau, is currently a dry basin known as Kaydak Bay. Today, these regions are characterized as *sors* - arid saline flats interspersed with areas of shoreline that are densely vegetated. Further inland, a series of low sand dunes stretches across the terrain.

The northern coastline of the Mangyshlak Peninsula is bordered by the waters of Mangyshlak Bay. To the east, the bay is limited by the Buzachi Peninsula's shoreline, while to the west, it is adjacent to Kulaly Island.

Along the northern coastline of the Mangyshlak Peninsula, shallow waters stretch out into the sea. The Dolgiy Peninsula extends northward from the western coast of the Buzachi Peninsula.

The shoreline along the western coast of the Middle Caspian, from the latitude of Chechen Island to Zhiloy Island, is quite consistent. There is only one embayment in the north - the Agrakhan Bay - while in the south, the Apsheron Peninsula juts significantly into the sea, accompanied by an archipelago of islands sharing its name. For the remainder of this coastal stretch, only minor headlands slightly extend into the sea, representing deltaic formations from rivers that flow into the Caspian. Between this coastal section and the Apsheron Peninsula, there are no natural harbors or bays that are suitable for anchoring vessels, and there are also no islands present.

From Chechen Island to Makhachkala, the coastline extends in a south-southwest direction. It subsequently shifts to a south-southeast alignment, which generally continues along the entire length to the Kilyazinskaya Spit, where it initially veers southward before gradually transitioning to an eastward trajectory.

Chechen Island is divided from the Agrakhan Peninsula by a very shallow strait. The Agrakhan Peninsula, which is essentially a spit, along with the mainland coast, creates a shallow bay that shares its name. The seaward side of the peninsula is low-lying and sandy, vulnerable to flooding during wind-driven storm surges. A series of sand ridges runs parallel to the shore. Vegetation in the sandy areas is sparse, primarily consisting of wild wormwood and other steppe grasses, while the southern section of the peninsula is thickly covered with reeds. The western shore, which faces the bay, has a steeper gradient. The mainland coast is low, marshy, and blanketed with dense reed beds, interspersed with several slightly elevated, grass-covered regions further inland. The vicinity of the Sulak River also features lowland, although minor elevations can be found.

The partly swampy nature of this lowland landscape gradually transforms. South of the Sulak River mouth, the terrain starts to exhibit characteristics of mountainous relief. Between the Sulak River and Makhachkala, the coast is sparsely vegetated, although some areas contain patches of deciduous forest. As one moves further south, the elevations draw nearer to the shoreline.

Close to Makhachkala, the coastline becomes mountainous, with uplands extending northwestward. To the southwest, Mount Tirkitaū rises, adorned with vegetation. At a significant distance in the same direction stands another mountain - Kukurtbash.

From Makhachkala to the Apsheron Peninsula, mountains appear sporadically along the coast, sometimes nearing the shoreline and at other times retreating inland. To the south of Makhachkala, they pull back into the interior, allowing the coastal plain to expand to a width of up to five miles. Close to Cape Buynak, the mountains again approach the sea, only to recede inland by 18–20 km, returning to the shoreline near Derbent.

The coastline stretching from Cape Makhachkala to Derbent is characterized by a plain covered in grass, with some areas featuring steppe interspersed with sandy mounds. In many locations, particularly south of Cape Buynak, the plain is crisscrossed by numerous streams and channels, most of which completely dry up during the summer months. Vegetation flourishes more abundantly around these streams and rivulets.

To the south of Derbent, the mountains gradually pull away from the coastline, and near the Samur River, they lie 18–20 km or more inland. The headwaters of the Samur originate on the slopes of the Sarydag mountain massif. As it flows through a narrow rocky gorge, the river traverses the coastal lowland in its lower course and creates a broad alluvial cone at its mouth. During flood periods, the Samur transports its fresh waters deep into the sea, with the boundary of the turbid outflow being sharply delineated. Due to the accumulation of fluvial sediments and the decline in sea level, the Samur River delta is progressively advancing further into the Caspian Sea.

Southeast of the Nizovaya Pier, the mountains once again draw near to the shoreline. South of Cape Amiya, Mount Beshbarmak rises near the coast. From Nizovaya Pier to Mount Beshbarmak, and continuing to Cape Sarykaya-Bashi, the coast is marked by barren steppe with sandy mounds and extremely sparse vegetation, which tends to wither during the summer. Even the mountains in this area lack vegetation.

From Cape Sarykaya-Bashi, the coastline outlines the northern and northeastern edges of the Apsheron Peninsula, which stretches further south and concludes at Cape Shakhova Kosa. The northwestern area of the Apsheron Peninsula is somewhat hilly, with its northern section featuring rolling terrain, while the eastern region is characterized by a flat, low-lying plain.

The eastern shoreline of the Middle Caspian, defined by the boundaries from Cape Kuuli in the south to Cape Tyub-Karagan in the north, contrasts sharply with the western coast. Although the general alignment of the shoreline follows the same northwest-southeast direction as the western shore, numerous headlands extend into the sea, creating gulfs and bays. This abundance of headlands and inlets leads to a coastline that is highly indented.

From Cape Kuuli to the Kara-Bogaz-Gol Strait, the shoreline trends northward. Along the stretch from Cape Kuuli to Cape Karasengir, the coast is intermittently lined with relatively high dunes that are covered with shrubs. North of Cape Karasengir, the coastline is defined by the low-lying southern Kara-Bogaz-Gol Spit, which is dotted with small hummocks. The Kara-Bogaz-Gol Strait serves as a connection between the sea and the expansive Kara-Bogaz-Gol Bay. The northern and eastern shores of the bay, which are adjacent to the plateau, are elevated and occasionally feature cliffs, while the southern shore remains low-lying. The only source that replenishes the water lost to evaporation in this extensive "evaporator" is the inflow through the strait.

From the Kara-Bogaz-Gol Strait to Bekdash Bay, the coastline is shaped by the northern Kara-Bogaz-Gol Spit. For much of its length, it remains low-lying, with only the northern section where low hills approach the shoreline. Several minor headlands extend into the sea from this area. Here, the shoreline changes its orientation to north-northwest.

The coastline stretches northward from Bekdash Bay to Kazakh Bay. Near Urgench, which is situated seven miles north of Cape Bekdash, the shore is characterized by low, sandy terrain; however, as one moves further north, it transitions into elevated, cliffed, and rocky formations. In this region, a mountain plateau approaches the coastline, with small uplands such as Urgench, Omarata, Srod, and others extending close to the water's edge.

Kazakh Bay is recognized as one of the largest bays in the Caspian Sea. It is located between Cape Rakushechny and Cape Adamtash, extending inland for 45 kilometers. At the bay's head, the shallow Kendirli Bay is found, separated from the main bay by the Kendirli Spit. The shores formed by this spit are low, while the mainland coast is mountainous, featuring uplands that run parallel to the shoreline.

From Kazakh Bay to the conventional boundary with the Northern Caspian at Cape Tyub-Karagan, the general orientation of the shoreline is northwestward; however, this stretch is highly indented. Numerous headlands, including Peschany, Melovoy, Skalistyy, and Urdjuk, extend into the sea, and several gulfs and bays penetrate the land. Generally, the coast is elevated, cliffed, and exhibits a relatively uniform appearance. Low-lying areas can be found in the gulfs and bays, as well as between Cape Peschany and Cape Melovoy. In certain locations, the land is covered with grass that tends to wither during the summer months.

At the northernmost part of the described coastline lies one of the largest peninsulas in the Caspian Sea - the Mangyshlak Peninsula. The plateau of this peninsula rises on average 150-200 meters above sea level. Due to the presence of easily eroded loose deposits beneath the limestones, the compact upper layers gradually collapse, resulting in unusual rock formations. The coastline at the tip of the peninsula, Cape Tyub-Karagan, is particularly steep and cliffed.

The entire eastern coastline of the Middle Caspian is part of an endorheic drainage basin.

The western shore of the southern Caspian Sea commences at the tip of the Apsheron Peninsula. From Cape Shakhova Kosa to Cape Sangachaly, the shoreline curves significantly towards the south. At the center of this curve, Baku Bay extends inland, offering excellent protection from prevailing winds. Between Baku Bay and Astara, the coastline trends southward. This stretch of shore features numerous small headlands and bays; the delta of the Kura River juts into the sea, and to the south lies the expansive Kirov Bay, which is bordered seaward by the Kura Spit. These characteristics result in a highly indented coastline in this area.

From the western edge of Baku Bay (Cape Shikhovo) to Cape Alyat, the coastline is characterized by a mountain massif that approaches the sea, accompanied by a narrow lowland strip along the water's edge. The heights of individual mountains can reach up to 400 meters, with many being of volcanic origin.

Cape Alyat is a small, isolated elevation, in proximity to intermittently active mud volcanoes. To the west of Alyat, extending to the slopes of the coastal mountains, the shoreline is represented by a saline lowland. From Cape Alyat to the mouth of the Kura River, the coast is primarily low and flat, displaying certain steppe-like features, covered with low hummocks and bordered by a sandy beach. In this area, Cape Pirsagat and Cape Byandovan extend into the sea, with Pirsagat Bay situated between them, bounded seaward by a rocky ridge. Near Cape Byandovan, the coastline is low-lying and features salt flats, with sand mounds stretching along the shore. This plain was once the bed of the now-dried-up Pirsagat Bay. In

May 1930, alterations in the shoreline configuration were noted near Cape Byandovan. During a span of two hours, the cape progressively extended 74 meters into the ocean, while its submerged coastal area elevated by 3.7 meters above sea level. A number of cracks appeared along the slope of the elevation, and the cliff face of the headland experienced a significant change in its profile.

Further south, deep into the sea, lies the delta of the Kura River, the largest river in Transcaucasia. Until recently, the Kura emptied into the sea via two distributaries: the northeastern and the southeastern. Currently, the Kura delta has effectively evolved into a single-channel system, with the river's waters primarily flowing through the southeastern distributary. The northeastern distributary is now nearly inactive, carrying only about 4–5% of the river's total discharge. The Kura transports over 12 million tonnes of sediment each year to the coastal zone, leading to the progradation of the delta and the expansion of shallow waters toward the southeast. Between the southern shore of the Kura delta and the mainland lies the shallow Zuid-Ostoviy Kultyuk Bay, which is linked to the Kura by a newly dug navigable canal that carries approximately 35% of the river's discharge.

As a result of the operation of this new canal, the seaward growth of the underwater section of the delta toward the southeast has halted. In the offshore zone near the southeastern distributary, active erosion processes are taking place, wearing away sediments that were previously deposited in this region. At the same time, there has been a significant increase in the delta's progradation southward toward the bay.

Between the Kura Spit, which extends far into the sea in a southerly direction, and the mainland coast lies the vast shallow-water Kirov Bay, which is part of the Kyzylagach State Nature Reserve — an important wintering habitat for migratory waterfowl.

South of Kirov Bay and stretching to Astara, the coastline runs almost straight. Northward to Lankaran, the coast is low-lying and, in some areas, covered with grass, while further south it rises and becomes mountainous. In the Lankaran–Astara region, the Talysh Mountain Range runs parallel to the coastline, situated 5.5–7.5 km inland from the shore. The coastal area itself is mainly low-lying, although in some spots it drops steeply towards the sea.

The Astarachay River, which empties into the sea, serves as the boundary with Iran. The Lankaran–Astara coastal zone is positioned at the latitude of the Mediterranean subtropics and shares similar climatic characteristics. Easterly and southeasterly winds carry dense, moisture-rich clouds from the sea towards the Talysh Mountains. As these clouds cool, they generate mountain streams that cascade through forested gorges, returning moisture to the Caspian Sea. Annual rainfall varies between 1,000 and 1,300 mm, with most precipitation occurring in the autumn and winter months. Summers are typically very hot and dry.

From Iranian Astara, located on the right bank of the Astarachay River, the coastline extends southward before generally trending eastward, and near Bandar-e Torkaman (formerly known as Bender Shah), it turns northward. Along the eastern coastline, the state border with Iran is situated south of Hasan-Quli. This entire stretch of coast is under Iranian jurisdiction.

Along the Iranian coastline (up to Bandar-e Torkaman), the Baghroudag and Alborz mountain ranges extend, reaching heights of up to 3,000 m, located 28 km from the coast. South of Iranian Astara, the mountain spurs nearly reach the water's edge, creating a high, cliffed coastline in certain areas. Where the mountains significantly retreat from the shoreline, the coast becomes low-lying with a narrow band of beaches. The mountain ranges generally present a uniform appearance, with many peaks capped in permanent snow. Several non-navigable rivers flow down from the mountains into the sea. The coastal zone is marked by lush vegetation. The mountain slopes are adorned with thick forests, while shrubs flourish at their bases.

Along this coastal stretch, similar to other sea areas, there are numerous capes, including Limir, Shirabad, Liār, Kerganrud, Essalem, Sefidrud, Kasumabad, Chaboksar, Turkrud, and Chalus. However, the shoreline remains relatively smooth, exhibiting minimal indentation, as the capes—aside from Cape Sefidrud—extend only slightly into the sea. These capes are of low elevation, with most covered in forest or shrubbery. A notable characteristic of these capes is that nearly all are situated near the mouths of rivers or streams, where sandbars have formed. A prominent example is Cape Sefidrud, which has emerged from sediment deposition carried by the Old Sefidrud River into the sea.

In addition to the many capes, two bays are found along the Iranian coast: Pahlavi Bay and Gorgan Bay. Pahlavi Bay is located in the southwestern region of the sea; it is shallow but hosts Iran’s largest Caspian port. The bay is separated from the open sea by spits and connects to it through a strait where the current is almost always directed seaward, due to the significant inflow of river waters into the bay. In the southeastern part of the Caspian, Gorgan Bay extends deeply inland toward the west.

Gorgan Bay is separated from the sea by the Miankaleh Peninsula, a low and narrow spit that stretches approximately 60 km. Gorgan Bay is categorized as a silting and overgrowing bay, making it morphologically similar to Kirov Bay. Currently, due to a decrease in water levels, the bay has become so shallow that navigation is no longer feasible; even the artificial navigation channel has become entirely unusable.

The eastern coastline stretching from Bandar-e Torkaman to the conventional demarcation between the southern and middle parts of the Caspian Sea (Cape Kuuli) is largely consistent and mainly flat. In certain regions, sand dunes can be found, gradually increasing in height from south to north.

The northern section of this coastal area is significantly carved by two major bays - the Turkmen Bay and the Krasnovodsk Bay - divided by the Cheleken Peninsula, which juts out extensively into the sea. The vegetation along the shoreline is quite limited; shrubs are occasionally present, and grass is seen only infrequently.

The coastal area extending from Gorgan Bay to the Atrek River is, from a physico-geographical standpoint, significantly different from the remainder of the southern Caspian coast; it embodies a Central Asian region defined by steppe landscapes. To the north, there is a gradual shift from the steppe landscapes of the Atrek and Hasan-Quli regions to the terrains of the Turkmen sandy desert.

Morphologically, the coastline is characterized by its low, shallow, and sandy nature. Influenced by winds, the sands along this section of the coast create ridge-like chains of dunes, which are typically irregular in shape. The sandy dune fields are bordered by a narrow, gently sloping sandy beach that separates them from the shoreline. In addition to the sand dunes, there are isolated hill-like formations of volcanic and erosional origin, some of which are specifically named, such as the Belyi and Zelenyi Kyzmama dunes and Mount Kherem. Along the entire stretch leading to Turkmen Bay, both the coast and the seabed consist of sands, generally fine-grained and occasionally containing shell fragments.
The Cheleken Peninsula, which divides the Turkmen and Krasnovodsk Bays, is the largest in the southern Caspian and is abundant in oil reserves.

Turkmen Bay is bordered by the mainland coast, the southern shore of the Cheleken Peninsula that curves southward, and on the seaward side, by the narrow Ogurchinsky Island, which is oriented in a north-south direction.

At its northern end, Turkmen Bay opens to the sea through the Cheleken-Ogurchinsky Strait. The shores of the bay are low and desert-like, resembling the coastline to its south. The eastern shore of the bay is deeply indented, featuring a series of small spits and minor coves. Overall, the bay is shallow.

Krasnovodsk Bay, recognized as one of the largest bays in the Caspian Sea, is bordered to the south by the northern coastline of the Cheleken Peninsula, and to the west by the Northern Cheleken and Krasnovodsk spits, which together form the entrance to the bay. The southern, eastern, and western shores of Krasnovodsk Bay are characterized by low-lying areas with sand dunes. In contrast, the northern shore is mountainous, featuring the Kubadag and Kaylidag ranges, which are marked by steep cliffs and deep gorges, along with the Shahadam Mountains. The bay is shallow, necessitating navigation to Krasnovodsk via a designated navigable channel. To facilitate a more direct route, an artificial passage has been constructed through the Krasnovodsk spit.

Along the brief stretch from Cape Tarta to Cape Kuuli, the coastline remains low, and a small bay known as Kianly Bay can be found.

Islands and shoals. The Caspian Sea is home to a variety of islands and shoals, predominantly situated in its northern and southern regions. In the Middle Caspian, such features are nearly nonexistent.

At the average long-term level of the Caspian Sea, the total area occupied by islands is 740 km^2 in the northern region, 120 km^2 in the middle region, and 1,300 km^2 in the southern region, resulting in a cumulative total of *2,160* km^2.

A comprehensive account of all islands and shoals is not required to grasp their distribution; it suffices to mention a select few. The highest density of islands in the northern Caspian Sea is located in its western section.

At the northern tip of the Agrakhan Peninsula (on the western shore of the Northern Caspian) are the Chechen Islands, which consist of Chechen, Yaitchny, and several smaller isles. The most prominent of this group is Chechen Island, which is elongated along the parallel. Its beaches are sandy and lined with reeds and grass. Southeast of Chechen Island are the

Pichugin and Lopatin Islands, which have merged with Chechen Island due to the drop in sea level.

Between the Chechen Islands and the village of Bolshoye Ganyushkino *(Big Ganyushkino),* situated at the source of the Malyy Aral (Small Aral) branch of the Volga River, the coastline is deeply indented with numerous channels and distributaries of the Volga delta, effectively creating a multitude of islands.

A notable characteristic of the marine area adjacent to this section of the coast, as well as the entire western portion of the Caspian, is its shallow depth and the abundance of islands, shoals, and sandbanks.

To the north-northwest of the Cheleken Islands is Tyuleniy Island. The island's surface mainly consists of sandy deposits with shell fragments. Its coastlines are typically low, except for the northwestern section, which is somewhat raised. A wide shoal extends southeast from the island's eastern shore. During strong offshore winds, the eastern shore can dry out over a span of 2–3 km.

North of Tyuleniy Island is Tyulenya Shoal; to the east lies Tbilisi Shoal, and to the south is Bakhtemir Shoal, among others. Further to the east, there is a collection of additional shoals: to the southeast is Bolshaya Zhemchuzhnaya (*Big Pearl*), and to the north of it, aligned in a north-south direction, are Srednyaya Zhemchuzhnaya and Rakushechnaya Shoals. This region also features several islands, including Maly Zhemchuzhny, Chistaya Banka, and Iskusstvenny.

To the south and southeast of the settlement Bolshoye Ganyushkino *(Big Ganyushkino),* are the islands Dzhambaysky, Novinsky, Zhestky, and Ukatny. All of these islands were formed on the sites of previous shoals and vary significantly in size.

A short distance southwest of the Zolotoy distributary mouth of the Ural River is the Peshnoy Peninsula, which was created from the former islands of Peshny, Yegorycheva, and Shalygi, which merged due to shoaling.

The eastern section of the Northern Caspian lacks the same number of islands found in the western region. Only at the entrance of Mangyshlak Bay, on the shoal that extends from its eastern coastline, can one find a cluster of islands known as the Tyuleniy Islands. This group consists of Kulaly, Morskoy, Podgory, Rybachiy, and Novy Islands. Kulaly Island is the largest among them. It features an arcuate shape that is concave towards the northeast and southeast, and is made up of alluvial sand mixed with silt and marine vegetation.

In the central region of the Caspian Sea, islands are quite rare. To the east and north of the Absheron Peninsula, one can find the islands, shoals, and rocks that make up the Absheron Archipelago. Based on the widely accepted classification of the Caspian into different regions, Oil Rocks Island (Ostrov Neftyanye Kamni) is categorized as part of the southern section. The most significant islands within this archipelago are Artem and Zhiloy. Additionally, there exists another island in the central area of the sea, close to the eastern shore - Karaada Island -which provides shelter to Bekdash Bay from the west. This island is small and rocky.

The southern Caspian, similar to the northern section of the sea, is abundant in islands and shoals. Located south of the Absheron Peninsula are Nargen, Vulf, and Peschanıy Islands. Stretching from Baku Bay to the end of the Kurin Spit, there are numerous islands: Duvannıy, Bulla, Glinyany, Los’ (Elk), Svinoy (Pig), Oblivnoy, Kurinsky Kamen’, and Ignatiy Stone, along with shoals such as Savenkov, Persiyanin, Kumani, Pogorelaya Plita, Kornilov-Pavlov, Golovanov, Voenmor, Bezymyannaya, Andreev, Kalmychkov, Karagedov, Borisov, and others. All these islands and shoals are part of the Baku Archipelago. The largest islands in this archipelago include Bulla, Glinyany, Los’, and Svinoy.

The area in question is prone to volcanic activity, which has been historically documented and persists to this day. This volcanic activity is characterized by gas eruptions that are often accompanied by the expulsion of rocks and liquid mud. Eruptions from underwater volcanoes can sometimes result in the uplift or sinking of the ocean floor. Consequently, in the regions of the Absheron and Baku archipelagos, the morphology of the seabed is altered, affecting the configuration, height, and size of islands, as well as the locations of shoals. The release of large amounts of sediment and the elevation of the seabed frequently convert shoals into islands, which may subsequently erode and revert to shoals due to the effects of currents and wave action.

Alongside the many islands and shoals, this region is also home to oil fields, where drilling rigs have been established.

Numerous oil rigs are situated near Artem Island and Zhivoy Island. The offshore oil extraction at Neftyanie Kamni, also known as "Oil Rocks," stands as one of Azerbaijan's notable accomplishments, showcasing considerable technical advancement. Located on the eastern shore of the Southern Caspian, Ogurchinsky Island marks the western edge of Turkmen Bay. This island is characterized by its low elevation, sandy terrain, and scattered dunes, extending in a north-south orientation and tapering into a slender spit to the south.

In the same maritime region, one can find the shoals of Livanov, Zhdanov, Ulsky, and the Dirty Volcano. The Livanov Shoal has frequently surfaced as an island, only to later sink back beneath the waves.

These succinct details regarding the islands and shoals in the sea offer only a broad perspective. Due to the varying levels of the Caspian Sea, maps can only provide an approximation of the actual, ever-evolving morphology of the region.

Source: "Physical processes in the Caspian Sea in connection with fluctuations in its level". Baku, "Elm" Publishing house,1971, pp. 5-27. Author: K. K. Gyul and others.

1.2. A BRIEF HISTORY OF CASPIAN SEA RESEARCH

The Caspian Sea holds the title of the largest lake globally. Its extensive size and saline waters led to its classification as a 'sea' in ancient times.

The economic importance of the Caspian Sea, coupled with its unique physico-geographical features, has consistently drawn the interest of researchers. Many scholars, both from Russia and abroad, have dedicated their studies to the Caspian.

Nevertheless, the most in-depth and thorough research has primarily been conducted by Russian scientists and naval experts.

Throughout different eras, notable scholars such as P. S. Pallas, E. I. Eichwald, E. Kh. Lenz, K. M. Baer, N. I. Khanykov, N. M. Filippov, G. S. Karelin, A. I. Voeikov, N. I. Andrusov, N. M. Knipovich, Yu. I. Shokalsky, A. V. Voznesensky, P. A. Pravoslavlev, S. A. Kovalevsky, L. S. Berg, A. I. Mikhalevsky, A. A. Kaminsky, G. R. Bregman, B. A. Apollov, S. V. Bruevich, and V. B. Shtokman, among others, have engaged in research on the Caspian Sea.

The history of this ancient lake-sea dates back to the depths of geological time. Throughout its existence, the Caspian has shifted between being a warm, enclosed, saline body of water and a cold, open, freshwater basin. The Caspian Sea has undergone numerous changes in its appearance and size before reaching its current form.

Investigating these changes involves reconstructing the environmental conditions that existed in earlier periods, including its shoreline morphology and other physico-geographical characteristics, as well as the flora and fauna that once thrived there.

The descriptions of the Caspian Sea found in the writings of ancient geographers and authors tend to be imprecise and frequently contradictory.

Some scholars from that time believed that the Argonauts - mythical heroes featured in the works of the ancient Greek poet

Homer - had journeyed from the Black Sea into the Caspian Sea through the Manych Strait.

Subsequent Greek scholars and geographers - *Hecataeus of Miletus, Herodotus, Aristotle, and Eratosthenes* - viewed the Caspian as either a closed sea or a gulf of the ocean (Fig. 1). A few of them argued that instead of the Caspian, there were two separate enclosed seas linked by a strait. Strabo illustrated the Caspian as being elongated along a west - east orientation.

The depiction of the Caspian Sea that most accurately reflects reality is found in the maps created by Ptolemy.

The belief among the ancient Greeks that the Caspian was a gulf of the ocean was not coincidental. This likely referred to a time when the Caspian, filled with meltwater from glaciers, extended significantly to the north and was connected to the Black Sea via the Manych Strait.

The understanding of the Caspian Sea among Western European scholars during the Middle Ages and even into the Renaissance was quite limited. The maps created by Marino Sanuto (1320), the Pizzigani brothers (1367), and the Catalan Atlas (1375), which were based on the voyages of the Genoese, illustrate the Caspian Sea and its adjacent regions in a notably inaccurate way.

Among these maps, the one by Fra Mauro (1459) is particularly noteworthy for offering a relatively accurate representation of both the overall shape of the Caspian Sea and its distinct areas.

In all the previously mentioned maps, the Amu Darya River is depicted as flowing into the Caspian Sea, with no sign of any link to the Black Sea. Numerous islands are illustrated within the sea.

A sufficiently accurate description of the Caspian Sea, along with a corresponding map, was created by Adam Olearius in 1636.

In 1558, the Englishman Anthony Jenkinson embarked on a journey through Moscow and Astrakhan to Khiva and Bukhara. The map he produced offers a distinctly inaccurate portrayal of the Caspian Sea, and the descriptions that accompany it are similarly flawed.

Details regarding the Caspian Sea can also be found in various works by Arab authors and geographers. Some represented the Caspian as circular, while others depicted it as elongated along a parallel. The Arab traveler and geographer Abu Ishaq Ibrahim ibn Muhammad al-Farisi al-Istakhri, who lived in the 10th century (951–1000 CE), illustrated the Caspian Sea as a circle in the maps attached to his *Book of the Paths of States*, referring to it as *Bahr al-Khazar*. His map includes several neighboring states, with two islands situated in the center of the sea.On the maps created by Abu Abdullah Muhammad al-Idrisi (1099–1165 CE), the Caspian Sea is shown oriented from north to south.

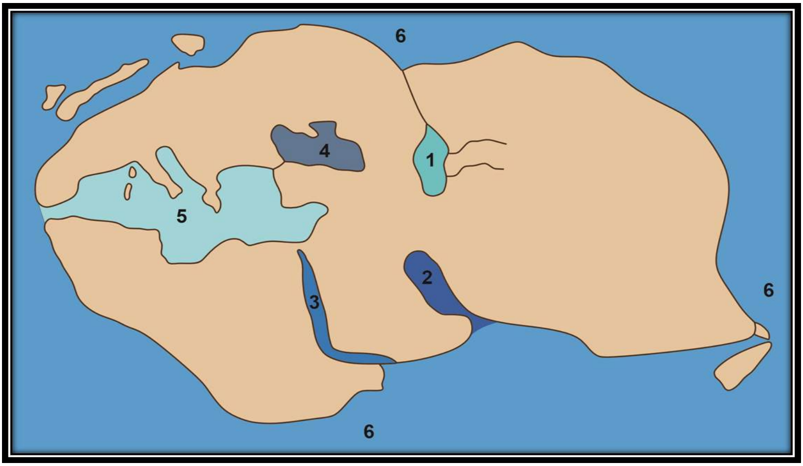


Fig. 1 The Caspian Sea as depicted on Eratosthenes' world map from the 3rd century BCE:

1 — Caspian Sea; 2 — Persian Gulf; 3 — Arabian Gulf; 4 — Pontus Euxinus (Black Sea); 5 — Mediterranean Sea; 6 — Ocean.

Muhammad ibn Ali ibn Ahmad al-Sharafi (1601), influenced by the works of al-Idrisi, illustrated the Caspian Sea on his map, referring to it as *Bahr al-Khazar*.

The Caspian was also mentioned by al-Farghani, al-Mas‘udi, Ibn Hawqal, and al-Qazwini. Throughout its extensive history, the Caspian Sea has been known by as many as forty different names. These names were typically derived from the various peoples living along its shores or from the names of cities, regions, and countries situated along its coastline.

Consequently, the Arabs referred to the Caspian as the Hyrcanian Sea—named after the coastal area of Hyrcania (“the land of wolves”); the Abeskun Sea—after the coastal town of

Abeskun; as well as the Daylamite Sea, the Jurjan Sea, the Kulzum Sea, and the Khazar Sea—named after the Khazars, a group that resided on its northwestern shore.

In Russian tradition, the Caspian Sea was called the Khvalyn Sea, named for the people living at the mouth of the Volga River.

In the Russian epic poem about the Novgorod merchant Sadko, it is stated:

“Sadko, the merchant, the affluent guest, would navigate with his ships along the Volkhov... He traveled along the Volga River, fully aware of it down to its mouth and the lower realm of Astrakhan. He sailed upon the sea, upon the azure Khvalyn Sea.”

The term "Caspian Sea" originates from the Caspii, a group that lived along its southwestern coastline.

The Caspian Sea and its surrounding areas have been recognized by the Russians since antiquity. The Iranian historian Ibn Isfandiyar documents Russian voyages in the Caspian and their arrival at the port of Abeskun in the year 909.

In 913, under Igor's rule, 50,000 Russian warriors set sail on 500 ships for the Caspian Sea. They departed from the Dnieper, entered the Black Sea, navigated through the Kerch–Yenikale Strait into the Sea of Azov, and then ascended the Don River. Near the Kachalinskaya stanitsa, they transported their vessels overland and launched them into the Volga, navigating to the southwestern region of the Caspian Sea.

A similar expedition took place in 943–944, during which Russian navigators reached the Absheron Peninsula and even ventured up the Kura River, reaching as far as the city of Barda. Subsequently, Russian merchants began trading along the Caspian Sea's shores, utilizing it as a route to India.
For example, the Tver merchant Afanasy Nikitin visited Derbent and Baku in the latter half of the 15th century on his journey to India.

Additionally, a 12th-century map exists (Fig. 2).

By Ivan IV's decree in 1551, the *Great Plan of the Entire Muscovite State, as well as All Neighboring States* was created. Although the original *Great Plan* has not survived, its preserved description shows that the Caspian Sea was already illustrated on it.

In 1623, the Russian merchant Fedot Kotov journeyed through Astrakhan to Iran. During the 17th century, Russian cartographers continued to produce increasingly precise maps of the Caspian Sea.

Semen Remizov's maps also featured illustrations of the Caspian Sea. Nevertheless, genuine hydrographic research of the Caspian Sea only commenced during the rule of Peter I.

Following Peter's orders, the examination of the eastern coastline of the Caspian Sea was carried out in 1715 by Guards Lieutenant Prince A. Bekovich-Cherkassky, and in 1718 by Lieutenants Urusov, Kotin, and Travin.

Upon discovering the ancient Uzboy channel, Peter I aimed to redirect the Amu Darya back to its original path, intending to create a waterway to India.

Prince A. Bekovich-Cherkassky was tasked with assessing the viability of redirecting the Amu Darya into its historical channel leading to the Caspian Sea.

In 1720, Van Verden and Soymonov carried out surveys and created detailed accounts of the western and southern coastlines of the Caspian Sea. I. F. Soymonov, a notable statesman of the era, not only mapped the Caspian's shores from 1719 to 1729 but also developed an extensive hydrographic description of the sea.

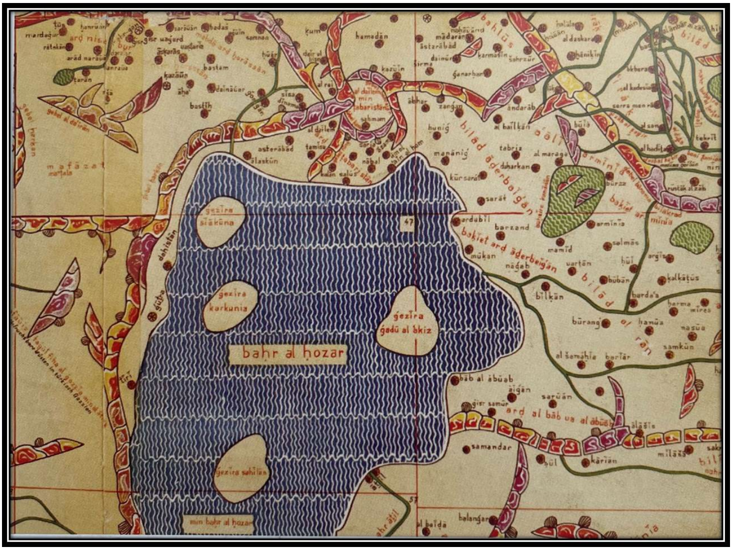


Fig. 2. Map of the Caspian Sea (al-Idrisi, 12th century).

The maps detailing the Caspian Sea and its adjacent areas, created by Bekovich, Urusov, Kotin, Travin, Soymonov, and Van Verden, along with some reproductions, are still housed in the manuscript department of the Academy of Sciences of the USSR. Although they contain some inaccuracies, these maps are recognized as authentic nautical charts. I. F. Soymonov was responsible for the first comprehensive description of Baku Bay and its original map.

Van Verden’s map utilized twelve astronomical points, established in partnership with I. F. Soymonov. In 1721, Peter I forwarded this map to the Paris Academy of Sciences, where it was published in French. This map laid the groundwork for precise representations of the Caspian Sea in Western European cartography and continues to hold scientific significance today (Fig. 3).

Fig. 3. Map of the Caspian Sea created under the directive of Emperor Peter I. Lithographed in 1730 in Augsburg, Germany.

The initial atlas of maps and the first sailing directions (loiçia) for the Caspian Sea were created in 1731 by I. F. Soymonov. This publication was named *“Description of the Caspian Sea* *from the Mouth of the Volga, from the Yarkovokoy Channel to the Mouth of the Astrabad River, of the Western and Eastern Shores, Depths and Bottoms, and Views of Notable Mountains."* In 1736, a map of the Caspian Sea was released in London by the Bowles publishers (Fig. 4).

The examination of the eastern coastline was conducted by Tokmachev during 1764–1765. In 1762, Panin explored the southern coastline. The enhancement of the hydrography of the Caspian Sea persisted throughout the 18th century.

Alongside research primarily focused on cartography and hydrography, the St. Petersburg Academy of Sciences tasked P. S. Pallas with performing scientific studies in the Caspian Sea from 1769 to 1773. Pallas developed the accurate theory that connected variations in the Caspian Sea level to climatic influences. This era also saw the contributions of Gmelin. By the dawn of the 19th century, all previously mentioned maps had become obsolete.

Because of the fluctuating levels of the Caspian Sea, partial surveys were insufficient to amend the existing maps or to provide a precise representation of the entire sea.

Consequently, in 1826, a new atlas of the Caspian Sea was published, based on surveys carried out by navigator A. I. Kolodkin from 1813 to 1817. Kolodkin's efforts improved the maps and descriptions of his predecessors, aligning them more closely with reality. The atlas comprised 17 maps.

The chronometric expedition, which took place from 1838 to 1839 along the Iranian coastline under the direction of the General Staff, enhanced Kolodkin's surveys.

Hydrographic surveys of specific areas of the Caspian Sea were carried out by hydrographers Muravyov, Basargin, Mikhaylov, and others.

Fig. 4. A map depicting the Caspian Sea from the early 18th century, created by Herman Moll. This map is included in the David Rumsey Historical Map Collection.

In 1825, the expedition led by naturalist and zoologist E. I. Eichwald gathered extensive data on the fauna of the Caspian

Sea and its coastal regions. From 1832 to 1836, G. S. Karelin's expedition studied the physical geography of the eastern shore, conducting a series of surveys that resulted in the creation of ten maps. G. S. Karelin was the first to explore Kara-Bogaz-Gol Bay, chart its features, and identify a strong current flowing from the sea into the bay, correctly linking this phenomenon to the significant evaporation occurring within the bay.

At that time, the fluctuations in the Caspian Sea's level were already recognized among its physical and geographical characteristics. Unlike other seas connected to the ocean, the Caspian Sea experienced periodic level changes. These fluctuations had captured the interest of the local populations along its shores since ancient times.

The unusual variations in the Caspian Sea's water level inspired numerous legends among the local inhabitants, including tales of an underground connection between the Caspian and the Black and Aral Seas; a subterranean channel linking it to the Persian Gulf, into which Caspian waters were believed to flow, causing a drop in sea level; stories of water retreating into the "Black Mouth" - Kara-Bogaz-Gol Bay - where it was said that water disappears into the earth through a whirlpool; and accounts of numerous volcanoes on the sea floor that supposedly either absorb or release the water anew.

At the start of the 19th century, the burgeoning fisheries and navigation on the Caspian Sea faced significant setbacks due to a drop in its water level. This issue drew the interest of the Imperial Academy of Sciences. To explore the reasons and characteristics of these changes, the Academy sent Academician E. Kh. Lenz to the Caspian region. Upon reaching Baku in 1850, E. Kh. Lenz set up two permanent benchmarks (reference points) — one on a rock located south of the city wall, and the other on a rock in a small eastern cove of Nargin Island. These benchmarks, made of iron bolts embedded in the rock, were designed for comparative measurements of sea levels recorded in various years.

At the behest of Academician E. Kh. Lenz, in 1836 the Ministry of Finance directed the Baku Customs Office to implement systematic observations of the Caspian Sea level in Baku Bay, with the aim, as outlined in the directive, *"to secure definitive evidence of the alleged decrease in the surface of the Caspian Sea, or, as some contend, its cyclical rise..."*.

In 1837, the Ministry of Finance provided comprehensive guidelines for carrying out these observations. As a result, on February 1, 1837, under the oversight of the customs office head, Spassky-Avtonomov, systematic instrumental observations of the Caspian Sea level began. These measurements were conducted using a tide gauge placed in a channel opposite the customs house.

By the directive of Colonel Alekseev, who was the head of the Hydrographic Department of the Caspian Sea, observations were moved in 1866 to the naval harbor, where a new tide gauge was set up at Cape Bailov.

The monitoring of sea level at Cape Bailov has been ongoing ever since.

Interest in the thorough examination of the Caspian Sea and its physical geography surged in the latter half of the 19th century, as the establishment of postal and passenger steamship services, along with naval vessel navigation, necessitated accurate charts and hydrographic descriptions.

The Naval Ministry's expedition, led by Captain 2nd Rank N. A. Ivashintsov, commenced its research in 1856. Despite facing numerous challenges and setbacks, which resulted in the loss of some expedition members, Ivashintsov successfully concluded his investigations a decade later in 1867.

In 1870, N. A. Ivashintsov, who had risen to the rank of Rear Admiral, passed away before the results of his fourteen years of labor could be published. These results were eventually released in 1877 by his close associate, N. Pushchin.

The expedition's efforts resulted in the creation of 25 highly detailed charts covering various areas of the Caspian Sea, 24 accurate plans, and two atlases. N. A. Ivashintsov also compiled a comprehensive atlas of magnetic declination and made the initial attempt to calculate the water balance of the Caspian Sea. Lieutenant Ulsky, another member of the expedition, prepared a depth chart. The contributions of Ivashintsov’s expedition were acknowledged not only by navigators but also by the academic community.

In 1853, Academician N. V. Khanykov initiated an investigation into the nature and causes of the long-term fluctuations in the Caspian Sea level, concluding that these variations were influenced more by climatic factors than geological ones. To gather historical data on the sea's levels, N. V. Khanykov made extensive use of accounts from Eastern authors.

From 1853 to 1856, a scientific expedition led by K. M. Baer and Danilevsky conducted research on the ichthyofauna and hydrochemistry of the Caspian Sea.

The exploration of the Caspian Sea's fauna was further developed through the contributions of zoologist O. A. Grimm and others. The findings of the Aral–Caspian Expedition, published in 1876 under O. A. Grimm's editorship, refuted the mistaken notion, which dated back to E. I. Eichwald's time, that the Caspian Sea lacked diversity in invertebrate species and individuals. This publication also provided the first account of the fauna found in Baku Bay.

The expedition led by O. A. Grimm revealed that the fauna in the southwestern and southern regions of the Caspian Sea is considerably more diverse than that found in the eastern region. The same observation holds true for its vegetation.

In 1897, N. I. Andrusov's expedition carried out research on the hydrography, hydrochemistry, and geology of Kara-Bogaz-Gol Bay. N. I. Andrusov analyzed the geological composition of the region, gathered specimens of local flora and fauna, and found that fish brought into the bay by the current die upon entering the highly concentrated brine, undergoing a natural salting process, and are later washed ashore, providing sustenance for birds and the local community.

The expedition's most notable finding was the identification of a layer of pure Glauber’s salt on the bay floor, which measured 13-14 meters in thickness.

In 1904, A. A. Lebedintsev studied the hydrochemistry of the Caspian Sea. The goal of the expedition was to explore the migration patterns of Caspian herring and the herring fishery. A significant number of water samples were collected, allowing for the determination of the chemical composition of water across various regions of the Caspian Sea.

In 1911, the Department of Commercial Ports set up the Hydrometeorological Service of the Caspian Sea, which included seven hydrometeorological stations along with a central station situated in Petrovsk (currently known as Makhachkala). This central station was managed by A. F. Vangenheim.

The outcomes of three expeditions to the Caspian Sea, led by the distinguished marine researcher, Prof. N. I. Knipovich, represented the peak of Caspian Sea research during the pre-Soviet era. Among these, the third expedition, which took place from 1914 to 1915, held the most importance.

The results from all three expeditions were compiled into a significant report published in 1921. This document offered a comprehensive physical and geographical overview of the entire Caspian Sea, detailing the distribution of temperature, gases, salinity, and marine life, as well as analyzing currents and variations in water levels.

With the advent of Soviet governance, a new chapter in the exploration of the Caspian Sea commenced, marked by a considerable growth in the hydrometeorological network and an increase in the frequency of scientific expeditions.

In 1922, the Baku Marine Observatory was founded by the Administration for the Safety of Navigation on the Caspian Sea. The observatory was established to carry out a thorough and detailed examination of the physical, geographical, and hydrophysical conditions of the Caspian Sea, leading to research in marine meteorology, sea climatology, hydrology, aerology, synoptics, and terrestrial magnetism. A network of hydrometeorological stations and ice observation posts was set up throughout the sea, and within the observatory, a Weather Bureau and a Time Service were also created. In 1930, the Unified Hydrometeorological Service Administration of the Azerbaijan SSR and the Caspian Sea was formed, consolidating the vast network of hydrometeorological stations across the republic's land and along the Caspian coast. A. I. Mikhalevsky and N. V. Malinovsky are credited with the establishment of the Baku Marine Observatory and the effective organization of its operations.

A number of expeditions have been sent to the Caspian Sea with the goal of conducting a thorough investigation. During 1933–1934, expeditions organized by the Academy of Sciences of the USSR gathered extensive data on the hydrochemistry of the Caspian Sea, which allowed S. V. Bruyevich to refine its hydrochemical characteristics.

B. D. Zaikov conducted significant work to determine the water balance of the sea. Geological surveys are underway to investigate offshore oil fields, and the hydrogeological conditions of oil-rich areas are being examined.

Hydrographic expeditions are consistently monitoring all alterations in the sea's contours and depths, thus supporting the requirements of the region's vast navigation system.

The ambitious plans for national economic development necessitate not only a comprehensive understanding of the current hydrological regime of the Caspian Sea but also its future projections - an area of research currently being explored by scientists in our nation.

Source: "The Caspian Sea". Baku, "Aznefteizdat" Publishing house, 1956, pp.12-24.
Author: K. K. Gyul.

1.3 REVIEW OF STUDIES ON THE CASPIAN SEA COASTLINE

The Caspian Sea and its surrounding regions have consistently drawn interest from a diverse array of scholars. This summary primarily highlights significant studies pertaining to the geological, hydrological, hydrobiological, hydrochemical, and geophysical examination of the Caspian shoreline. Consequently, we will provide concise mentions of those investigations that offer new insights regarding the Caspian Sea's shores, with a particular focus on geomorphological studies. Regarding the historical context of geological and hydrological research on the Caspian Sea coast, it is essential to reference several recent comprehensive studies that address these topics in considerable detail: Issues I and IV of the *Proceedings of the Comprehensive Southern Geological Expedition* (1953, 1959), Volume XXII of *Geology of the USSR* (1957), *Geomorphology of Azerbaijan* (1959), the monograph authored by P. V. Fedorov (1957), as well as works by M. P. Kazakov, M. M. Charygin, and their collaborators (1958), along with the collection titled *Aerial Geological Survey of the Shallow Zones of the Caspian Sea*, edited by V. V. Sharkov (1958). The history of hydrological studies concerning the coastal waters of the Caspian is detailed in Volume XV of the

Proceedings of the Institute of Oceanology (edited by B. A. Apollov, 1957), which focuses on the examination of fluctuations in the Caspian Sea level.

Information regarding the early research history of the Caspian Sea coasts—from ancient times to the mid-19th century—can be found in the writings of L. Bagrov (1912), L. S. Berg (1934), and the pamphlet authored by E. L. Shteinberg (1949).

The evolution of the study of the Caspian Sea shores can be broadly categorized into three distinct phases stated below:

1. 1717-1809 – The development of the first schematic maps derived from visual observations and survey reports.

2. 1809-1934 – The production of precise geographic maps utilizing instrumental techniques, alongside geological studies of the coasts that included more detailed descriptions.

3. From the mid-1930s to the present – Comprehensive geomorphological research, the identification of marine terrace systems, the reconstruction of the Quaternary history of the Caspian Sea, and the exploration of contemporary coastal dynamics employing various scientific approaches.

Prior to the early 18th century, information about the Caspian coastline was notably limited and often inaccurate. The primary sources consisted of accounts from "trading people" who occasionally journeyed by sea to Persia and Turkmenistan. The systematic study of the Caspian shores began in 1715, when, at the behest of Peter I, a special expedition was established under the leadership of A. Bekovich-Cherkassky, who was the first to document and chart the eastern shore of the Caspian from Astrakhan to the Krasnovodsk Gulf. This map was later refined between 1716 and 1718 through the efforts of A. Kozhin and V. A. Urusov. During this same timeframe, F. I. Soymonov, K.-P. van Verden, and V. A. Urusov created maps of the western and southern coasts of the sea.

More extensive hydrographic information was gathered through subsequent expeditions led by F. I. Soymonov (1726-1731), who, among other contributions, offered general descriptions of Kulaly Island, the Mangyshlak coast, and the approaches to Kara-Boghaz-Gol (refer to Fig. 1).

The hydrographic studies conducted by Tolmachev and Lodyzhensky furthered these efforts, as they detailed the coasts of the Tyub-Karagan Peninsula and identified Kenderli Bay and Spit. Lodyzhensky noted, *"This spit, with a small island at its end, creates a good and secure harbor, protected from sea disturbances, where the water reaches depths of up to 5 fathoms..."* (quoted in E. L. Shteinberg, 1949, p. 24).

In Lodyzhensky's journal, there is an entry regarding the Krasnovodsk Spit, which mentions that "the entire spit was washed through by water." The expedition also included a brief overview of the former Balkhash Bay and conducted a survey of the island (now a peninsula) of Cheleken.

In 1766, Tolmachev advanced the hydrographic survey of the eastern coast, while navigator Panin recorded details of the northern shoreline of the Caspian.

During the 1780s, a military-hydrographic expedition under M. I. Voinovich explored part of the western coastline, visited Zhiloy Island and several nearby islands close to the Absheron Peninsula, and assessed the southern (Iranian) coast of the

Caspian Sea. M. I. Voinovich also provided a description of Ogurchinsky Island and was the first to suggest the hypothesis of underwater oil deposits in the vicinity based on observations near Zhiloy Island (E. L. Shteinberg, 1949).

The hydrographic investigations carried out in the 18th century allowed Admiral A. I. Nagaev to create a comprehensive map of the Caspian Sea, which was published in 1796. This map was the first to illustrate data on the contours of the Caspian Sea and the depths of its coastal regions, gathered through systematic compass surveys and the findings of previous researchers.

Further enhancement of understanding regarding the shores of the Caspian Sea took place due to various hydrographic and geographic expeditions carried out in the 19th century. Among these, the hydrographic surveys and descriptions led by A. E. Kolodkin, who created the first hydrographic atlas of the Caspian Sea, were particularly significant. These efforts initiated a new phase in the exploration of the Caspian coastline.

The hydrographic surveys conducted during A. E. Kolodkin's expedition (1809–1814) were based on astronomical control points, which lends them a thoroughly documented and trustworthy nature (refer to Fig. 2). From this time forward, previous maps saw a marked improvement in accuracy and could serve as a foundation for examining the trends and characteristics of alterations in the Caspian Sea's shoreline.

It is important to note that the maps in Kolodkin's atlas provide several indications of a relatively elevated sea level during the survey period. For instance, instead of Tyuleniy Island, the map depicts a shoal with a mere depth of 3 feet; the Agrakhan Spit is illustrated as being split by a strait; and the Dervish Spit is shown as being separated from Cheleken by a channel (O. K. Leontyev, 1951).

The expeditions of G. S. Karelin (1832–1836) also made significant contributions to the hydrographic examination of the Caspian shores, particularly exploring the northeastern coast – an area previously unvisited by geographers or hydrographers. Karelin notably proposed the accumulative origin of the Peshny Islands and the now-extinct Mokrye, Sokolsky, and Gogol Islands, which currently belong to the Ural River delta plain. He was the first to document the coasts of the Dead Kultuk and Kaidak, conducted surveys of the Buzachi and Mangyshlak coasts, and took depth measurements near the entrances to Kara-Bogaz-Gol. In 1836, G. S. Karelin was the first European to explore Kara-Bogaz-Gol, where he put forward a hypothesis about the significance of this bay in the overall water balance of the Caspian Sea – a theory that was later validated by instrumental research. Additionally, Karelin conducted surveys and created maps of Krasnovodsk and Astarabad Bays, along with the coastal areas surrounding Hasan-Kuli, Aleksandr Bay, the Balkhan region, and northern Azerbaijan.

The increasing interest of Imperial Russia in the nations surrounding the Caspian Sea, along with the consequent necessity for a more detailed examination of the coastal waters and shorelines of the Caspian, resulted in the establishment of a comprehensive hydrographic expedition. The main goal of this expedition was to systematically survey the entire coastline and create a pilot guide for the Caspian Sea. This endeavor, directed by N. A. Ivashintsev, commenced in 1856. Throughout the duration of the project, which lasted until 1871, over 60 astronomical reference points were established. A variety of nautical charts depicting the entire Caspian coastline were created in Mercator projection at different scales. Additionally, depth measurements were taken in open waters, including the deepest areas of the southern basin. In 1877, after the passing of N. A. Ivashintsev, the findings of the expedition were published by his close associate I. F. Pushchin. Concurrently, an atlas of navigational charts and the first official pilot guide to the Caspian Sea were issued. In the years that followed, Ivashintsev's charts were only updated and improved, and it was not until the 1940s-1950s that a complete hydrographic survey was conducted again, utilizing a modern sheet index system and the latest depth-measurement techniques.

K. M. Baer made a notable contribution to the understanding of the geography, especially the geomorphology, of the Caspian Sea coast through his research. He was the pioneer in highlighting the unique landforms that were subsequently referred to as "Baer's mounds" and put forth a hypothesis regarding their formation, which significantly influenced later studies of these features. Additionally, Baer offered a comprehensive description of the shores of Krasnovodsk Bay. His publications also mention the presence of mud volcanoes along the Caspian coastline.

Early observations on the geological structure of the Caspian Sea's coastal regions appear in the works of S. G. Gmelin, K. L. Tabritz (a participant in M. I. Voinovich's expedition), K. M. Baer, and G. S. Karelin. However, comprehensive and systematic geological investigations did not begin until the 1890s, when N. I. Andrusov launched a series of pioneering studies. Among the most significant outcomes of his work was the development of a detailed stratigraphic framework for the

Pliocene and Quaternary deposits along the coastal zone, alongside a foundational analysis of the Caspian Basin's

The contributions of N. M. Knipovich were of exceptional importance, as he led a comprehensive program of oceanographic research across various regions of the Caspian Sea during the early decades of the 20th century. Through the collaborative efforts of Knipovich, S. Ya. Shcherbak, and A. I. Mikhalovskii, extensive data on the hydrology and climatology of the Caspian Sea were systematically compiled. This work significantly advanced the understanding of current patterns and hydrometeorological conditions, offering a more accurate and nuanced perspective than had previously been available—an essential foundation for analyzing the unique characteristics of coastal dynamics and morphology. Concurrently, geological investigations of specific coastal zones were conducted by P. A. Pravoslavlev, V. N. Weber, K. P. Kalitsky, D. V. Golubyatnikov, and I. M. Gubkin, further enriching the scientific understanding of the region.

In the aftermath of the Great October Socialist Revolution, a new phase commenced in the exploration of the Caspian Sea and its adjacent areas. This era was characterized by a thorough and systematic examination of the natural environment within the Caspian Basin, with the goal of facilitating the sustainable utilization of its rich resources. Research was conducted at the state level by various scientific institutions. In addition to hydrological, hydrochemical, and hydrobiological studies, geological research – both along the coastline and on the seabed – expanded significantly beyond previous efforts. A network of hydrometeorological stations was created, and permanent scientific research facilities were established, including those located on Artem Island and within the Volga Delta. The Caspian Commission was established to oversee the broad spectrum of research and exploration activities. The breadth and variety of this work were so vast that it is not feasible, within the confines of this text, to succinctly describe all the scientific fields explored in the Caspian region over the last decade. Consequently, we will confine ourselves to a concise summary of those studies that are most pertinent to the subject at hand – specifically, the geomorphology of the Caspian Sea coastline – placing particular emphasis on comprehensive research related to Quaternary Geology, Seabed Geology, and the Geomorphology of the Coast itself.

Quaternary deposits found along the coast of the Caspian Sea were initially explored by N. I. Andrusov, and later examined by P. A. Pravoslavlev (1926–1929), M. M. Zhukov (1945), B. P. Zhizhchenko (1950), N. I. Nikolaev (1937, 1949, 1953), D. A. Tugolesov (1948), V. P. Grichuk (1954), O. V. Dashevskaya (1940), M. V. Karandeyeva, V. A. Nikolaev, and G. I. Rychansky (1958), B. G. Vekilov (1956), V. R. Volobuev (1944, 1945), I. F. Pustovalov (1938), V. D. Golubyatnikov (1936), and P. V. Fedorov (1946, 1950, 1956, 1957), among others. The most thorough synthesis of Quaternary deposits in the entire Caspian region is found in the monograph by P. V. Fedorov (1957), who dedicated over ten years to studying the Quaternary history of the Caspian Sea.

Given that the formation history of the Caspian Sea during the Quaternary primarily revolves around its transgressions and regressions (P. V. Fedorov, 1957), research on Quaternary geology is intricately linked to studies of Caspian Sea level changes throughout historical periods. In this area, notable contributions were made by B. A. Apollov, who led a team of researchers from the Institute of Oceanology in extensive, long-term studies of sea-level variations (B. A. Apollov and I. V. Samoilov, 1946 and 1955). Recent fluctuations in the Caspian Sea level have also been addressed in the works of S. A. Kovalevsky (1938), L. S. Berg (1934), S. Yu. Geller (1949), O. K. Leontyev (1951, 1959), V. G. Richter (1954, 1960), among others.

Extensive research has demonstrated that the Quaternary history of the Caspian Sea is marked by four principal transgressive phases: the Baku, Khazarian, Khvalynian, and Novocaspian stages. Notably, during both the Khazarian and Khvalynian stages, two distinct transgressions can be discerned, separated by intervening regressive intervals. A consensus among scholars attributes these transgressive events primarily to climatic fluctuations, establishing a clear correlation between the Caspian Sea's transgressions and regressions and the interglacial and glacial periods of the Russian Plain. Additionally, certain researchers, such as D. I. Tugolesov (1948), have posited that earlier transgressions during the Upper Pliocene were similarly driven by climatic factors.

The geomorphological evolution of the Caspian coastline is intricately linked not only to the Quaternary development of the sea but also to investigations into the seabed's relief and geological structure. Particular emphasis is warranted on the extensive work conducted from 1932 to 1956 under the leadership of M. V. Klenova. Initial sediment surveys of the Northern Caspian were performed in 1932, followed by sediment sampling in the Southern Caspian in 1933 by a joint expedition from the Institute of Geology and Mineralogy of the

Academy of Sciences of the USSR and the Marine Geology Laboratory of the State Oceanographic Institute. These efforts accelerated substantially in 1934, when a fleet of ten research vessels undertook comprehensive marine geological investigations throughout the Middle and Southern Caspian. The resulting data facilitated the compilation of the first sediment distribution maps of the Caspian Sea and revealed key characteristics of the Seabed Relief and ongoing sedimentary processes.

Between 1936 and 1940, the Marine Geology Laboratory, led by M. V. Klenova, carried out detailed geological investigations within the Volga Delta and its adjacent coastal zone. The findings from this research were subsequently published in a dedicated volume of the *"Proceedings of the State Oceanographic Institute"* (Klenova et al., 1951). Beyond elucidating the geological structure, these studies provided significant insights into the Geomorphology of the Volga Delta and identified characteristic patterns of its Contemporary Dynamics.

The marine geological results obtained during this period were primarily disseminated in the monograph *"Modern Sediments of the Caspian Sea"* (Klenova et al., 1956), as well as through individual articles authored by M. V. Klenova, L. Ya. Yastrebova, V. P. Baturin, A. S. Pakhomova, S. G. Sarkisyan, and other specialists. In 1945, marine geological research in the Caspian Sea was further advanced by the marine unit of the Azerbaijan Oil Expedition, part of the State Oceanographic and Polar Survey (SOPS). This team conducted comprehensive studies of bottom sediments in the regions of the Absheron and Baku archipelagos, along with the Kura Coastal Area. The results were partially included in the aforementioned collection and also published in separate works by D. M. Suleymanov, S. G. Sarkisyan, L. V. Pustovalov, and A. D. Sultanov.

Since 1948, comprehensive marine geological exploration has been conducted in the pre-Absheron sector of the Caspian Sea and along the Dagestan coastline by the *Azmorneft* association and the Dagneft trust. These efforts encompassed systematic, large-scale seabed surveys employing diverse methodologies, including direct seabed inspection via diving equipment and marine drilling aimed at detailed geological mapping. Beginning in 1950, the Laboratory of Aeromethods of the Academy of Sciences of the USSR integrated into this research initiative. The adoption of advanced aerial photographic techniques, utilizing specialized film capable of capturing seabed imagery, combined with subsequent geomorphological and geological interpretation of these aerial photographs, substantially expedited the geological mapping of the underwater coastal slope and continental shelf. This advancement directly supported the accelerated exploration and development of offshore hydrocarbon fields. The outcomes of these aerogeological investigations were comprehensively documented in a dedicated monograph by V. V. Sharkov (1958) and disseminated through numerous articles in the *"Proceedings of Aeromethods"* and other scientific periodicals.

As a result of the combined geological and aerial photographic surveys, key features of the Relief Structure across extensive coastal seabed areas were delineated, the correlation between relief forms and the Basement Rock Structure and Lithology was established, widespread modern abrasion surfaces were identified, as well as distinctive bottom accumulative formations were characterized. It is important to highlight that Geomorphological Methodologies involving photo-interpretation and structural mapping were extensively employed throughout these studies, consistently producing reliable and valuable results for Geological Exploration.

Between 1950 and 1956, Marine Geological Research persisted for scientific objectives under the Marine Geological Expedition directed by M. V. Klenova and V. F. Solovyov, while applied exploration and prospecting activities were carried out by the "Azmorneft" organizations. The findings of these efforts were incorporated into the Geological, Geotectonic, and Geomorphological maps of the Azerbaijan SSR, published between 1954 and 1957, as well as in a Comprehensive Monograph on the Baku Archipelago authored by A. L. Putkaradze (1958). Concurrently, extensive geological investigations along the eastern Caspian coastline were conducted through collaboration between the Marine Geological Expedition and the Aeromethods Laboratory. The cumulative results of these marine geological studies were synthesized in the Substantial Monograph "*Geological Structure of the Underwater Slope of the Caspian Sea"* (1962), produced by a collective team led by M. V. Klenova.[1]

Between 1957 and 1960, investigations into the geology of the Caspian Sea floor were carried out under the direction of V. F. Solovyov by the marine division of the Integrated Oil and Gas Geological Expedition (now the Laboratory of the Research Institute for Oil and Gas). A key outcome of this research was the discovery of an extensive system of underwater ridges in the Southern Caspian. This finding prompted a Fundamental Reassessment of existing conceptions regarding the Bathymetry and Tectonic Framework of the South Caspian Depression and considerably broadened the Offshore Petroleum Exploration potential in the Region. The newly identified ridge structures were shown to be closely linked, both orographically and tectonically, to the systems of oil-bearing brachyanticlinal uplifts previously documented onshore in the Absheron Peninsula, Gobustan, and the Kura Lowland.

Marine Geological Research has played a pivotal role in advancing scientific understanding of the Tectonic Evolution of the Caspian Sea and its surrounding regions. Since the initial regional geotectonic frameworks – beginning with the model proposed by D. Arkhangelsky (1947) – various hypotheses regarding the Geostructural Configuration of the Caspian Sea floor have been incorporated into tectonic schemes. However, until relatively recently, these interpretations were predominantly speculative or deductive in nature, often lacking direct observational support. Substantial contributions to the Theoretical Development of Caspian Sea tectonics were made by A. L. Yanshin (1951), the Southern Integrated Geological Expedition (*Proceedings of the SIGE*, Vol. I, 1958 and subsequent volumes), and by researchers such as V. F. Solovyov (1954, 1956), V. A. Gorin (1953), G. Richter (1959), L. I. Lebedev (1961), and A. Yu. Yunov (1960). A structural correlation model linking the western and eastern coastal zones of the shallow Caspian Basin–based on analyses of seabed morphology – was proposed by S. S. Shulz and B. N. Mozhayev (1958), as well as by O. K. Leontyev (1959, 1961). The tectonic framework of the Southern Caspian, in particular, has been comprehensively developed in the works of V. F. Solovyov and collaborators (Solovyov, Kulakova, Lebedev, and Maev, 1962). It is important to emphasize that geophysical investigations –

including seismic, magnetic, and gravimetric surveys – have been at least as influential as geological mapping in shaping geotectonic interpretations of the Caspian Sea floor, and in some respects, have proven even more decisive. Conducted primarily in the context of applied geological exploration, these studies have expanded significantly in the Caspian region over the past five to six years, as evidenced in the works of A. A. Gagelgants (1958), Yu. N. Godin (1958), E. I. Galperin, I. N. Kosminskaya, and R. M. Krakshina (1962), as well as A. T. Donabedov, T. A. Korovina, and K. V. Timarev (1962).

As previously noted, the breadth of geological research conducted both onshore and in areas adjacent to the Caspian Sea following the establishment of Soviet power became so vast that even a comprehensive enumeration of the authors whose work addresses the geological structure of various coastal sectors would span dozens of pages. Therefore, this overview is limited to highlighting several key integrative works that offer general insights into the Geological Structure of major regions along the Caspian coastline.

For the Northern Pre-Caspian region, the most substantial synthesis of Geological and Tectonic Data is presented in the Monograph compiled by a team of authors under the leadership of M. P. Kazakov (1958). This work is significantly enriched by the collective contributions of M. V. Karandeyeva, V. A. Nikolaev, and G. I. Rychagov (1958); O. K. Leontyev and N. I. Foteeva (1963); as well as articles by A. G. Doskach (1954, 1957) and Yu. A. Meshcheryakov (1953, 1957). These studies, in addition to presenting geotectonic frameworks, provide detailed descriptions of the Unconsolidated Sedimentary Cover and the Geomorphological characteristics of the Coastal Zone.

In the northwestern Pre-Caspian region, the most Comprehensive Overview is offered in the collective volume *Geology and Petroleum Potential of the Eastern Fore-Caucasus*, edited by I. O. Brod (1958), further complemented by the work of G. I. Rychagov and O. K. Leontyev (1960). Additionally, the aforementioned monograph by P. V. Fedorov (1957) contains valuable synthesized material pertaining to both the northern and northwestern sectors of the Pre-Caspian region and remains the most authoritative study to date on the Quaternary Geology of the Caspian Coastal Zone.

The Geological Structure and, to a lesser extent, the Geomorphology of the western Caspian coastline are addressed in several major works, including *"Proceedings of the Integrated Oil and Gas Expedition"* (Vol. IV, 1959; Vol. VII, 1962), the summary volumes *"Geology of Azerbaijan"* (1956) and *"Geomorphology of Azerbaijan"* (1959), as well as in monographs by A. L. Putkaradze (1958) and D. A. Lilienberg (1962). The Quaternary deposits and marine terraces of Dagestan and Northern Azerbaijan are examined in the publications of P. V. Fedorov (1957), O. K. Leontyev (1959), and N. V. Pashaly (1959), while the coastal region of Lankaran is analyzed in a substantial monograph-style study by B. A. Antonov (1953).

Principal sources on the Geological Structure of the Eastern Caspian coast include Volume XXII of the "*Geology of the USSR"* series (1958), dedicated to the Geology of Turkmenistan, and a detailed paper on the Mangyshlak Peninsula by B. F. Dyakov (1957).

While most of the aforementioned geological and geomorphological syntheses contain incidental references to the

Morphology of the Caspian Shoreline, they generally lack a Systematic Treatment of Coastal features. A notable exception is the Monograph by P. V. Fedorov (1957), which offers not only a Comprehensive Analysis of ancient coastal formations, such as marine terraces, but also a concise Geomorphological Overview of both the eastern and western Caspian coasts. Nonetheless, prior to 1946 – when the series of investigations summarized in the present volume was initiated – dedicated studies focused specifically on the Morphology and Dynamics of the Caspian Sea coastline were extremely limited.

In 1935 -1936, coastal geomorphological investigations along the western shore of the Caspian Sea – pecifically in Dagestan and Northern Azerbaijan – were carried out by M. A. Pervukhin (1938). In a separate publication (1937), he also provided a detailed Morphological Analysis of the Kara-Boghaz Spit and produced a Geomorphological Map of this prominent accumulative Coastal Landform.

In 1938, V. P. Zenkovich and A. V. Zhivago conducted studies on the Morphology and Dynamic processes of the Mangyshlak coastline (Zenkovich, 1940). Notably, these investigations marked the first use of shallow-water diving equipment in Caspian coastal research. This Methodological Advancement led to the discovery of Submerged Shoreline features in the vicinity of Alexander Bay, which were interpreted as indicators of former low sea-level stands associated with regressive phases in the Caspian Sea's Geological History.

In 1938, research conducted by the State Hydrological Institute included Morphological descriptions of the Krasnovodsk Bay shores and a segment of the Coastline south of Cheleken (M. I. Aleksandrova, 1940). It is important to note that these studies primarily consisted of descriptive morphological accounts; issues relating to Coastal Dynamics were either omitted or addressed inadequately and, in some cases, inaccurately. An exception to this general trend was the work of V. P. Zenkovich and A. V. Zhivago, although their findings were published only in a highly condensed form.

More focused investigations into the morphology and dynamics of specific coastal sectors – particularly accumulative deltaic shores – are limited to the aforementioned studies on the Geological Structure and Morphology of the Volga and Ural deltas (e.g., *Geology of the Volga Delta*, 1951; N. G. Krasnova, 1938). This essentially completes the sparse list of scientific publications addressing the Geomorphology of the Caspian Coastline prior to 1946.

Consequently, the Geomorphology of the Caspian Sea coasts before 1946 remained inadequately explored. The majority of the Coastline had not been systematically surveyed from a Geomorphological standpoint, and the few existing studies fall short of providing even a Preliminary understanding of the overall Morphology and Dynamic processes shaping the Caspian shores.

In 1946, the newly established Institute of Oceanology of the Academy of Sciences of the USSR initiated systematic investigations into the Geomorphological Structure of the Caspian Sea coastline. These efforts were modeled after research conducted in 1945 along the Crimean coast of the Black Sea, led by V. P. Zenkovich, then head of the Department of Coastal Morphology and Dynamics at the Institute of Oceanology.

As part of the Caspian Sea expedition organized by the Institute, a specialized Coastal Research Team was assembled under the direction of V. V. Longinov. The team comprised early-career researchers – including E. N. Nevesky, V. I. Budanov, O. K. Leontiev, N. I. Foteeva, and G. N. Moroshkina – who were embarking on their initial studies of Littoral processes and Marine Shoreline Dynamics. During the 1946 field campaign, the team conducted a detailed Geomorphological survey of the Coastal Zone stretching from the Samur River to the mouth of the Manasozhen River. Approximately 20 cross-shore profiles were established to investigate the subaqueous slope. Hydrographic operations included seabed sediment sampling using grab samplers and in situ observations via shallow-water diving systems utilizing oxygen-based breathing apparatuses. These underwater inspections complemented surface measurements, providing a comprehensive understanding of Nearshore Sediment Dynamics and Coastal Morphology.

In 1947, the coastal geomorphological investigations were extended to encompass the Dagestan shoreline, specifically the stretch from the Manas River to the northern extremity of the Agrakhan Peninsula. Along this segment, 18 marine cross-shore profiles were established and surveyed. Additional research was undertaken on Chechen Island, the archipelago situated between the Agrakhan Peninsula and Chechen Island, as well as along the coastal margins of Agrakhan Bay. The field team was led by V. I. Budanov and included E. N. Vasiliev (serving as diving operations supervisor), along with A. A. Aksenova, O. K. Leontiev, E. N. Nevesky, N. I. Foteeva, and T. N. Moroshkina. Field operations were carried out using a motorized four-oar research boat, facilitating both hydrographic measurements and nearshore sediment sampling. Toward the conclusion of the field season, E. N. Nevesky also conducted sedimentological sampling of littoral deposits along the northern coast of Azerbaijan, thereby extending the geographical scope of the investigation.

During the 1948–1949 research campaigns, a comprehensive understanding was developed of the geological structure of the submarine portion of the Eastern Dagestan anticline zone, as well as the bathymetry of the continental slope and the principal characteristics of shoreline morphology and coastal dynamics within the Izberbash, Kayakent, and Berekay coastal sectors. In consultation with I. O. Brod, data obtained from deep-sea drilling were incorporated into the analysis, culminating in the creation of the first geological-structural map of the marine areas associated with the Izberbash and Kayakent oil fields.

In 1950, the research team acquired an expeditionary vessel – the seiner "*Dagneft*" – which significantly enhanced the scope of field operations. Geological and geomorphological surveys were extended further south of Berekay, encompassing the seabed adjacent to the Derbent and Rubas coastal zones of southern Dagestan. In addition, a series of echo-sounding transects were conducted northeast of Izberbash in an effort to locate the hypothesized Pushchin Bank; however, its existence was not confirmed. Supplementary investigations were also undertaken in the vicinity of the offshore oil infrastructure near Izberbash.

During the 1950 field campaign, focused investigations were conducted on the geological framework and geomorphological features of the terrestrial coastal zone. O. K. Leontyev, I. O. Brod, and P. N. Kuprin produced detailed structural maps of the Izberbash oil field and elucidated the structural interrelations between the Izberbash formation and the adjacent Kayakent structure to the south. Terrestrial geomorphological surveys identified, in addition to the shoreline corresponding to the Upper Khvalynian Sea highstand, a younger stadial shoreline of the same marine transgression, prominently preserved at an elevation of approximately 12 meters above the present Caspian Sea level. These observations corroborated the hypothesis of a dominant littoral sediment transport system directed along the Dagestani coast, flowing from south to north. Comprehensive seabed sampling yielded refined sedimentological data, enabling precise delineation of bottom sediment distribution patterns. Concurrent Hydrographic soundings further defined the bathymetric profile and morphological characteristics of the submarine slope, enhancing the understanding of the submerged Coastal Geomorphology.

In 1951, work on submarine geological surveying was completed. Marine operations were conducted from the towing vessel *"Razvedchik"* and covered the northern coastal zone of the Dagestan foreland – from the mouth of the Kolichi River (north of Izberbash) to the city of Makhachkala. Terrestrial investigations enabled a refinement of the understanding of the Geomorphology of the coastal plain and shoreline zone. That same year, a reconnaissance survey of Tyuleniy Island was carried out.

As a result of instrumental geological and geomorphological investigations organized by the underwater division of the *"Dagneft"* trust, the compilation of both geomorphological and geological maps of the submarine coastal slope of the Dagestan shoreline was completed by 1952. Additionally, integrated structural-geological and geomorphological maps of the entire coastal area were produced. These studies revealed characteristic features of the geological structure of the Eastern Dagestan Anticline segment concealed beneath the marine water column.

The mapping efforts involved contributions from O. K. Leontyev, P. A. Kuprin, S. E. Salnikov, N. I. Foteeva, T. A. Osipova, V. S. Medvedev, D. M. Ibrahimov, V. N. Agriansky, and other specialists. Diving operations throughout the survey period were overseen by shallow-water diving instructors E. S. Vasiliev and K. K. Vasilieva.

The outcomes of the terrestrial investigations conducted by the field team were subsequently presented in the doctoral dissertation of N. I. Foteeva (1954) and were synthesized cartographically in the form of a large-scale geomorphological map authored by the same researcher. This map encompasses the entire coastal plain and the eastern piedmont slopes within the distribution zone of the Ancient Caspian (Akchagylian) marine terraces.

Following a two-year hiatus, research on the Caspian Sea littoral resumed in 1954 under the auspices of the Faculty of Geography at Moscow State University, in accordance with a formal agreement established with the *"Groznefterazvedka"* Trust. Pursuant to this agreement, the Western Caspian Expedition – organized and led by O. K. Leontyev – was tasked with surveying Quaternary deposits and undertaking Geomorphological investigations along the northwestern coastline of the Caspian Sea, specifically within the coastal plain of Northern Dagestan and the former Grozny Region, including the Terek River delta. In parallel, a geomorphological survey of the marine shoreline was initiated, extending from

Agrakhan Bay southward to the vicinity of the settlement of Kaspiysky, located south of the Volga River delta. These investigations were carried out in coordination with the Southern Integrated Geological Expedition, directed by I. O. Brod. Terrestrial survey teams were led by A. A. Chistyakov and G. I. Rychagov, while the geomorphological division of the Southern Expedition, working in collaboration with Leontyev's group, was headed by N. I. Foteeva. P. V. Fedorov actively participated in several field traverses, contributing significantly through expert consultation and methodological guidance. V. S. Myakokin chaired the marine operations unit.

Following the investigations carried out in 1954, multiple maps were created for the Eastern Region of the Cis-Caucasian Lowland. These included a Geomorphological Map, a Map of Quaternary deposits, and a Structural-Geomorphological Map. The research uncovered the significant presence of ancient Deltaic formations in the Area studied, determined the age of the Terek River delta, analyzed the thickness of the Quaternary cover, and established relationships between subsurface geological structures and the thickness of the unconsolidated deposits.

Along the coastline, 16 marine cross-sections were completed. The research demonstrated the significant role of wind-driven (seiche-like) water level fluctuations in coastal dynamics and identified the main features of the evolutionary history of the abandoned deltaic shoreline. Local sediment transport pathways were identified, supplying major accumulative forms such as the Bryanskaya and Suyotkina spits. Mineralogical analysis of coastal and bottom sediments indicated the presence of Volga-derived material entering Kizlyar Bay under the influence of the

Volga River's drift current. Additional fieldwork was carried out on Chechen Island. Throughout both coastal and inland operations, aerial photographic materials were extensively utilized–the expedition had at its disposal aerial imagery covering the entire study area.

The results of the research conducted along the northwestern Caspian coast were partially published in the works of O. K. Leontyev (1956; 1957a, b), O. K. Leontyev and G. I. Rychagov (1950), G. I. Rychagov (1960), A. A. Chistyakov (1956), and O. K. Leontyev, M. B. Bakhtina, and T. A. Dobrynina (1959).

A year later, coastal research on the Caspian Sea was recommenced under the scientific leadership of O. K. Leontyev, as part of a joint research project involving the Faculty of Geography at Moscow State University, the Institute of Oceanology, and the Southern Integrated Geological Expedition of the Academy of Sciences of the USSR. In the first half of the field season, research activities were focused on the northern coastline of Azerbaijan and the Apsheron Peninsula region. Terrestrial studies aimed at identifying and tracing paleoshorelines, with a specific focus on the morphology of ancient coastal accumulative features and their spatial and genetic connections to previous abrasion zones and sources of fluvial sediment. These investigations shed light on significant aspects of coastal evolution in the northern part of the Apsheron Peninsula, emphasizing the vital role of aeolian processes in influencing its current morphodynamic regime. A total of 27 marine cross-sectional profiles were completed in this region, many of which utilized underwater survey methods, including extensive diving operations.

Additional surveys were conducted on Zhiloy and Artem Islands, as well as on several smaller rocky islets located to the northwest of Zhiloy. Utilizing the expedition vessel "Obruchev", echo-sounding and underwater investigations were performed in the strait between Zhiloy Island and the "Neftyanye Kamni" ("Oil Rocks") outcrops. These operations were carried out in connection with the planned installation of a submarine oil pipeline across the strait.

The 2nd half of the 1956 field season was dedicated to geomorphological investigations along the eastern Caspian shoreline, extending from Cape Melovoy to Kenderli Bay. Within this sector, 13 marine cross-sectional profiles were completed, incorporating echo-sounding bathymetric surveys and bottom sediment sampling. At Aleksandr-Bay and Cape Melovoy, diving operations were undertaken to study the morphology and sedimentary structure of the submarine coastal slope.

Surveys of the coastal terrestrial zone were conducted via brief shore landings from the research vessel and through short overland traverses coordinated with adjacent marine profiling activities.

In addition to O. K. Leontyev, the 1956 expedition team included V. I. Budanov, Yu. S. Dolotov, and A. M. Protonin, with D. M. Ibrahimov contributing to research activities along the western coast. The results of the western coastal investigations were subsequently published in an article by O. K. Leontyev (1961), while the findings from the eastern sector were presented in a joint publication by O. K. Leontyev, V. S. Myakokin, and L. G. Nikiforov (1960).

Specialized geomorphological investigations of the Apsheron Peninsula were carried out by N. Sh. Shirinov in 1954 as part of the Transcaucasian Geomorphological-Tectonic Expedition organized by the Institute of Geography of the Academy of Sciences of the USSR , and independently according to the plan of the Institute of Geography of the Academy of Sciences of the Azerbaijan SSR in 1956 - 1958. The findings from these studies were published in articles in scientific journals of the Academy of Sciences of the Azerbaijan SSR in 1957 - 1960.

In 1957, geomorphological research concerning the coasts of the Caspian Sea reached its peak, especially along the eastern shore. This work was conducted by two field teams utilizing automobiles, boats, and the expedition vessel “Obruchev”. The participants included O. K. Leontyev, V. I. Budanov, V. S. Myakokin, M. E. Turkova, S. N. Vinogradova, E. A. Kudusov, A. M. Protonin, and V. N. Zvezdov. The investigations covered the coast of the Tyub-Karagan Peninsula, Kulaly Island, the shores of the Mangyshlak Plain, the Kenderli-Kayasan Plateau, Kara-Bogaz-Gol Bay, and the Krasnovodsk Peninsula. A total of 70 marine cross-sections were conducted, which included echo sounding, sediment sampling, and diving surveys. Geomorphological maps of the land portions of the coastline were also created. Aerial photographic materials (including photographs and photomaps) were extensively utilized throughout the research.

The research carried out in 1957 resulted in a thorough understanding of the evolution of the eastern Caspian coastline during the Quaternary period. This study identified stadial shoreline positions corresponding to the Lower and Upper Khvalynian basins, clarified the sites of submerged ancient shorelines, and detailed the key features of the current dynamics of the eastern Caspian Sea coast. The investigations validated the persistence of coastal forms and processes, as well as the distinctive nature of shoreline evolution during periods of marine transgression and regression. Notably, significant insights on this topic were obtained through the geomorphological analysis of the shores of Kara-Bogaz-Gol Bay and the sandbar that separates this Bay from the open sea.

The findings from the investigations conducted in 1957 were partially published in articles authored by O. K. Leontyev (1961a, b), L. G. Nikiforov (1959, 1960), and in a collective work by O. K. Leontyev, V. S. Myakokin, and L. G. Nikiforov (1960).

In the fall of 1957, geomorphological research along the northern Caspian coast was initiated by a team under the leadership of N. I. Foteeva (Southern Integrated Geological Expedition), which included contributions from O. K. Leontyev, L. Ya. Zakharova, and L. M. Shlykova. This research focused on the coastline stretching from the Volga River delta to the city of Guryev, as well as the southeastern section of the Volga-Ural interfluve. During the field studies, aerial photographic materials were employed alongside aerial visual observations in the Ryn Sands area. The outcomes of the 1957 northern coast investigations were documented in an article by O. K. Leontyev, N. I. Foteeva, L. Ya. Zakharova, and L. M. Shlykova (1958).

The investigations carried out in 1958 were primarily of a concluding nature. They mainly focused on the southeastern and southwestern shores of the Caspian Sea, in addition to the vast regions of the North Caspian Lowland. Furthermore, additional work was performed near the Pre-Karaboğaz area, and Ogurchinsky Island was examined by V. S. Myakokin and L. G. Nikiforov.

In 1958, marine research was carried out on the expedition vessel *Truzhenik.* Along the southeastern coast, 28 cross-sections were completed; 6 were conducted near the southern Karabogaz Spit, and 7 were near the shores of Ogurchinsky Island. These cross-sections included echo sounding and sediment sampling, while detailed seabed surveys were executed using scuba diving equipment in the approaches to Kara-Bogaz-Gol Bay. The participants in the studies along the eastern coast comprised O. K. Leontyev, L. G. Nikiforov, V. S. Myakokin, A. M. Protonin, I. A. Pravotorov, S. N. Vinogradova, along with graduate students from the Institute of Geography of the Academy of Sciences of the Azerbaijan SSR, N. N. Mekhtiev and Kh. A. Veliev. The findings from the 1958 research were partially published in articles authored by L. G. Nikiforov (1959, 1960, 1961) and I. A. Pravotorov (1961).

The terrestrial studies concentrated on the geomorphological structure, Quaternary deposits, morphology, and dynamics of the shores of Krasnovodsk Bay and the Cheleken Peninsula, as well as the western Karakum coast from Cheleken to Hasan-Kuli. Furthermore, V. S. Myakokin and G. N. Solovyeva conducted a reconnaissance route by automobile from the northern coast of Kara-Bogaz-Gol, traversing the Karynjaryk depression to Fort Shevchenko.

Due to factors outside the expedition's control, research along the southwestern coast was confined to the region between Artem Island and the mouth of the Shirvan Canal (approximately 25 km north of the Kura River delta). Fieldwork was carried out by O. K. Leontyev, L. G. Nikiforov, N. N. Mekhtiev, and Kh. A. Veliev using a vehicle. At sea, aboard the expedition vessel *"Truzhenik"*, I. A. Pravotorov and V. I. Budanov performed 22 cross-sections, utilizing both echo sounding and manual depth measurements. Following this, Kh. A. Veliev made landings on the islands of Bulla, Svinoy, Glinyany, and Duvanny, offering brief morphological descriptions of each.

Research on the northern coast, directed by N. I. Foteeva with contributions from O. K. Leontyev and A. A. Aleksin, was conducted in two main areas. First, the Volga delta was comprehensively examined, mainly for practical purposes – to locate buried structural zones that are promising for oil and gas through geomorphological techniques. In addition to detailed descriptions of cross-sections and motorboat surveys through the delta channels, aerial photographic materials were thoroughly analyzed and aerial visual surveys were performed.

Secondly, route surveys were carried out within the interfluve of the Volga and Ural rivers, in the Ural delta and its valley, as well as in the eastern section of the Pre-Caspian Lowland, which includes the Priustyurt region and the northern Ustyurt Plateau. The aims of these investigations were to gather information on the development of the northern Caspian coastline during the Khvalynian and Neocaspian periods, to pinpoint stadial ancient shorelines and link them with the relic deltaic formations of the Ural, Emba, Sagiz, Uil, and other rivers in the Northern Pre-Caspian, to examine ancient shorelines on the northern slope of the Ustyurt Plateau, and to elucidate the impact of salt dome tectonics on the landscape as well as the interplay between exogenous and endogenous factors in shaping the surface of the Pre-Caspian Lowland. The findings from the 1958 study in the Northern Pre-Caspian were disseminated in articles authored by O. K. Leontyev, N. I. Foteeva, and A. A. Aleksin (1960, 1961), by these same authors in collaboration with L. Ya. Zakharova (1962), by N. I. Foteeva (1962), and in the monograph by O. K. Leontyev and N. I. Foteeva (1959). Additional data were also incorporated into publications regarding the Neocaspian transgression (O. K. Leontyev, 1960) and concerning the relief and tectonics of the northern Caspian Sea area (O. K. Leontyev, 1961b).

During the fieldwork conducted between 1957 and 1958, data were collected that enabled the refinement of the modern shoreline's position in various regions of the Northern Caspian, Kara-Bogaz-Gol Bay, and Krasnovodsk Bay. While the shoreline adjustments on the map were made with the relative accuracy achievable during route surveys, this does not lessen the importance of these refinements. In all these coastal regions, the shoreline position can be represented with an accuracy of approximately 1 to 2 kilometers due to the influences of wind-driven setup and seiches. The magnitude of the observed changes is highlighted by the fact that the actual shoreline of Kara-Bogaz-Gol Bay was determined to be 20 to 30 km closer to the central areas of the bay than indicated on the latest maps.

In 1959, geomorphological research was carried out solely in the Northern Pre-Caspian region. N. I. Foteeva, along with A. A. Aleksin, continued their investigations in the western section of the Volga River delta and performed surveys in the southern area of the Ryn sands and along the Bolshoy and Maly Uzen river valleys. The findings from these studies were partially utilized in the development of this monograph.

Since 1960, the Caspian Scientific Research Station of the Institute of Geography of the Academy of Sciences of the Azerbaijan SSR has conducted specialized field studies along the Caspian coastline – from the mouth of the Astarachay River to Kizlyar Bay, and partially along the eastern shore of the sea. These investigations, supervised scientifically by A. I. Khalilov, one of the authors of this monograph, aim to ascertain both the quantitative and qualitative characteristics of the primary factors influencing the development of the contemporary Caspian coast and their Systematic Relationship with the fluctuations in Sea Level.

The researchers who participated in the expeditions and the subsequent analysis of field survey data from 1960 to 1963 included scientific staff members N. N. Mekhtiev and E. A. Kudusov, along with laboratory assistants V. P. Petrushov, G. A. Emineva, and T. M. Antonova. The outcomes of these studies concentrated on refining the divergence scheme of two sediment transport pathways along the western coast of the Caspian Sea, quantitatively evaluating the impact of river discharge on the formation of the modern shoreline, identifying the causes of increased marine abrasion along the delta fronts of several major rivers, as well as the Krasnovodsk and Kurin spits, which hold significant scientific importance. Notably, the Caspian Scientific Research Station identified the most dynamic coastal areas of the sea, where numerous permanent benchmarks and transects of cross-sectional profiles were established and regularly monitored.

The analysis of data gathered from yearly and seasonal surveys performed at these permanent transects enables the acquisition of accurate quantitative insights into the dynamics of morphological alterations in coastal areas. The findings from these investigations have been documented in various scientific publications (A. I. Khalilov, 1960–1963; O. K. Leontiev, A. I. Khalilov, 1962; N. N. Mekhtiev, 1960–1961). These studies were conducted by a substantial group of research scientists.

The studies mentioned above were carried out by a sizable team that included research scientists, field geologists, student interns, seafarers, technical personnel, and laboratory assistants.

Source:"Natural Conditions of the Formation of the Caspian Sea Shores", Baku, Publishing House of the Academy of Sciences of the Azerbaijan SSR, 1965, pp. 12-24. Author: O. K. Leontiev.

1.4 GEOMORPHOLOGY OF THE COASTS AND SEAFLOOR OF THE CASPIAN SEA

The morphological features identified on the seafloor of the Caspian Sea include the Continental Shelf, the Continental Slope, the Abyssal Plain (deep-sea floor), and Deep-Sea Depressions. The continental shelf has a gradient that does not exceed 30 arcminutes (30′), and its width varies in different regions. The shelf break, which is the transition from the shelf to the slope, occurs at varying depths: in the western and southern sections of the sea, it is located at depths of 50–100 meters, while in other regions, it is found between 100 and 130 meters. The shelf break follows a contour that connects points with a slope of 30′. Beyond this point, the continental slope begins, extending down to a depth of about 650 meters. Beneath this depth lies the abyssal plain, where the gradients decrease again and do not exceed 30′. Further down are the deep-sea depressions. In the southern Caspian Sea, there are two significant depressions: the *Azerbaijani Depression*, which reaches a maximum depth of *1,025 meters* (the deepest point in the Caspian Sea), and *the Iranian Depression*, with a depth of approximately *800 meters*. In the Middle Caspian, the *Derbent Depression* reaches a depth of *788 meters*.

The development of the Caspian Basin was shaped by the interplay of several unique geological structural foundations: the Russian Paleozoic Platform, the Epigeosynclinal Turan Platform, and the Alpine-Himalayan Orogenic Belt.

Consequently, the Caspian Sea is divided into three nearly independent depressions – the Northern Caspian, the Middle Caspian, and the Southern Caspian – which vary considerably in depth, morphological characteristics, geological composition, and spatial dimensions. These basins are divided by sublatitudinal underwater uplifts, specifically the Mangyshlak and Absheron Ridges.

The Northern Caspian covers almost one-third of the entire sea area. It receives water from significant river systems such as the Volga, Ural, and Terek, whose deltas create extensive sedimentary deposits at their mouths. Until recently, these rivers contributed over 60 million tons of sediment each year to the sea. Currently, this contribution has diminished by a factor of 2 to 3. Additionally, approximately 20 million tons of aeolian (wind-blown) sediments are brought into the basin annually. Because of the shallow depths and the considerable fluvial sediment influx, an accumulative plain has formed on the seabed. During the quaternary period, the floor of the Northern Caspian underwent multiple cycles of exposure (desiccation) and flooding, resulting in the creation of various subaerial relict landforms, especially erosional features. Among the most prominent of these are channels – paleogeographic extensions of former river valleys.

The coastal region of the Caspian Sea showcases a diverse array of landforms, including the foredeltas of the Volga, Ural, Terek, and Sulak Rivers, which are interspersed with erosional channels created by river distributaries.

At the outer edge of the Volga foredelta, significant accumulative features such as bars and submarine ridges are prominently developed. In some locations, these features rise above the water, creating low-lying islands. The Coastal Zone – especially in its Northeastern Section – is also distinguished by the existence of wind-desiccation zones, where periodic exposure caused by wind-induced fluctuations in water levels carves out unique coastal relief forms. The Middle Caspian is situated at the convergence of the Epigeosynclinal Turan Platform and the Caucasian segment of the Alpine-Himalayan Orogenic Belt. The primary seafloor feature in this area is the Derbent Basin, which attains a maximum depth of 788 meters. The Middle Caspian comprises over one-third of the total surface area of the sea and holds approximately 34% of the Caspian Sea's overall water volume.

Before the Caspian Sea was formed, the region currently known as the Middle Caspian was once a vast plain. This plain geographically aligned with the eastern section of the Turan Platform and the subsided peripheral area of the Eastern Caucasus, which is situated along a fault system to the west. As a consequence, the seafloor of the Middle Caspian exhibits a complex morphology and an asymmetric cross-sectional profile. The eastern side of the Middle Caspian Basin is characterized by a gentle slope and a wide continental shelf, whereas the deepest section of the sea—the Derbent Basin—is located on the western side, where the shelf is narrow and complicated by tectonic faulting. A prominent and morphologically distinct shelf break with steep escarpments descends sharply into the Derbent Basin.

The Paleo-Volga River, which received tributaries from this ancient plain, drained the region and emptied into the sea within the Southern Caspian Basin, creating a large delta near the Absheron Peninsula, made up of sediments from the Productive Series.

To the southwest of the Derbent Basin, situated between the basin and the Bogaz abrasion-accumulative plain, the shelf is part of the southeastern extension of the morphostructures of the Greater Caucasus. During the neotectonic phase, these structures underwent uplift ranging from 1.5 to 5.0 kilometers, and the Mesozoic deposits that formed them were significantly eroded. This erosion resulted in the creation of submarine ridge-like abrasion plains. In the coastal area of these submerged plains, the *"Dibrar Cliffs",* formed from highly resistant limestone formations, greatly complicate the local seabed topography.

The vast, gently sloping, and slightly dissected (5–8 m) Samur-Divich Lowland extends along the western coast of the Middle Caspian, aligning with the Kusar-Divich Foredeep. During the Pliocene and Pleistocene epochs, this area underwent subsidence, which was offset by the accumulation of sediments. Although the formation of marine terraces was generally unfavorable in these circumstances, such terraces did emerge south of Velvelichay and north of the Samur River, where abrasion-accumulative plains can be found. The Samur-Divich Lowland is flanked to the southwest by anticlinal foothills, including Telebi, Bilidzhy, Kyzylburun, Varafte, and Beshbarmag, with elevations ranging from 550 to 1,500 meters.

The Southern Caspian is centrally located within the Alpine-Himalayan orogenic belt, representing its most tectonically active zone, positioned between the outer and inner belts of the orogen. As a distinct structural entity, the Southern Caspian was established during the recent (neotectonic) developmental phase. Its subsidence was accompanied by the deposition of molasse-type sediments, with a cumulative thickness exceeding 15 km.

During the initial phases of its neotectonic development, the Southern Caspian Basin displayed a more complex structural arrangement. These sub-basins ultimately merged into a single depression starting in the Akchagylian stage. The rate of subsidence increased during this period, leading to the pre-Akchagylian surface in the Azerbaijani sub-basin of the Southern Caspian being lowered to depths ranging from 4.0 to 6.5 kilometers.

Across the Southern Caspian Basin, recent (neotectonic) sedimentary sequences show varying degrees of structural deformation. The level of deformation is inconsistent and influenced by factors such as basement structure, tectonic environment, and recent geodynamic processes. In the Baku Archipelago area, situated south of the Absheron Peninsula, and within the Absheron–Pre-Balkhan Zone, recent deposits are highly deformed and distinctly visible in the seabed topography. Conversely, on the Turkmen Shelf and the nearby central Caspian zone, these same deposits are found in almost horizontal, concordant layers, gently covering basement elevations. The fold structures present in this area are gentle, expansive, and minimally represented in the current relief, and they remain unaffected by significant tectonic disturbances.

In the subsidized region of the Pre-Balkhan Zone, the folds are larger, clearly defined morphologically, and more densely packed; their complexity is increased by the presence of mud volcanoes. In stable regions, gentle uplifts occur with a reduced density of structural features. The dynamics of the contemporary Caspian coastlines are influenced by geological structure, lithology, the slope of the underwater shelf, and sediment presence. Three primary types of coastlines are identified: *abrasional, accumulative,* and *abrasion-accumulative.* The predominant types are abrasion and abrasion-accumulative coasts. These are mainly found in the areas of the Krasnovodsk and Mangyshlak Peninsulas, along the Dagestan coastline, within Azerbaijan on the Absheron Peninsula, southeast of Gobustan, and extending northward from the Absheron Peninsula to Mount Beshbarmak. In Iran, abrasion is primarily observed along the Sefidrud Peninsula. Since the rise in the Caspian Sea level that began in 1978, several accumulative coasts – located on the Lankaran coast, Bogaz Plain, Pre-Balkhan Zone, north of Mangyshlak, and on specific sections of the western Turkmen and Iranian coastlines – have faced intensified abrasion processes. A significant reduction in solid riverine sediment supply has led to considerable erosion along deltaic coasts in northern Dagestan, the Samur delta, the Kura delta, and other areas.

In the Southern Caspian Basin, neotectonic deposits are spread across the region; however, the extent of deformation differs based on the geological framework, characteristics of the basement, and recent tectonic activities. In the area of the Baku Archipelago, located south of the Absheron Peninsula and within the Absheron–Pre-Balkhan Zone, neotectonic deposits are significantly deformed and clearly visible in the seabed topography. Conversely, on the Turkmen Shelf and the nearby central Caspian zone, these deposits are positioned almost horizontally, gently covering the basement elevations. The observed folds are mild, only slightly noticeable in the landscape, and are not influenced by major tectonic disruptions.

Latitudinal folds distinguish the Azerbaijani Basin from the Iranian Basin and are primarily evident within the deposits of the Productive Series. These folds are faintly represented in the terrain, which is due to substantial subsidence and sediment build-up.

Folds with northwest-southeast and meridional (north-south) alignments are the most recent, having developed during late orogenic activities. Folds oriented northeast-southwest are comparatively older, while those aligned in the latitudinal (east-west) direction represent the oldest structural features in the region.

A proportional relationship exists across the region, linking the size and morphology of folds, their spatial density, and the activity level of deep-seated faults.

In the subsided section of the Pre-Balkhan Zone, folds are generally larger, more morphologically distinct, and more densely packed; they are often complicated by mud volcanism. Conversely, in tectonically stable regions, gentle uplifts are more common, usually marked by a lower density of structural features. The dynamics of the contemporary Caspian shoreline are influenced by various factors, such as geological structure, rock lithology, submarine slope gradient, and sediment availability. Three primary coastal types are identified:

abrasional, accumulative, and abrasion-accumulative. Among these, abrasional and abrasion-accumulative coasts are the most prevalent. They are particularly well-developed along the Krasnovodsk and Mangyshlak Peninsulas, the Dagestan coast, the Absheron Peninsula in Azerbaijan, southeast of Gobustan, and from the northern Absheron coast to Mount Beshbarmak. In Iran, abrasion is most pronounced along the Sefidrud Peninsula.

Following the rise in the Caspian Sea level in 1978, abrasional processes have started to impact several accumulative coasts, including those along the Lankaran coast, Bogaz Plain, the Pre-Balkhan Zone, north of Mangyshlak, and in certain areas of western Turkmenistan and the Iranian coastline. Moreover, a significant decrease in solid riverine discharge has resulted in heightened erosion of deltaic shores, including those of northern Dagestan, the Samur Delta, the Kura Delta, and others.

Source: "Variability in Hydrometeorology and Ecogeographical Issues of the Caspian Sea". Baku, "Elm" Publishing House, 2007, pp. 21-31.
Author: R.M.Mamedov

1.5. BOTTOM SEDIMENTS OF THE CASPIAN SEA

The Caspian Sea is part of the Mediterranean tectonic belt, which includes the Black, Azov, Caspian, and Aral Seas within the former Soviet Union. Geologically, this endorheic water body is a remnant of the Tethys and Eastern Paratethys—extensive marine basins that once surrounded Eurasia; their sediments are prevalent in the Paleozoic, Mesozoic, and Cenozoic deposits of the area.

The formation of the Caspian Sea can be viewed as a consequence of the gradual retreat of marine waters due to the uplift of adjacent landmasses, linked to the Alpine orogeny. Key stages in this process include geological events that took place during the early Oligocene, late Miocene, and Pliocene.

In the early Oligocene, tectonic uplift in the Pontic geoanticline and the Balkan region severed the connection between the Mediterranean and the Black Sea–Caspian paleobasins.

During the late Miocene, the growth of the Caucasian Island and its eventual attachment to the Anatolian landmass initiated the first separation between the Caspian and Black Sea branches of these marine systems.

Ultimately, the rise of land north of the Caucasian Island, in the Stavropol Uplift area, completely isolated the Caspian Sea from the Black Sea. Since this separation, tectonic movements, river inflow, evaporation, erosion, and subterranean water exchange have continuously modified the depth, surface area, salinity, biological activity, and sedimentation patterns of the Caspian Sea.

The contemporary Caspian Sea is situated within a profound continental depression. Its surface area measures around 378,400 km^2; it stretches nearly 1,030 km in the north-south direction, with its width fluctuating between 196 and 433 km.

The Caspian Sea represents a highly intricate natural system, where geological, geographic-climatic, biological, physicochemical, and other elements are closely interconnected. As a natural laboratory, the Caspian offers considerable potential for enhancing our comprehension of various environmental processes and for guiding the sustainable development of regional economic activities. Nevertheless, effectively studying such a complex system necessitates an interdisciplinary and integrative approach – one that intersects multiple scientific fields, utilizes a broad array of methodological tools, and integrates advancements from related disciplines.

Unfortunately, thorough and systematic studies of the Caspian Sea are still predominantly supplanted by fragmented, multi-disciplinary observations carried out by experts from different areas. This may partially clarify why numerous facets of the Caspian's geological evolution remain unclear. For example, the reasons behind the long-term fluctuations in sea level are not yet completely understood; the hydrodynamics of groundwater inflows are still inadequately researched; the influence of mud volcanism on the formation of contemporary sedimentary deposits is not sufficiently examined; the paleohydrological reconstruction of eastern inflows, especially from the enigmatic Uzboy River, is largely underdeveloped; and only recently have the hydrocarbon potential of the basin started to be evaluated in a more thorough manner. Moreover, there exists a considerable deficiency of geological data concerning the structure of the sedimentary cover, and the information pertaining to the anthropogenic effects on the chemical composition and volumetric attributes of the Caspian water mass and sediment budget is notably disjointed.

The main aim of this research was to create a thorough understanding of current sedimentation processes as well as to examine the key factors influencing modern marine deposition in the Caspian Sea.

The drainage basin of the Caspian Sea covers an area of about 3.5 million km^2, including regions of the former USSR (90%) and parts of Iran and Turkey (10%). The ratio of the sea's surface area to that of its drainage basin is approximately 1:10, highlighting the crucial role of terrestrial contributions in providing sedimentary materials to the basin.

Geologically, the drainage basin consists of four distinct structural and tectonic components: the Ural orogenic system, the Russian Platform, the Greater Caucasus, and the Lesser Caucasus mountain ranges.

The Ural Fold Belt serves as a highly diverse source region. A notable characteristic of this area is the extensive presence of ophiolitic and ultramafic belts – submeridional chains made up of Large Gabbro, Peridotite, Dunite, and Pyroxenite massifs. These intrusive complexes are spatially linked to a variety of mineralizations, such as *titanomagnetite-vanadium, copper-sulfide, gold-platinum, chromite, and apatite deposits*. From a Geochemical Standpoint, this positions the northeastern part of the Caspian Sea catchment area as a significant source of elements related to early-stage magmatic differentiation – specifically Ti, V, Fe, Cu, Au, Pt, Cr, and others. The weathering crusts and soils in the Ural region are marked by the prevalent presence of serpentinites and montmorillonite clays. The Ural section of the drainage basin is fluvially linked to the Caspian Sea through the Ural and Emba Rivers, as well as by left-bank tributaries of the Volga River.

The Russian Platform is situated in the northwestern section of the Caspian Sea drainage basin. The geological composition of this area mainly consists of carbonate-evaporite and terrigenous-clayey formations. It is believed that rivers flowing from the East European Plain – especially the Volga and its tributaries – carry significant amounts of carbonate material. Among the clayey suspended sediments, hydromica (illite) is the most prevalent. A notable characteristic of this part of the catchment is the development of a highly specific accessory mineral assemblage. Due to repeated redeposition and extended sedimentary "maturation," only the most chemically stable weathering products from the Baltic Shield remain – specifically quartz, kyanite, staurolite, and sillimanite.

The mountainous formations of the Greater Caucasus, which are shaped by the erosion from the Terek, Samur, Sulak, and other rivers, are primarily made up of sandy-terrigenous deposits with a small carbonate component. The most common Jurassic black shale formations contain considerable amounts of beryllium (in the form of siderite and sulfides), tungsten, cobalt, nickel, and lead. These formations also serve as a significant source of chlorite minerals, which are plentiful in the suspended loads of Caucasian rivers. The region is marked by the dominance of relatively unstable minerals, including leucoxene, sphene (titanite), pyroxenes, amphiboles, andalusite, micas, chloritoid, epidote, chromian spinels, and apatite

The Lesser Caucasus region is located in the southwestern part of the Caspian Sea drainage basin. Its geological structure is dominated by mafic and intermediate volcanic rocks, including intrusive bodies associated with ophiolitic belts. From a metallogenic standpoint, this region closely resembles the

Urals, with a prevalence of chromite, titanomagnetite, and copper-pyrite (chalcopyrite) mineralization. However, a distinctive feature of the Armenian sector of the Lesser Caucasus is the presence, alongside elements typical of early-stage magmatic differentiation, of significant concentrations of Pb, Zn, Hg, Sb, As, Mo, and other chalcophile elements.

The mountainous terrain of the Lesser Caucasus appears to contribute to the Caspian Sea both stable minerals derived from mafic rocks – such as chlorite and chrome-picotite – and less stable phases, including hornblende, pyroxenes, and amphiboles. Among clay minerals, magnesium-rich silicates are widespread – minerals generally characteristic of mafic igneous rocks in a variety of geological settings. The Lesser Caucasus is drained by the Kura River and its right-bank tributaries.

A unique characteristic of the Caspian Sea as a sedimentation basin is its inflow from both humid and arid regions – this presents a significant contrast to the Black Sea, whose drainage basin is predominantly situated within a humid climatic zone.

On the western shore of the southern Caspian, arid conditions commence at the Apsheron Peninsula and stretch across the Kura River delta and a portion of the adjacent Prikura Lowland. Conversely, the neighboring areas of the Greater Caucasus and Transcaucasia are encompassed by humid climatic zones, with high-altitude regions even experiencing glacial conditions that facilitate the movement of sedimentary materials.

Consequently, the Caspian Sea is nearly entirely surrounded by a belt of desert and semi-desert landscapes. Almost all rivers that flow into the sea obtain their sediment load from humid (and, less frequently, glacial) source regions, yet they transport this material through arid zones before ultimately depositing it into the terminal basin.

Roughly two-thirds of the Caspian drainage basin is fluvially drained, while the remaining one-third comprises endorheic depressions. These arid regions – particularly in the eastern and northeastern areas – serve as important sources of aeolian material.

The Volga River is the predominant contributor of water, representing nearly 80% of the total riverine inflow. It is succeeded by the Kura (6.2%), the Ural (3.2%), and subsequently the Terek and Samur rivers (2.6–2.0%). If we evaluate the solid (suspended) sediment discharge of rivers not by current, heavily regulated figures –impacted by dams and irrigation systems – but rather based on the natural flow patterns observed in the 1930s and 1940s [Lopatin, 1952], a different sediment supply pattern is revealed. The estimated annual suspended sediment input (in million tons/year) is as follows: Sulak – 26.8, Terek – 25.8, Volga – 25.7, rivers of Lankaran and northern Iran – 10.7, Ural – 4.1. This leads to a notable imbalance in the sediment budget of the Caspian Sea: the western region receives a considerably higher amount of fluvial suspended material compared to the eastern region, where, under favorable meteorological conditions, sediment input is mainly influenced by aeolian (aerosol) transport.

The geochemical characteristics of the source provinces within the Caspian Sea drainage basin are primarily evident in the composition of both light and heavy mineral fractions found in sandy sediments deposited in river deltas. Typomorphic minerals identified in the Volga River include kyanite, staurolite, and andalusite. Conversely, the most distinctive accessory minerals associated with the rivers of the Greater Caucasus (such as the Terek and Akchay) are green micas (from the chlorite group) and dolomite. Meanwhile, sediments carried by rivers that erode the Lesser Caucasus structures (like the Kura and Alazani) are significantly enriched in unstable pyroxenes and hornblende.

There is also substantial evidence suggesting that the geochemical characteristics of the drainage basin are reflected in the chemical composition of suspended sediments from various rivers. For example, reliable indicators of the distribution of basic magmatic rocks in eroded areas include trace elements such as Cr, Co, Ni, V, Cu, and Mo. These elements are found in the highest concentrations in the Ural and Kura rivers, which drain regions rich in ultrabasic (ultramafic) rocks, while the lowest concentrations are observed in the Terek, Sulak, and Samur rivers, where sedimentary rocks and granitoids predominate.

An analysis of the pelitic (fine-grained) fraction of suspended matter has revealed that rivers originating in the Caucasus (including Terek, Urukh, Cherek, Sulak, Koisu, and Kuma) contain higher proportions of hydromica (illite) and chlorite. In contrast, rivers draining the Russian Platform and the Ural Mountains (such as the Volga and Ural) are characterized by a clay mineral assemblage dominated by montmorillonite.

Hydrodynamic processes and sedimentation patterns in the Caspian Sea are intricately linked to its Morphometry, which is, in turn, influenced by the Geological Structure of the surrounding Region.

From a Tectonic Viewpoint, the Caspian Basin is situated within three primary first-order structural domains. The northern and northeastern regions of the Northern Caspian are positioned on the Russian (East European) Precambrian Platform. The Middle Caspian includes a portion of the epi-Paleozoic Scythian–Turan Plate, while the South Caspian Basin is found within the Area of Alpine Orogeny.

In the northern region, a Paleozoic–Mesozoic sedimentary layer overlays the Precambrian Crystalline Basement. This layer is notably complicated by salt tectonics and creates a significant downwarp – the Precaspian Syneclise – where sedimentary sequences can reach thicknesses of 12–15 km [Borisov, 1967].

To the south of the Mangyshlak Threshold, there exists a section of the Scythian–Turan Plate. In this area, Mesozoic–Cenozoic sedimentary layers rest on pre-Jurassic crystalline rocks. Within the Terek–Sulak and Apsheron depressions, the basement is found at depths of 10–12 km. In this segment of the Caspian, geophysical data still suggest the existence of a so-called "granitic" layer, although it seems to taper off toward the Apsheron Sill.

Throughout much of the South Caspian area, the "granitic" layer is likely missing, and the exceptionally thick sedimentary fill – exceeding 24 km in certain locations –sits directly atop "basaltic" layers. Consequently, the structure of the South Caspian crust is regarded as being similar in nature to oceanic crust.

In line with the tectonic zonation outlined earlier, the Caspian Sea is distinctly divided into three morphologically unique depressions.

The Northern Caspian, which has an average depth of no more than 6.2 meters, serves as a gently sloping platform that retains remnants of ancient landforms and submerged paleochannels. These features include the Ural Trough, the paleo-Volga Depression, and the Mangyshlak Furrow.

Erosional relief is a defining characteristic of the entire northern region of the Caspian Sea, which is gradually being leveled and covered by continuous sediment deposition. These characteristics clearly suggest that the Northern Caspian's floor was, in the relatively recent geological past, part of a vast lowland terrestrial area.

The Middle Caspian is a genuine deep-water basin. Its primary feature is the Derbent Basin, which is surrounded on all sides by a narrow continental shelf. This basin reaches maximum depths of 770–780 meters. Its northwest-southeast alignment channels a strong cyclonic current, which serves as a pathway for fine-grained clastic materials – either eroded from the northern basin floor or brought in by the Terek, Sulak, and Samur rivers – into this deepwater Halistatic Trap.

The slopes of the Derbent Basin often show signs of mass wasting processes, such as submarine landslides and turbidity flows. On the northern part of the eastern slope, one can trace erosional incisions of paleo-channels and temporary flows.

The Southern Caspian constitutes a highly intricate structural depression, attaining a maximum depth of 1,025 meters. The western edge is sharply inclined, while the eastern edge ascends gradually, leading into an expansive shelf platform [Leontiev, 1963]. The basin floor and shelf area of the South Caspian are made complex by a multitude of mud volcanoes and tectonic uplifts, many of which are reflected in the Topography of the seafloor.

The morphological variations among the Northern, Middle, and Southern Caspian have a significant impact on the hydrodynamics of the basin. A number of researchers [Knipovich, 1921; Lednev, 1943; Mikhalevsky, 1931; Shtokman, 1940] have found that the Caspian Sea overall exhibits a cyclonic circulation pattern. However, subsequent research has shown that in the Northern Caspian, circulation is closely linked to wind direction and seiche-like (wind setup and setdown) variations in water level, while in the Southern Caspian, a distinct anticyclonic gyre has been identified.

The Caspian Sea's waters are particularly rich in sulfates, especially magnesium sulfate ($MgSO_4$). They also display a very high alkaline reserve, ranging from 3.16 to 3.5 mg-equiv, along with elevated pH levels of 8.3 to 8.4.

Salinity levels in the Caspian Sea vary considerably based on its morphological divisions. The lowest salinity is observed near the Volga River delta. In the Northern Caspian, the average salinity is approximately 2.2‰, with 1.8‰ in the western region and up to 3.2‰ in the eastern region [Ivanova, 1953]. In the Middle and particularly the Southern Caspian, surface salinity rises significantly, reaching its peak near the Cheleken Peninsula and in the Krasnovodsk Gulf, where salinity levels fluctuate between 13 and 13.4%. This rise in surface salinity is mainly due to high evaporation rates under hot and dry climatic conditions. In the deep depressions of the Middle and Southern Caspian, salinity levels generally surpass those of the surface waters.

A notable aspect of the southern Caspian Sea and the surrounding areas of Azerbaijan and Turkmenistan is the significant presence of mud volcanism. For instance, in Azerbaijan [Gorin, Bunyat-Zade, 1971], within the triangular region defined by the city of Shemakha, Oil Rocks Island, and the submerged Kurinsky Bank, there are around 200 mud volcanic centers, many of which are distinguished by their considerable size. In the marine region of the southern Caspian, approximately 136 submarine mud volcanoes have been documented. Numerous ones are prominently featured in the seafloor topography, creating shield-like formations. Furthermore, in western Turkmenistan, near the cities of Cheleken, Nebit-Dag, and Hasan-Kuli, there exist about 50 terrestrial mud volcanoes, some of which have shown activity in the recent past.

During eruptions, mud volcanoes release substantial amounts of mud breccia, gases, and fluids into the sedimentation zone.

It is clear that the mud volcanic activity on the seafloor of the southern Caspian, along with allochthonous input, aeolian processes, coastal erosion, and the actions of benthic organisms, should be considered a primary source of sediment supply to the seabed.

The majority of suspended matter in the Caspian Sea is made up of pelitic particles; only in river mouth regions and sediment resuspension areas do clay particles intermingle with sand- and silt-sized fractions.

The mineral composition of the suspended matter generally includes subcolloidal and clay minerals, chemogenic and terrigenous calcite, quartz grains, feldspar, lithic fragments, mica, and heavy mineral fractions.

The environmental conditions of the Caspian Sea facilitate the suspension of not just carbonates brought in by river inflow and wind-blown dust, but also those generated through chemogenic processes. The most effective formation of chemogenic carbonate occurs in areas where river and marine waters mix, as well as in shallow open regions of arid climates.

According to the spatial distribution characteristics of suspended matter in the Caspian Sea, four primary regions can be distinguished: the Northern Caspian, the western and eastern shelves, and the deep-water basins.

In the Northern Caspian, the dynamics of suspended matter are completely influenced by river discharge; during the spring flood, the highest levels of terrigenous suspended material are observed in the estuarine zones of the Volga and Ural rivers. In the summer months, the total quantity of suspended matter in this area diminishes, but due to the vigorous growth of phytoplankton, the role of organic components becomes increasingly important.

In the autumn, heightened riverine input in the estuaries of the Volga and Terek rivers, coupled with frequent storms, once again encourages the widespread occurrence of marine terrigenous suspension in the near-bottom water layers, while the concentration of biogenic components correspondingly decreases.

Longshore currents carry around 13 million tons of marine suspension each year from the Northern Caspian to the Middle

Caspian. Additionally, a significant quantity of terrigenous suspended material is transported to the western shelf of the Middle Caspian due to riverine contributions from rivers that erode the Caucasus region. A.S. Pakhomova and B.M. Zatuchnaya 1966] noted that before flow regulation, the Kura River's suspended sediment load was as high as 37 million tons annually. Recent studies show that the Terek River contributes about 11 million tons, the Samur River contributes between 4.7 and 13.0 million tons, and the current Kura River contributes between 11.2 and 17.1 million tons each year. Consequently, in the Middle and Southern Caspian, the concentration of terrigenous suspension in the surface layer of the western shelf can reach up to 21.2 mg/L, while in the near-bottom layer, it can be as high as 18.8 mg/L.

On the eastern shelf, there is no riverine input, and the suspended matter is formed solely through coastal erosion, wind-driven processes, and the chemical precipitation of carbonate materials. The extensive presence of shell debris on the seafloor helps to prevent the resuspension of silts in the eastern shelf area. As a result, the water column above the eastern shelf has 1.5 to 3 times less suspended matter than that above the western shelf. It is also important to mention that the suspended matter on the western shelf is predominantly composed of clay, while the eastern shelf is characterized by a predominance of carbonate components. Sands represent one of the most prevalent lithological types of bottom sediments found in the Caspian Sea. They create a continuous ring around the basin, with the most significant occurrences located in the northern region of the sea and along its western shelf. The lower limit of sand distribution is observed at depths between 2 and 100 meters, which varies based on the hydrodynamic conditions of a specific area, the seabed's morphology, and the amount of incoming sandy material. A large sand field situated at relatively deeper depths along the Mangyshlak Threshold seems to have developed through non-erosional processes affecting the alluvial Mangyshlak formations, in addition to the redeposition of sand in sheltered areas south of this structure. Typically, the sands are poorly sorted and, due to the consistent presence of shell debris, display a bimodal grain-size distribution curve.

Coarse silts are also extensively distributed, although they show a distinct preference for river delta environments. In the Northern Caspian, they can be found along the Ural littoral zone, within the Ural Depression, as isolated distributary branches in the prodelta region of the Volga, and in the Mangyshlak and Kizlyar Bays. On the western shelf, coarse silts are present in the deltas of the Samur River and other smaller rivers. Similar to the sands, quartz, feldspars, and glauconite are the dominant minerals; carbonates are less common and appear in the form of detritus, discoidal aggregates, crusts, and spherulites.

Biogenic (shell-bearing) sediments are notably prevalent in the Northern Caspian and are typically linked to positive relief features. On the western shelf of the Middle and Southern Caspian, these sediments appear as scattered patches, whereas on the eastern shelf, they manifest as a continuous belt. In their fresh state, shell deposits consist of a fluid sediment abundant in mollusk shells and detritus. When dried, they form a weakly cemented structure and take on yellow, red, gray, or black hues. Admixtures of sand, silt, or oolitic aggregates are frequently found within them.

Chemogenic sediments in the Caspian Sea include sands and carbonate-clayey muds. Oolitic sands are found as isolated patches widely spread across the eastern part of the basin, often linked to structural highs. This sediment resembles coarse-grained sand, containing up to 80% carbonate ooids, with the rest made up of shell fragments, shell detritus, or terrigenous material. Carbonate-clayey muds are characteristic of deep-water basins.

The examination of the geochemical properties of contemporary sediments in the Caspian Sea reveals another dimension of sedimentary processes – specifically, the connection between the methods of mobilization, types of migration, and distribution patterns of chemical elements within the terminal basin of a drainage system.

Based on their behavior across various sediment types, all chemical elements can be categorized into three distinct groups.

The first group consists of Cr and Zr, which reach their highest concentrations in relatively coarse-grained clastic sediments. Both elements are found in substantial quantities in silty types of muds, a phenomenon influenced by their migration forms in riverine settings.

The second group includes Fe, Mn, P, Mo, Ga, Ni, Co, Cu, organic carbon (C_{org}), and, to a certain degree, Pb; these elements are known to accumulate predominantly in the finest-grained clayey muds.

Occupying an intermediate position between the first and second groups are Ti, V, and Ge. These elements, which make up the third group, display dual behavior: on one hand, they are similar to Cr in that they concentrate in fine silt muds; on the other hand, akin to Fe and Mn, they also tend to accumulate in fine-grained clayey sediments.

The third group of elements – V, Ti, and Ge – holds an intermediate position regarding distribution patterns on the Caspian Sea floor, situated between the Cr–Zr group and the Be group, although they are more closely associated with elements linked to stable minerals.

The behavior of chemical elements from the first and second groups is primarily influenced by their modes of entry into the basin through river waters, as well as the transformations they experience in the aquatic environment.

A comparative analysis of the geochemistry of contemporary bottom sediments from the Caspian and Black Seas was conducted based on lithological sediment types, which include sands, silts, clayey muds ($CaCO_3$ < 30%), clay-carbonate muds ($CaCO_3$ = 30–50%), and carbonate-clayey muds ($CaCO_3$ > 50%). This comparison also utilized geochemical diagrams created using equivalent classification intervals.

The data comparison leads to the conclusion that the modern sediments of the Black Sea are considerably richer in most chemical elements—this is true for elements from both the first and second groups

Source: “The Caspian Sea: Problems of Sedimentogenesis”. Moscow, "Nauka" Publishing House, 1989, pp. 151-171. Authors: V.N. Kholodov, Yu.P. Khrustalev, I.Yu.Lubchenko, V.V. Kovalev, D.S. Turovsky

1.6. SALINITY OF SEAWATER

A popular Scandinavian folk tale claims that the ocean is salty due to a magical salt mill that operates endlessly somewhere on the ocean floor. Interestingly, this narrative is gradually gaining traction in scientific circles. Contemporary geophysical studies have confirmed the existence of such a "factory" in the form of the mid-oceanic ridge–a continuous, winding feature that spans all major ocean basins, totaling around 40,000 miles in length. In areas where the ocean floor is diverging, juvenile water–water that has never existed in a liquid state before – is brought to the surface alongside basaltic material (MacIntyre, 1970).

Nevertheless, this theory does not apply to the Caspian Sea. The variations in salinity within the Caspian are mainly influenced by changes in river inflow, which affects the hydrological balance. Other elements – such as precipitation, seasonal variations, evaporation from the sea surface, surface turbulence, and water exchange between different areas of the sea – have a lesser impact on the spatial distribution of salinity across the sea's surface.

The salinity patterns of the Caspian Sea have been extensively studied in scientific research. Specifically, the salinity dynamics of the Northern Caspian are often examined independently, due to the unique Hydrological and Morphological conditions that define this Area.

As depicted in Figure 1, the long-term average salinity of the Caspian Sea's surface waters shows considerable variation. The current salinity distribution within the Caspian Sea features a wide range of long-term average values, spanning from 1.0 to 13.5‰. This variability is particularly evident in the Northern

Caspian, where river inflow has a significant impact. In this area, salinity increases as one moves southward over several hundred kilometers, starting from nearly 0‰ near the river mouths and reaching about 10‰ further offshore. As a result, the Horizontal Salinity Gradients in this Region are extremely steep, with values approaching approximately 0.1‰ per kilometer. In other sections of the sea, the spatial variation in salinity is much less pronounced, and these regions can be classified as relatively Homoghaline. As shown in the figure, the salinity difference between the freshwater-influenced Volga Delta Area and the southeastern edge of the Basin is as much as 13.5‰. This peak value corresponds to the Isohaline that outlines the eastern coastline of the Southern Caspian, stretching from Turkmenbashy to Bandar-e Anzali. Almost all other surface waters in the sea display salinity levels ranging from 12.5 to 13.0‰. Notably, near the Apsheron Sill, the 12.5‰ isohaline curves around the Apsheron Peninsula, creating a protrusion that appears to push the more saline waters eastward. This phenomenon can be linked to the freshening effect caused by river discharge from the Western Shore, which is redistributed by the branches of the main Caspian Current system, exhibiting both cyclonic ad anticyclonic characteristics. From the city of Aktau heading south, the 12.5‰ isohaline runs along the Central Axis of the Sea. The lack of a river network in the southeastern Caspian region leads to higher salinity levels in the adjacent waters, reaching 13.0-13.5%.

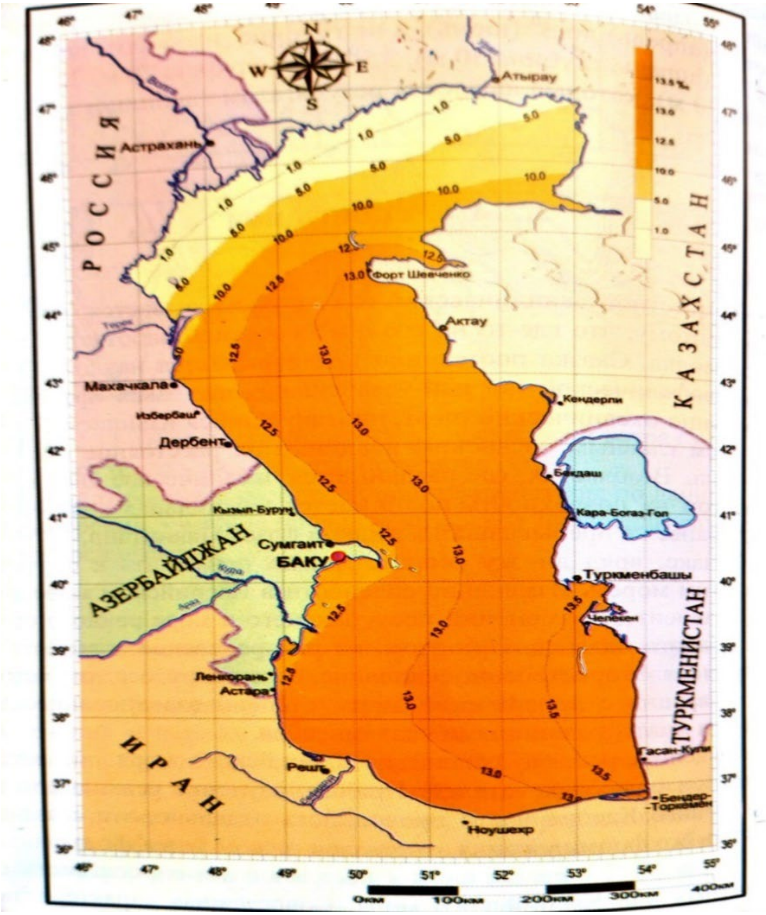


Fig 1. Spatial distribution of long-term mean salinity in the surface layer of the Caspian Sea.

The long-term changes in the salinity of the Caspian Sea are mainly influenced by variations in the discharge of the Volga River and the resulting changes in sea level. It is well known that the salinity of the Caspian Sea, being an enclosed basin, is heavily reliant on its water volume, and salinity changes gradually in response to fluctuations in this volume. Over extended durations, consistent alterations in the sea's water volume (whether a decrease or an increase) result in corresponding shifts in salinity (either an increase or a decrease, respectively).

For example, the notably low-flow period from 1932 to 1940 led to a rise in sea level and a subsequent drop in salinity. During the 1940s, an increase in the salinity of the Volga and Ural Rivers was noted, alongside a decrease in the salinity of the Northern Caspian.

From 1978 to 1995, the sea level increased by 2.5 meters, which resulted in an approximate increase of 700 km^3 in the sea's water volume. In examining the connection between salinity and sea level, Aliyev A.S. (2004) posited that if the primary reason for the sea level rise during 1978–1995 was a positive water balance (influenced by hydrometeorological factors, i.e., climatic conditions), then the additional water volume in the sea should have caused a gradual decline in salinity.

Using empirical data, time series of simultaneous salinity and sea level measurements were evaluated for the observation stations in Makhachkala, Bekdash, "Oil Rocks" *("Neft Dashlary"),* and Sangy-Mugan. For each station, correlation coefficients between the monthly average Sea Level and Salinity Values were computed using the least squares method (Ref. to the Table).

As indicated in the table, the highest correlation coefficients were recorded at the "Oil Rocks" *("Neft Daslary")* and Bekdash monitoring stations, which can be mainly attributed to their geographical positioning. The salinity levels at the

Makhachkala station are greatly affected by the direct discharge from the Volga River. Naturally, the salinity of the Caspian Sea shows seasonal fluctuations. In the winter months, there is a general rise in salinity observed across the entire basin, reaching into the northern areas. During this time, most of the sea is characterized by isohalines between 13.0 and 12.5‰, with relatively small spatial gradients. As the effect of riverine freshwater input on the dilution of waters along the western coast diminishes, the prevailing salinity levels tend to stabilize around 12.5%.

No.	Points	Observation Duration	Correlation Coefficient
1	Oil Rocks	1978- 1995	-0,68
2	Bekdash	1978- 1993	-0,64
3	Sangy-Mugan	1978 - 1992	-0,48
4	Makhachkala	1978 - 1992	-0,25

Correlation Coefficients Relating Sea Level to Water Salinity at Different Observation Stations

During the summer months, the horizontal variability of these parameters in the Northern Caspian experiences a significant increase, with values fluctuating between 1.0 and 12.0‰. The steepest gradient is noted along the depth contour (slope zone), where salinity levels rise markedly over a short distance – from 8.0 to 12.0‰. The most saline waters in this region tend to migrate southeastward, while the central part of the basin remains relatively uniform.

It is important to highlight that, in addition to the aforementioned patterns, exceptionally high salinity levels – excluding the hypersaline waters of Kara-Bogaz-Gol Bay (which can reach up to 300‰) – are also present in certain locations due to human activities. Starting in summer, a zone of increased salinity (around 13.0‰) develops near the Absheron Archipelago; by autumn, this zone usually diminishes in size.

Based on long-term average data, the surface water salinity in the Azerbaijani sector of the Caspian Sea typically ranges from 12.5 to 13.0‰. In winter, salinity levels in this area rise, while in summer, they decrease, ranging from 12.5-13.0‰ and 12.0-13.0‰, respectively. In the first scenario, the difference in values is approximately 0.5‰, and in the latter, about 1.0‰, with a relatively consistent spatial distribution throughout the basin.

Source: "Variability in Hydrometeorology and Ecogeographical Issues of the Caspian Sea". Baku: "Elm" Publishing house, 2007, pp. 71-75.
Author: R.M. Mamedov

1.7 DISTRIBUTION PATTERNS OF MUD VOLCANOES ON THE CASPIAN SEA FLOOR

The South Caspian Basin stands out globally due to its remarkable number of mud volcanoes and the vigor of their activity. The identified mud volcanoes in this area are located within the coastal zone, forming islands and banks on the Caspian Sea shelf, and are also prevalent in deeper waters. For an extended period, the unique characteristics of the marine environment hindered a comprehensive understanding of the actual extent of mud volcanic activity on the Caspian Sea floor. Nonetheless, 88 mud volcanoes have been documented within the southern Caspian basin.

Mud volcanoes generate positive relief features through their activity– elevations made up of solid eruption materials. Clearly, the substances expelled by underwater mud volcanoes play a role in shaping the microrelief of the adjacent seabed, leading to notable, localized changes in sea depth. Consequently, it has been suggested to utilize morphometric techniques, analyzing navigational charts and tectonic maps of the southern Caspian depression, to uncover previously unrecognized mud volcanoes The analysis of the developed profiles, which effectively depict the geomorphological traits of seabed elevations, has enabled the reliable identification of submarine mud volcanoes. This identification is further corroborated by the alignment of their locations with those found through alternative investigative approaches.

The compilation of data regarding known mud volcanoes alongside those discovered through morphometric techniques has enabled the characterization of their distribution patterns across the Caspian Sea floor. It has been determined that the mud volcanic province nearly covers the entire Apsheron Threshold and the whole southern Caspian Basin, spanning an area of about 60,000 km². Within this area, a total of 142 mud volcanoes have been identified. Based on the density of these mud volcanoes, five distinct zones can be recognized: northern, western, central, eastern, and southern (refer to figure).

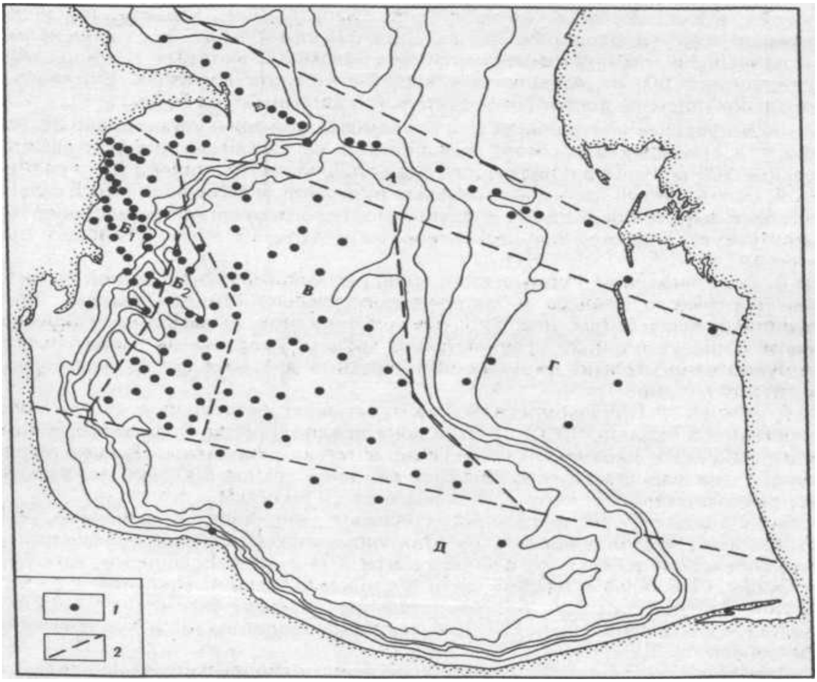
1. The Northern Zone, also known as the Apsheron Threshold Zone *(A),* is situated in the northern section of the region, stretching from the Apsheron Peninsula in the west to the

Cheleken Peninsula in the east. In this zone, 27 mud volcanoes have been identified, forming a chain that runs in a northwest-southeast orientation. The volcanic cones are primarily located at depths of up to 200 meters and typically have heights between 10 and 20 meters, a feature linked to the vigorous scouring by bottom currents along the Apsheron Threshold.

2. The Western – Azerbaijani Zone *(B)* runs along the western shoreline of the Caspian Sea, from the settlement of Karadag to the city of Astara. This zone is further divided into two subzones based on its characteristics: The Shelf Subzone *(B_1),* which includes the area of the Baku Archipelago, and the Deep-Water Subzone *(B_2).*

In the shelf subzone, which is bounded to the east by the 100-meter isobath, a total of 39 mud volcanoes have been documented (refer to Fig. 1); these have been relatively well researched. The majority of these mud volcanoes are found along three southeast-oriented alignments that begin near the capes of Alyat, Khamamdag, and Byandovan. The heights of the underwater volcanic cones vary between 0.5 and 50 meters.

The deep-water subzone is linked to the western continental slope of the South Caspian Basin, stretching from the 100-meter isobath down to the base of the slope at around 800 meters in depth. This region is home to 29 mud volcanoes (see figure). Their arrangement also exhibits a southeastward trend, akin to that seen in the shelf subzone. The seabed topography in this area is intricate, characterized by a mix of hills and elevations interspersed with canyons and depressions, where water depths surpass 900 meters. The absolute heights of the mud volcano cones in this subzone can be quite significant, reaching as much as 500 meters.



Distribution of Submarine Mud Volcanoes in the South Caspian Basin:

1 - mud volcanoes;
2 - zone boundaries:
A - Northern Zone (Apsheron Threshold)
B - Western Zone (Azerbaijani Zone)
B_1 - Shelf Subzone
B_2 - Deep-Water Subzone
C - Central Zone (Deep-Water)
D - Eastern Zone (Turkmen Zone)
E - Southern Zone (Pre-Elburz Zone)

3. In the Central or Deep-Water Zone, 36 mud volcanoes have been recognized, with most having cones that rise over 100 meters in height. The seafloor in this area is predominantly flat, except for some submarine elevations found in the northern and northeastern regions. While the flat seabed features mud volcano cones, there is no noticeable alignment or orientation among the individual volcano groups, unlike in the previously mentioned zones.

4. The Eastern or Turkmen Zone spans a large area of the eastern shelf and continental slope of the South Caspian. This zone has only 5 identified mud volcanoes. The seabed is generally calm and flat, exhibiting a slight gradient towards the west. The volcanic cones reach heights of several tens of meters compared to the surrounding seafloor.

5. The Southern or Pre-Elburz Zone encompasses the southern coastal waters of the Caspian Sea. Within this zone, 6 mud volcanoes are believed to exist and are categorized as "probable". The seafloor remains mostly flat, with depths surpassing 600-800 meters. The heights of the mud volcano cones vary widely, ranging from 70 to 600 meters.

A comparison of the distribution of mud volcanoes across the identified zones indicates that the majority are found within the Azerbaijani and Deep-Water Zones, where a total of 104 mud volcanoes are situated, representing about 74% of all mud volcanoes in the southern Caspian Sea. There is a distinct trend showing a decrease in the number of mud volcanoes from west to east: starting from the Azerbaijani Zone (68 volcanoes), moving to the Deep-Water Zone (36), and finally to the Turkmen Zone (5).

This study highlights the largest mud volcanoes in the South Caspian region, where their vigorous activity has resulted in the creation of significant seabed elevations.

Utilizing the morphometric method for identifying mud volcanoes greatly minimizes the extent of field investigations needed, enabling researchers to concentrate their efforts on particular sea areas where the geological conditions are conducive to the formation of diapiric features.

Source: "Edited volume "Geological and Geomorphological Studies of the Caspian Sea". Moscow, "Nauka" Publishing house, 1983, pp. 70–72. Authors: A.A. Yagubov, F.G. Dadashev, A.T. Makhtiyev.

1.8 SEA LEVEL VARIATIONS AND THE WATER BALANCE OF THE SEA

The Caspian Sea and its surrounding coastal area possess considerable natural resources and economic potential, making their rational utilization crucial for the countries bordering the sea. Nevertheless, the socio-economic advancement of the entire region is significantly influenced by alterations in natural conditions—primarily, variations in the Caspian Sea's water level.

Between 1978 and 1995, a 2.5-meter increase in sea level led to a tense and critical situation in the coastal zone. This recent transgression inflicted substantial damage on the agro-industrial complex, oil and utility sectors, transportation, and various other industries. Most importantly, it had a severe impact on the local population, who found themselves in a state of ongoing anxiety. Some communities were either flooded or transformed into islands. Hundreds of families had to leave their homes, giving rise to the phenomenon of environmental "refugees." The population had not received adequate warnings about the looming threat. This underscores that fluctuations in sea level continue to be one of the most urgent challenges confronting the Caspian Sea region. Historically, abrupt transitions between transgressions and regressions have influenced the destinies of entire ethnic groups. L.N. Gumilev [1964] noted that one of the factors that weakened the ancient Khazar state's power was a sudden transgression of the Caspian Sea in the 10th century AD, which submerged a large portion of pastureland in the northern Caspian area.

In the 1950s and 1960s, a time marked by a decline in sea levels, the dominant slogan was "Save the Caspian." This led to a variety of engineering proposals, including the diversion of northern rivers into the Caspian Sea, the construction of a large dam to separate the Northern Caspian, and the closure of the outflow into the Kara-Boghaz-Gol, among other initiatives.

However, the forecasts made by most scientists regarding a continued decline in sea levels leading up to the year 2000 did not materialize. In the 1980s, during a period of rising sea levels, new protective measures were introduced under a different slogan: "Save ourselves from the Caspian." Equally ambitious proposals emerged, such as the construction of a massive Caspian dam, the pumping of Caspian water into the Aral Sea and the endorheic basins of Mangyshlak, and increasing the outflow into the Kara-Boghaz-Gol, among others.

All of these initiatives were reactive rather than strategic; they were primarily speculative and did not take into account the cyclic and highly dynamic historical evolution of the Caspian Sea.

Even a fluctuation in sea level of 1–2 meters can significantly impact the hydrological, biological, and chemical regimes of the basin. For instance, the annual cycle of mean surface temperature experiences changes; isotherm patterns are altered; the depth at which thermocline forms is modified; and substantial variations occur in coastal areas, where the amplitude can reach up to 2°C. Seasonal factors and the geographical location within the sea also play a significant role. Changes in depth in nearshore regions affect the characteristics of wind-driven surface waves, current velocities and directions, turbulence regimes, evaporation rates, and more.

The Caspian Sea represents a cohesive natural geosystem where geological, hydroclimatic, anthropogenic, and even cosmic elements interact in intricate manners. The capacity to forecast fluctuations in sea level is fundamentally tied to the depth of scientific comprehension and the identification of all factors and forces that influence these variations. In recent years, there has been a growing interest from international organizations regarding the dynamics of Caspian Sea levels. This is, in part, connected to the increasing strategic significance of the region and its natural resources for the world's foremost nations, as well as to the chance to leverage the growing experience in tackling the challenges of sustainable environmental management in the context of considerable sea level changes, serving as a model for examining the effects of climate warming.

Two categories of sea-level fluctuations are identified in the Caspian Sea: volumetric and deformational. Volumetric fluctuations arise from alterations in the volume of water within the sea basin, influenced by changes in the components of the water balance. Conversely, deformational fluctuations occur with variations in the height of the sea surface while the total water volume remains constant. These can be further classified into short-term and long-term fluctuations. Short-term deformations are caused by the combination of wind-driven surges, seiches, and tidal movements. Long-term deformations are mainly the result of geological processes taking place within the sea basin.

It can be asserted with certainty that, currently, there are no sufficiently reliable predictions regarding future changes in Caspian Sea levels, which significantly impedes economic planning and regional development within the basin. The creation of such forecasts continues to be one of the most pressing challenges in the study of the Caspian Sea.

Violations and Declines of the Caspian Sea. From the earliest geological periods, the Caspian Sea basin has been filled with water; however, its dimensions and hydrological characteristics have experienced ongoing alterations. Throughout geological history, the sea's outlines have alternately expanded in both meridional and latitudinal directions. During the Tertiary period, which commenced around 70 million years ago, the Caspian basin gradually became isolated and separated from the southern seas and the Tethys Ocean. By the conclusion of the Pontian stage, in the mid-Pliocene (approximately 10 million years ago), the extensive inland Sarmatian Sea – previously encompassing the regions of the modern Black and Caspian

Seas – fragmented into distinct bodies of water, resulting in the establishment of the Caspian Sea as a standalone, enclosed basin.

Numerous marine terraces along the current coastline, frequently located at considerable elevations, along with submerged *paleoshorelines* identified on the seabed, signify repeated alterations in the Caspian shoreline during the most recent geological epoch. It is believed that during the Pliocene, the sea's surface area was less than it is today, and during specific intervals of the mid-Pliocene, the sea may have only filled the southern depression – indicating that the sea level was considerably lower than present levels. Therefore, the history of the Caspian Sea represents a narrative of transgressions and regressions – a record of persistent fluctuations in sea level.

Four Key Phases in the Development of the Caspian Sea have been recognized: the Baku, Khazar, Khvalyn, and Novocaspian phases [Rychagov et al., 1994; Fedorov, 1956]. The absolute ages and positions of ancient shorelines along the Dagestani section of the Caucasian coast of the Caspian Sea, as identified by T.I. Rychagov and colleagues [1994] and through our own research, are detailed in the table.

From the Tertiary period to the present, four distinctly different basins in terms of shape and characteristics have succeeded one another in the region currently occupied by the Caspian Sea: the Pontian, Kimmerian, Akchagyl, and Absheron seas. The sea continued to diminish further during the Baku and Ancient Caspian phases, gradually adopting its contemporary outline. It has been determined that during the Quaternary period – around 500,000 years ago – the range of fluctuations in the Caspian Sea level reached approximately 600 meters. Additionally, it is known that during this time, the Caspian Sea was hydrologically linked to the Azov and Black Seas through the Kuma -Manych Depression.

The study of the Caspian Sea's historical regime changes is of great significance, as it may provide insights into possible future variations. During the Holocene epoch (the last 10,000 years), when a climate similar to today's was established, evidence from *paleoshoreline* positions linked to absolute elevations suggests that sea level changes could have surpassed 20 meters in amplitude, with the long-term average level around -25 meters in absolute elevation.

The earliest documented observations of Caspian Sea level changes are found in the writings of classical authors from Ancient Greece and Rome. Accounts by Herodotus and Aristotle – likely referencing the 6th century BCE – suggest that the sea level was believed to be quite low. Conversely, records from Patrocles (early 2nd-4th centuries BCE) and Ptolemy’s map, which likely originates from the same period, indicate a much higher sea level – about 40 meters above current levels – during a time when extensive areas of the Caspian lowlands were submerged. It is crucial to highlight that Ptolemy’s map illustrated only the southern Caspian, emphasizing the limited geographical coverage of early cartographic information.

Scattered mentions of Caspian Sea levels from the 12th century BCE in the writings of scholars, geographers, and literary figures of that era rely on indirect and often questionable evidence, resulting in diverse interpretations. Nevertheless, contemporary archaeological excavations have enabled the determination that, in the 12th century BCE, the sea level range reached as high as 15 meters. By the 1st century BCE – around

3,000 years ago – the sea level was recorded at over 14 meters above the present-day level [Veliev, 1992; Lenz, 1836; Khanikov, 1853]

After examining the writings of various medieval and later scholars, along with integrating oral histories and observations from local residents, E.A. Lenz [1836] determined that the Caspian and Black Seas were interconnected as early as the start of the Common Era. He also estimated that the amplitude of fluctuations in the Caspian Sea level since that time had reached as much as 50 meters. N.V. Khanikov [1853], utilizing a more extensive dataset than Lenz and his own field observations, reached comparable conclusions. However, the range of sea level variation he documented was considerably smaller – totaling 30.5 meters, with only 15 meters recorded for the 915-1850 CE period.

Many scholars [Apollov, 1935; Berg, 1934; Gumilev, 1980] attribute the notable decline in sea level between the 10th - 13th centuries CE – when the Caspian Sea level dropped to 12 meters below its current level – to the halt of the Amu Darya river's inflow into the Caspian. This inflow is thought to have continued uninterrupted from the 5th century BCE until the 10th century CE – a duration of nearly 14 centuries. From the early 13th century to the mid-16th century, the discharge of the Amu Darya into the Caspian resumed, resulting in a significant increase in sea level. Throughout this three-century timeframe, the sea level fluctuated within a range of about 6 meters.

Between the 10th and 15th centuries, there was a notable expansion of knowledge regarding the Caspian Sea. During this era, Arab geographers documented variations in sea level. Certain sources indicate that from the late 13th - 16th centuries, the Caspian Sea underwent a highstand. This period also includes the observations of the Azerbaijani geographer Abdar Rashid Bakuvi, who reported that parts of the towers and walls of the ancient Baku fortress had been submerged, with the sea level approximately 3.5 meters higher than it is today.

Archaeological studies along the Caspian coastline, along with radiocarbon dating of coastal and marine deposits, as well as historically documented and clearly interpretable data, allowed S.S. Veliev (1992) to reconstruct the changes in sea level of the Caspian Sea over the last 4,000 years. His analysis revealed that the sea-level history of the Caspian exhibits a quasi-periodic rhythm of about 200–250 years, alongside a broader cyclicity of approximately 450–500 years. Specifically, within a timeframe of 200–250 years, the sea level consistently rises, followed by a similarly lengthy period of decline. Two consecutive sea-level rhythms constitute a single cycle, with the start and end marked by extremely lowstands (below -33 meters relative to the current sea level). Veliev identified a total of eight such cycles:

The 1st cycle lasted until the mid-13th century BCE;

The 2nd spanned from the mid-13th – the 8th century BCE;

The 3rd extended from the 12th century BCE – the mid-3rd century BCE;

The 4th ranged from the mid-3rd century BCE – the mid-2nd century CE;

The 5th occurred from the mid-2nd century CE – the mid-7th century;

The 6^{th} lasted from the mid-7^{th} - the mid-12^{th} century;

The 7^{th} extended from the mid-12^{th} – the 16^{th} century;

The 8^{th} commenced in the 17^{th} century and continues to the present day.

It is crucial to recognize that both transgressive and regressive phases unfolded in a non-linear, stepwise fashion, instead of as gradual trends.

The most crucial timeframe for comprehending the dynamics of Caspian Sea levels is the past 500 years, during which numerous shifts between lowstands and highstands have been documented. L.S. Berg [1934] noted that the sea level was remarkably low in the mid-16th century, recorded at –26.6 m absolute elevation. About a century later, it achieved a notable highstand of –23.93 m, followed by a decrease that resulted in another minimum level of –26.0 m at the start of the 18th century. Following this, after a significant regression, a lengthy transgressive phase began, reaching its peak in the early 19th century when the Caspian Sea attained its highest recorded level of the modern era – approximately – 22.00 m absolute elevation. In 1995, P.A. Kaplin, R.K. Klige, and colleagues asserted that they had reconstructed historical sea-level variations over a span of 2,500 - 3,000 years with decadal-scale precision.

During the historical timeframe, the average medieval sea level is estimated to have been around -27 m. The long-term trend of sea-level changes fluctuated, with a regression rate of -0.4 m per century (the 6^{th} century BCE – the 7^{th} century CE) and a transgression rate of +0.3 m per century (the 8^{th} century CE onward). Throughout recorded history, the sea level predominantly (about 70% of the time) remained within the range of -24 to -30 meters.

This provides a generalized overview of the centennial-scale variations in the Caspian Sea level. However, it is important to highlight that all sea-level reconstructions during this period – especially those related to the geological past –are inherently approximate and should be viewed as conditional estimates.

Long-term fluctuations in sea levels are most accurately assessed through instrumental observations, which were systematically established by academician E. Lenz in 1837 in Baku. The outcomes of direct measurements collected from the Baku tide gauge (staff gauge) over the last 167 years, as shown in Figure 3.3, demonstrate the key features of the Caspian Sea's level regime throughout this timeframe.

Between 1830 and 1930, the average annual levels of the Caspian Sea varied by about one meter. Highstand periods (elevations at or above -25.4 m) were noted in 1837-1839, 1868-1869, and from 1877 to 1883. In 1882, the annual mean sea level peaked at -25.5 m, marking the highest recorded value during the entire duration of instrumental observations. The most significant decline in sea level took place from 1920 to 1925, reaching a low of -26.6 m by the end of that period.

The long-term average sea level for the years 1830 to 1930 was -25.83 m. The linear trend over this century-long span shows a decrease of about 0.34 m. The average sea levels for the sub-periods of 1830-1880 and 1881-1930 were nearly the same, although the latter half-century displayed a slight downward trend.

A relatively stable equilibrium state of the sea level transitioned into a phase of rapid regression between 1930 and 1941, during which the level fell by 1.9 m. A renewed, albeit less severe, regression phase commenced in the late 1940s, with the sea level dropping by 1956 to 2.5 m below its 1929 level. In the 1960s, the long-term dynamics of sea level showed relative stabilization around -28.4 m, followed by another sharp decline beginning in 1970. By 1977, the level had nearly reached -29.0 m. The total decrease over the entire period of systematic observation was 3.8 m, with 3.2 m of that loss occurring during the 20th century alone. The average rate of sea-level decline was approximately 4 cm per year. However, during the periods of 1930-1941 and 1970-1977, this rate significantly accelerated, reaching 16 cm/year and 14 cm/year, respectively.

Beginning in 1978, the level of the Caspian Sea started to increase significantly, achieving an annual mean height of -26.54 m by 1995. The average rate of increase in sea level during this timeframe was around 14 cm annually, with maximum yearly rises hitting as high as 30 cm in specific years. This transgressive phase marks the fastest and most extended sea-level rise recorded in the complete history of instrumental observations in the Caspian Sea.

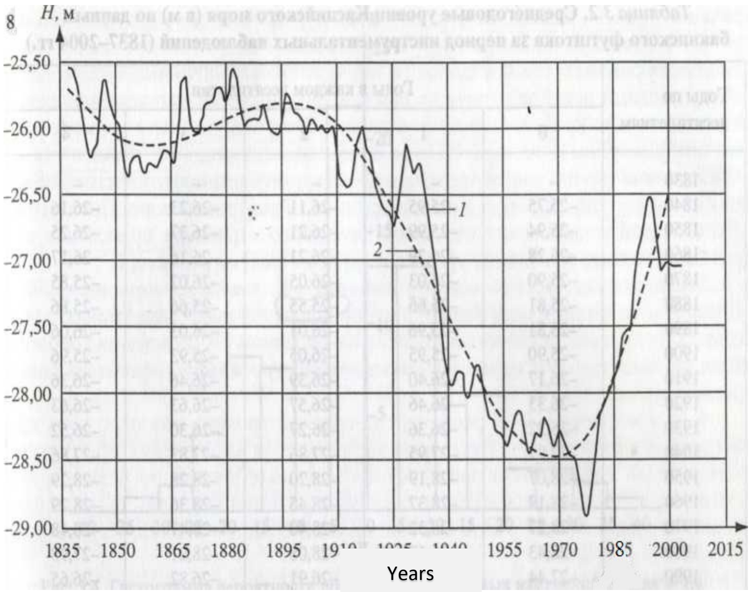


Fig. 3.3. Average annual sea levels of the Caspian Sea based on instrumental observation data from the Baku tide gauge.

1 – Sea level; 2 – Trend in sea level

The water balance of the Caspian Sea can be expressed as:

$$\Delta H = Q_{пов}/S + Q_{повз}/S - Q_{кБг}/S + P - E \pm \Delta H_{б},$$

Where:

Qsurf/S ($Q_{пов}/S$) – surface runoff into the sea, accounting for river discharge losses in the deltas;

$Q_{groundw}/S$ ($Q_{повз}/S$)– groundwater inflow to the sea over the given time interval;

P, E – thickness of precipitation and evaporation layers, respectively, measured in millimeters;

Q_{kbg} /S (*$Q_{кбг}$/S)* – outflow from the sea into the Kara-Bogaz-Gol Bay;

ΔH_b ($\Delta H_б$) – sea level variation caused by changes in water density due to fluctuations in the thermal and hydrological balance of the sea;

S – surface area of the sea, which varies depending on the sea level;

ΔH – increment of sea level caused by changes in the balance components over a specific time interval.

The long-term average values of the water balance components for the entire observation period are as follows:

Qsurf/S (*$Q_{пов}$/S*) = 299.5 km^3 / 77.2 cm;

$Q_{groundw}$ (*$Q_{повз}$*) = 4 km^3 / 1 cm;

Q_{kbg} ($Q_{кбг}$) = 13,0 km^3/3,4 cm;

P = 76.8 km^3/19.8 cm;

E = 376,6 km^3/97,0 cm

Source: "The Current State of the Caspian Sea". Moscow, "Nauka" Publishing house, 2005, pp. 113-121. Authors: G.N. Panin, R.M. Mamedov, I.V. Mitrofanov.

PART II.

BIODIVERSITY, BIORESOURCES AND ECOGEOGRAPHICAL ISSUES OF THE CASPIAN SEA

2.1 ALGAE

The algal flora found in the Caspian Sea comprises a wide variety of species; however, as one moves southward and southeastward, the diversity of species diminishes due to the loss of freshwater varieties. At the same time, the percentage of marine species rises from about 10% in the Northern Caspian to nearly 30% in the Southern Caspian. The dominant groups consist of diatoms *(phylum Bacillariophyta)*, green algae *(phylum Chlorophyta),* and cyanobacteria *(phylum Cyanophyta).* The presence of dinoflagellates *(phylum Dinophyta)* and red algae *(phylum Rhodophyta)* is somewhat less, while euglenoids *(phylum Euglenophyta),* brown algae *(phylum Phaeophyta),* stoneworts *(phylum Charophyta),* and golden algae *(phylum Chrysophyta)* are represented by a limited number of species. The vast majority of these species form phytoplankton communities, which are free-floating organisms suspended in the water column.

A significantly smaller number of species exist as individual benthic plants, which grow attached to submerged substrates. These species are categorized as macrophyte benthos or macrophytes.

Phytoplankton acts as the primary producer of organic matter in the Caspian Sea. The annual biomass production is substantial, reaching up to 200–230 million tons each year. Phytoplankton serves as the essential trophic link within the marine ecosystem and is the main food source for the entire faunal community. Currently, the biomass of primary production generated annually by large macrophyte benthos remains unquantified, even in approximate terms.

Cyanobacteria (Cyanophyta) in the Caspian Sea include species that are freshwater, brackish, and marine. To date, a total of 131 species and an additional 19 forms across 29 genera have been documented.

Cyanobacteria, commonly known as *blue-green algae,* achieve their peak biomass and abundance at the end of summer, sometimes leading to the occurrence of "water blooms" in certain warm, shallow water bodies and bays. However, such occurrences are infrequent in the Caspian Sea. In the other seasons, the population of cyanobacteria remains relatively low.

Most species add to the overall biodiversity but seldom create substantial biomass. The distribution of *cyanobacteria* throughout the Caspian Sea is uneven; their diversity and biomass are more pronounced in the brackish waters. The Northern Caspian showcases the highest variety of cyanobacterial species and forms, totaling 88.

The species composition of *cyanobacteria* in the Middle and Southern Caspian Sea is nearly identical. Essentially, the Middle Caspian contains the same cyanobacterial assemblages as the Southern Caspian, though in a somewhat diminished form. Conversely, the species composition of *cyanobacteria* in the Northern and Southern Caspian shows significant differences: 88 species and forms are documented in the Northern Caspian, while 84 are found in the Southern.

Nevertheless, only 21 forms are shared between both regions, with 19 being present throughout the entire sea.

Dinoflagellates, belonging to the phylum *Pyrrophyta*, are scarce in the Caspian Sea and exhibit limited diversity. To date, only 35 species from 13 genera have been identified. Although they do not significantly contribute to the total biomass, dinoflagellates serve an important ecological function as a favored food source for many zooplankton species. All dinoflagellate species in the Caspian Sea are unicellular planktonic algae. The highest recorded abundance (7 million cells per liter) and biomass (124 mg/m^3) are found in the deep-water regions of the Northern Caspian.

The maximum recorded abundance of dinoflagellates in the deep-water region of the Northern Caspian Sea is 7 million cells/m^3, with a biomass of 124 mg/m^3.

In the Caspian Sea, *golden algae (phylum Chrysophyta)* are represented by just two species from the genus Dinobryon. Both species are found solely within the plankton community, with Dinobryon balticum being a marine species that is rarely encountered.

Diatoms (phylum Bacillariophyta) experience significant growth in the Caspian Sea, dominating both in terms of abundance and biomass across nearly all regions. The diversity of diatoms surpasses that of other algal groups, with a total of 275 species and 53 additional forms from 62 genera identified in the Caspian Sea. Diatoms not only lead in species richness but also in quantitative growth and biomass throughout most areas of the sea. The diversity of diatoms is nearly the same in the Northern and Southern Caspian, while it is significantly lower in the Middle Caspian. The western part of the Southern Caspian exhibits the highest diatom diversity, with 167 species and 41 forms recorded.

Rhizosolenia calcaravis was introduced to the Caspian Sea after the Volga-Don Canal was opened and within 30 to 40 years became the predominant algal species, forming the foundation of primary production.

Brown algae (Phaeophyta) in the Caspian Sea are quite limited in number. All identified species are multicellular, yet none attain significant sizes. They are restricted to the Southern Caspian and do not contribute notably to overall biomass production. So far, five species have been documented from the Caspian Sea, with two being endemic to this region.

Red algae (Rhodophyta) in the Caspian Sea also show restrictions in species diversity and biomass contribution. All species are multicellular and can be found either as part of the macrophyte benthos or as epiphytic overgrowths. The majority of species are located in the Southern Caspian and, to a lesser degree, in the Middle Caspian. Isolated sightings from the Northern Caspian are likely incidental. Reports of significant growth of *Ceramium diaphanum* in the Northern Caspian need further confirmation. In total, there are 22 species from 11 genera currently recognized in the Caspian Sea.

Euglenoids (Euglenophyta) are represented by a limited number of species. Most are linked to river estuaries, although they can be found in low numbers throughout the entire sea. According to available information, only eight species from five genera have been reliably recorded.

Their abundance seldom surpasses 100,000 individuals per cubic meter, with an average biomass reaching up to 1.51 mg/m^3. The distribution of euglenoids is relatively even across the Caspian Sea. Their ecological significance in the sea's biological productivity and trophic balance is deemed minimal.

Charophytes (Charophyta) rank among the least researched algal groups in the Caspian Sea. On a global scale, around 300 species are recognized, categorized into just six genera. In the Caspian, only representatives from two genera have been identified.

All *charophytes* in the Caspian are relatively small, typically measuring 20–40 cm in length. Despite their restricted distribution, they fulfill a specific ecological function in Caspian biocenoses, acting as a favored food source for numerous waterfowl species.

From a review of existing literature and recent research outcomes, it can be inferred that the overall algal flora of the Caspian Sea consists of 623 species and an additional 98 forms.

Cyanobacteria (Cyanophyta) display the greatest diversity, with over 300 species and forms. They surpass all other algal phyla in species richness in the Northern, Middle, and Southern Caspian, and in most instances, they also dominate in total biomass.

Source: "Current State of the Caspian Sea". Moscow, "Nauka"Publishing House, 2005, pp. 209-216.
Authors: G.N. Panin, R.M. Mamedov, I.V. Mitrofanov.

2.2 HIGHER PLANTS (CORMOPHYTA)

The Caspian Sea region and its coastline host over 3,000 species of higher plants *(Cormophyta)*. Nevertheless, only a limited number of these species are directly linked to aquatic ecosystems. Among the higher plants, slightly more than 100 species are classified as truly aquatic or semi-aquatic. Their distribution throughout the Caspian basin is inconsistent, often reflecting the level of botanical research conducted in specific areas rather than the actual diversity of species. Regrettably, comprehensive floristic inventories for particular regions of the Caspian are either unavailable or challenging for the wider scientific community to access. This is particularly evident in the distribution and classification of certain genera such as *Juncu (rushes)*, *Potamogeton (pondweeds), Typha (cattails), Scirpus (bulrushes),* among others. Genera that are widely distributed, like *Cyperus (sedges)* and *Carex (true sedges),* are often omitted from aquatic flora checklists, despite their prevalence in moist environments – they are not exclusively tied to aquatic ecosystems.

Establishing a distinct separation between semi-aquatic species and those that thrive in wet habitats can be quite challenging, especially in light of rapid sea-level changes driven by wind-induced surges and regressions, which can alter the shoreline by several kilometers.

Across the Caspian Sea and within the deltas of its tributaries, a total of 132 species of submerged, semi-submerged, and floating higher aquatic plants have been documented, representing 44 genera. Among these, only 25 species are present in the sea itself. The Northern Caspian exhibits the highest species richness due to the extensive brackish regions found in the Volga and Ural River deltas. Beyond these deltaic areas, the marine flora is restricted to about 10-15 species from genera such as *Zostera (eelgrass), Potamogeton, Myriophyllum (water milfoil), Ruppia, Najas,* and *Ceratophyllum (hornwort).* The dominant semi-submerged plant throughout the sea is *Phragmites australis (common reed).*

The species composition in the Volga and Kura deltas (including the Ural River) is generally similar, although some floristic variations are noted. The lack of large deltas along the southern and southeastern coasts has led to a marked decrease in aquatic plant diversity in these regions – only 17 species have been recorded along the southern coast (Iran), and merely 7 species along the southeastern coast (Turkmenistan).

Of the 132 identified species, 12 species (approximately 10%) are categorized as rare or endangered and are included in the Red Data Books of Russia, Dagestan, Azerbaijan, and Kazakhstan.

Source: "Current State of the Caspian Sea". Moscow: "Nauka" Publishing House, 2005, pp. 217-222. Authors: G.N. Panin, R.M. Mamedov, I.V. Mitrofanov.

2.3 WATERFOWL IN THE CASPIAN SEA BASIN

Fish

Historically, the focus of biological resource exploitation in the Caspian Sea has been primarily on fish, especially sturgeon species. However, in recent years, *sprat (Clupeonella spp.)* has emerged as the dominant species in the region's commercial fisheries. The Caspian seal, along with various shrimp and crayfish species, has only a minor role in commercial significance. Unlike the Black Sea and other marine environments, the Caspian Sea does not host commercially valuable invertebrates such as oysters, scallops, mussels, squid, and similar organisms.

Approximately 100 species and subspecies of fish have been documented in the Caspian Sea (Kasymov & Rahimov, 1993). The most economically significant species *include beluga (Huso huso), Russian sturgeon (Acipenser gueldenstaedtii), stellate sturgeon (A. stellatus), ship sturgeon (A. nudiventris), Caspian brown trout (Salmo trutta caspius), whitefish (Stenodus leucichthys), kutum (Rutilus kutum), asp (Leuciscus aspius), common carp (Cyprinus carpio), bream (Abramis brama), roach (Rutilus rutilus), Caspian herring (Alosa spp.), catfish (Silurus glanis), shemaya (Alburnus spp.),* and *zander (Sander lucioperca).*

In terms of species diversity, the leading families within the Caspian ichthyofauna are *Clupeidae* (18 species and subspecies), *Cyprinidae* (23 species and subspecies), and *Gobiidae* (36 species and subspecies), which collectively account for approximately 77% of the total fish fauna. Among the species endemic to the Caspian basin*, Clupeidae* and Gobiidae are the most common. In the northern regions of the sea and its shallow bays, *Cyprinidae* are particularly prevalent.

A considerable segment of the Caspian ichthyofauna is of freshwater origin. This category encompasses all *sturgeons, cyprinids, pike (Esox lucius), catfish (Silurus glanis), loaches (Cobitidae), stickleback (Gasterosteidae), zander (Sander), perch (Perca fluviatilis),* and *ruffe (Gymnocephalus cernua)* (Kazancheev, 1981). Marine fish species found in the Caspian include *silverside (Atherina boyeri), pipefish (Syngnathidae),* and *mullet (Mugilidae).*_The Caspian trout and whitefish are of northern origin, having migrated into the Caspian through ancient river systems.

Species	1932	1940	1950	1960	1970	1980	1985	1990	1991
Sturgeons (Acipenseridae)	16,9	7,48	13,48	10,14	16,08	25,0	21,08	13,5	10,06
Herrings (Clupeidae)	81,82	136,55	56.08	54,88	1,85	1,17	3,49	2,26	1,51
Sprats (Clupeonella spp.)	6,94	8,94	21,64	175,96	423,22	304,78	269,38	235,29	365,16
Large cyprinids (Cyprinidae)	127,59	123,79	159,15	60,27	53,20	23,0	29,34	40,70	11,30
Caspian roach (Rutilus rutilus caspicus)	130,88	51,44	59,62	64,06	12,45	5,80	8,60	20,80	14,83
Small cyprinids	50,45	17,87	19,93	20,29	21,47	23,16	11,65	11,05	0,73
Mullet (Mugilidae)	-	0,07	0,30	0,76	0,64	0,17	0,24	0,17	1,20
Salmonids (Salmonidae)	0,91	1,14	0,44	0,01	0,001	0,02	0,03	0,01	0,02
Commercial fish species	1,60	2,28	0,88	0,16	0,05	0,001	-	0,17	-
In total	417,09	349,56	331,52	386,53	528,961	338,101	343,81	323,797	404,81

egarding abundance, pelagic fish are the most prevalent in the Caspian Sea. This group consists of *herring, sprat, silverside,* *mullet, beluga, asp,* and *sabrefish (Pelecus cultratus)*. Demersal species comprise *sturgeon, stellate sturgeon, roach, carp, bream, catfish, pike,* and *all goby species.* Although the quantity of pelagic and benthic fish species is relatively balanced, pelagic species – especially *sprat* – constitute the majority of the total biomass in the sea.

Total Fish Harvest from the Caspian Sea (thousand metric tons)

Prior to the establishment of the Mingachevir Hydroelectric Power Station on the Kura River, the majority (approximately 90%) of the spawning grounds for Kura-origin sturgeons were situated within the area that was later submerged by the reservoir. Currently, the remaining sturgeon spawning habitats, which span roughly 169 hectares, are restricted to the lower sections of the Kura River – extending from the Varvara Dam to the village of Pirazy – and in the Aras River – from the Bagramtapen Dam to the village of Karadonlu. The discharge of cold hypolimnetic waters from the Mingachevir Reservoir negatively affects sturgeon spawning by disrupting the river's thermal regime. Furthermore, a significant decrease in the Kura's water flow further obstructs the upstream migration of *sturgeons* to suitable spawning areas. Before the dam was built, the commercial yield from the natural reproduction of *sturgeons* in the Kura was estimated to be between 2.0 and 2.4 thousand tons annually. Currently, this number has plummeted to approximately 0.01 to 0.04 thousand tons, reflecting a considerable decline in the productivity of the natural stock.

Caspian Seal (Pusa caspica)

The Caspian seal is found throughout the Caspian Sea and occasionally ventures into the lower reaches of significant rivers, such as the Volga and Kura. Adult seals typically attain a body length of up to 160 cm and weigh around 100 kg. During the winter months, this species congregates on the ice fields of the northern Caspian Sea.

Historically, large gatherings of seals were noted around the islands of the Tyuleniy Archipelago. In recent years, the primary aggregation sites have shifted to the Middle Pearl Bank, along with the islands of Malyi Pearl and Kulaly. In the southern Caspian, smaller groups of seals have been observed near Ogurchinsky Island and along the Absheron Peninsula coast.

Commercial exploitation of the Caspian seal *(Pusa caspica)* has been ongoing since 1867. The average yearly harvest from 1867 to 1915 was around 115,000 individuals. This number rose to 154,000 seals annually during the period from 1931 to 1940, before falling to between 45,000 and 60,000 each year from 1941 to 1960 (Badamshin, 1966). In the 1980s and 1990s, the annual harvest levels further decreased to between 17,320 and 26,810 individuals. This reduction in seal catches is mainly attributed to a decrease in fishing intensity rather than solely to population depletion.

Crayfish and Shrimp

Three species and subspecies of *freshwater crayfish* are recognized to inhabit the Caspian Sea basin (Kasymov, 1987). *The thick-clawed crayfish (Astacus pachypus)* is located in the coastal areas of the eastern Middle and Southern Caspian. The typical subspecies of the *long-clawed crayfish (Astacus leptodactylus)* is predominantly found in the Volga-Akhtuba floodplain and the Volga River delta; it does not extend into the lake south of the avandelta region (Rumyantsev, 1989).

Historically, the main *crayfish* fishery was centered in Krasnovodsk Bay, where annual catches reached as high as 100 tons. However, since 1969, crayfish harvesting along the Turkmen coast has sharply declined due to the designation of significant *crayfish* habitats within the Krasnovodsk Nature Reserve.

Shrimp were introduced into the Caspian Sea from the Black Sea as part of the *mullet (Mugilidae)* acclimatization project (Karpevich, 1975). *Palaemon adspersus* can grow to a maximum body length of 66 mm and weigh up to 4,725 mg. In contrast, *Palaemon elegans* reaches a length of 50 mm and weighs about 2,500 mg. In the southwestern part of the Southern Caspian, shrimp populations are particularly abundant near the towns of Primorsk and Shikhov. The estimated annual shrimp catch in this region is around 100–300 kilograms.

Source: "Ecology of the Caspian Lake." Baku, "Adiloglu" Publishing house, 1994, pp. 12-19 Author: A.G. Kasymov

2.4. ZOOPLANKTON, MICROBENTHOS, AND MACROBENTHOS

Zooplankton

A total of 315 species and subspecies of *zooplankton* have been documented in the Caspian Sea (Kasymov, 1987), which includes: 135 species of *ciliates (Infusoria),* 2 species of *cnidarians*, 67 *rotifers*, 54 *cladocerans*, 32 *copepods*, 1 *ostracod*, 6 *mysids*, 5 *cumaceans*, 6 *amphipods,* 1 *isopod*, 1 *mite*, and 5 *species categorized as miscellaneous*. This miscellaneous group encompasses larval stages of mollusks, cirripeds, decapod crustaceans, as well as fish eggs and larvae, including those of *kilka (Clupeonella spp.)* and *mullet (Mugilidae).* By region, 216 species have been documented in the Northern Caspian, 196 in the Middle Caspian, and 180 in the Southern Caspian.

Ciliates are the predominant taxonomic group within the *zooplankton* community, representing 42.8% of the total species diversity. *Rotifers* (21.3%) and *cladocerans* (17.1%) also play a significant role in the overall biodiversity. Among the *rotifers* and *cladocerans,* freshwater species are particularly well represented and are frequently found in estuarine regions, especially in the prodelta area of the Volga River.

Microbenthos

A total of 566 animal species have been documented within the *microbenthos* of the Caspian Sea. *Ciliates (Infusoria)* are the most prevalent in terms of species diversity, followed by *nematodes*, with *ostracods* ranking third. The Caspian Sea is home to 18 recorded species of *foraminifera*, which primarily inhabit the coastal areas. Ciliate populations achieve their peak densities in shallow waters, specifically at depths between 0.5 and 5 meters. As the depth increases, there is a notable decline in the abundance of *psammophilic ciliates*, which are those adapted to sandy environments.

Macrobenthos

A total of 306 species of benthic invertebrates classified as *macrobenthos* have been recorded in the Caspian Sea.

Following the establishment of the Volga–Don Canal, numerous new *macrobenthic* species have settled in the Caspian basin.

L. A. Zenkevich (1963) identified four primary faunal complexes within the *macrobenthic community* of the Caspian Sea:

1. Autochthonous Caspian Complex – remnants of the ancient Tertiary marine fauna that have experienced significant evolutionary changes due to repeated alterations in the sea's hydrological regime.

2. Mediterranean–Atlantic Complex – species that have entered the Caspian Sea during various historical epochs.

3. Arctic Complex – species that migrated into the Caspian at the conclusion of the glacial period from the northern seas.

4. Freshwater Complex – relatively recent arrivals from river systems within the Caspian basin.

All four faunal complexes are represented within the native Caspian fauna, although Arctic and freshwater species currently prevail in terms of population density.

The estimated total benthic biomass in the Caspian Sea amounts to 32 million tons, with annual benthic production approximating 64 million tons. In order to sustain the complete *macrobenthic biomass*, it is necessary to have around 600 million tons of *phytomass*— comprising both living and detrital components. As a result, only about 40% of the primary production in the Caspian Sea is integrated into the two principal food chains, while the remaining portion sinks and aids in the enrichment of deep-sea sediments (Karpevich, 1975).

Source: "Ecology of the Caspian Lake." Baku, "Adiloglu" Publishing house, 1994, pp. 26-55. Author: A.G. Kasymov

2.5. THE FUNCTION OF MOLLUSKS IN WATER SELF-PURIFICATION

The self-purification mechanism in the Caspian Sea is influenced by a blend of biological and physico-chemical elements that work together. Microorganisms, along with invertebrate filter feeders and sedimentators, are crucial to this mechanism. This latter category encompasses various *crustaceans* and *mollusks*, with bivalve mollusks being especially significant for water filtration. In aquatic environments, bivalves serve as natural biofilters, effectively eliminating suspended particulate matter from the water column. In certain freshwater systems, the efficiency of particulate removal by *mollusks* can reach as high as 92–100% (Kondratyev, 1970). Concurrently, their filtration activities facilitate biogenic water circulation (Voskresensky, 1968), promoting the movement and renewal of water masses.

Numerous investigations have highlighted the filtration capabilities of *mollusks*. For example, V.P. Vorobyov (1938) noted that *Mytilus* edulis individuals measuring 60 mm or greater along the German coastline filter around 3 liters of water each hour. Conversely, members of the same species in the Black Sea filter only 25-60 ml/h (Voskresensky, 1968). O.G. Mironov (1949) indicated that the filtration rate of Black Sea *mussels* varies from 8 to 125 cm³/min. I.I. Greze (1971) discovered that *Mytilus edulis* and *M. galloprovincialis* exhibit filtration rates ranging from 99 to 900 ml/h. Greze also estimated that mussel biofilters in the northwestern region of the Black Sea filter and purify approximately 134 km³ of water on a daily basis. M.O. Alyakrinskaya (1966) reported that *mussels* can filter up to 20 ml/h. Among *marine copepods*, *Calanus finmarchicus* filters roughly 1.5 liters of water each day (Peres & Deveze, 1963).

According to O.G. Mironov (1972), a reduction in oil concentration was noted in aquaria with mussels after a period of 24 hours. When the water was agitated, *pseudofeces* broke down into smaller pieces and eventually settled at the bottom. Throughout a single day, an individual *musse*l filtered roughly 0.0032 mg of oil each hour. E.V. Bayko and Yu.M. Petrov (1975) highlighted the crucial role mussels play in the self-purification of marine waters from petroleum pollution by transferring oil-bound particles from the water column to the sediment.

In the Caspian Sea, water pollution negatively impacts the filtration rates and oxygen consumption of *mollusks*. In solutions contaminated with petroleum, *mollusks* show oxygen consumption rates between 0.001 and 0.009 ml/hour (Kasymov and Linkhodejeva, 1979).

Among the species studied, *Cerastoderma lamarcki* exhibited greater oxygen uptake in oil-polluted environments compared to *Mytilaster lineatus*. At higher oil concentrations, the water circulation caused by mollusks becomes nearly imperceptible, and their filtration activity nearly ceases. Among the bivalve species examined *(Mytilaster, Cerastoderma*, and *Abra)*, *Cerastoderma* was identified as the most efficient filter feeder, followed by *Mytilaster*, while *Abra* displayed the least filtration efficiency.

Mytilaster lineatus, with a length of 1.3 cm, demonstrated a filtration rate of 1.03 ml/h at an oil concentration of 16 mg/L (Artyom crude oil). In contrast, at a concentration of 24 mg/L, individuals of the same species measuring 1.2 cm filtered 2.4 ml/h. Similar findings were observed in experiments involving *Cerastoderma lamarcki:* individuals measuring 0.8 cm filtered 1.3 ml/h at 10 mg/L of Artyom oil, while at 16 mg/L, smaller individuals (0.7 cm) filtered 4.7 ml/h. At a concentration of 5 mg/L, *C. lamarcki* with a shell length of 0.8 cm filtered 2.6 ml/h, whereas larger individuals (1.5-1.6 cm) achieved a filtration rate of 11.2 ml/h.

Mytilaster individuals with shell lengths ranging from 1.3 to 1.4 cm filtered 6.0 ml/h in Artyom oil, while those measuring 1.5 to 1.6 cm filtered at double that rate – 11.0 ml/h. Comparable results were obtained in experiments utilizing “Oil Rocks” crude oil: individuals of *Mytilaster* measuring 1.1 to 1.2 cm filtered 5.0 ml/h, while those measuring 1.6 to 1.7 cm reached 12.3 ml/h.

At an oil concentration of 10 mg/l from "Oil Rocks", the influence of population density on individual filtration rates was examined. As the density increased to 5 individuals per aquarium, the filtration rate per mussel also rose; however, at densities of 10 or more individuals, the filtration rate declined. The highest filtration performance was recorded in a 500 cm^3 aquarium, where each *Mytilaster* individual had 100 cm^3 of water.

The filtration rate of *Abra ovata* in Sangachal crude oil solutions, with concentrations between 1.6 and 12.0 mg/L, ranges from 2.9 to 15.3 ml/h. Significant variations in filtration rates are noted among similarly sized individuals at a specific oil concentration of 6.6 mg/L: specimens that are 10 mm long filter at a rate of 2.9 ml/h, whereas those that are 12 mm long filter at 3.9 ml/h. Individuals measuring between 12 and 14 mm in length, at an oil concentration of 5.3 mg/L, show filtration rates from 4.7 to 5.04 ml/h. At a concentration of 2.3 mg/L, 14 mm long individuals achieve a higher filtration rate of 8.8 ml/h. A significant increase in filtration activity is noted at a concentration of 1.6 mg/L, where even the smallest individuals (8 mm in length) can filter up to 15.3 ml/h (Kasymov & Likhodeeva, 1983).

In Artyom crude oil, at concentrations ranging from 1.0 to 11.5 mg/L, *Abra* shows slightly reduced filtration rates compared to those observed in Sangachal oil solutions. At 1.0 mg/L of Artyom oil, the filtration rate is 15.0 ml/h, which is similar to the rate seen in Sangachal oil at 1.6 mg/L (15.3 ml/h). This indicates that Artyom oil may be more toxic than Sangachal oil, despite the comparable filtration responses at these specific concentrations.

In “Oil Rocks” crude oil solutions (0.6–12.0 mg/L), *Abra ovata* demonstrates lower filtration rates than in the other two types of oil. When comparing the filtration rates of *Abra* at the lowest concentrations of all three oil types (0.6 mg/L, 1.0 mg/L, and 1.6 mg/L, respectively), the lowest rates are found in “Oil Rocks” oil, even though its concentration was nearly 1.5 times lower than that of the other two oils. This is attributed to the greater toxicity of “Oil Rocks” crude oil.

The filtration rate of *Abra (a bivalve mollusk)* per unit of soft body mass has been assessed in several oil-contaminated aqueous solutions: in Sangachal oil solutions – 6.7 ml/day; in Artyom oil – 6.5 ml/day; and in "Oil Rocks" oil – 6.1 ml/day. An individual Abra can filter 1.73 liters of clean lake water daily, and 0.3–0.4 liters of water per day that contains 0.6 to 1.6 mg/L of dissolved oil.

The contribution of the amphipod |Pontogammarus maeoticus" to the self-purification of lake water has also been studied. The filtration rate for this species is greater in clay suspensions (300 mg/L), reaching 7.3 ml/h, while it significantly decreases in water contaminated with Oil Rocks crude oil, falling to 0.003 ml/h. A single amphipod filters between 6.3 and 7.3 ml/h in clay solutions (300 mg/L), 0.026 ml/h in Artyom oil (9.0 mg/L), and between 0.003 and 0.6 ml/h in Oil Rocks oil (1.2–11.0 mg/L).

Filtration rates per unit mass of soft tissue in bivalve mollusks reveal the following:

In *Cerastoderma (cockle),* the rate reaches 20.3 ml/day in Sangachal oil, 9.3 ml/day in Artyom oil, and 5.6 ml/day in Oil Rocks oil.

In *Mytilaster (a small mussel),* rates are 9.6 ml/day in Sangachal oil, 4.6 ml/day in Artyom oil, and 3.9 ml/day in Oil Rocks oil.

In *Abra,* values are 6.7 ml/day (Sangachal), 6.5 ml/day (Artyom), and 6.1 ml/day (Oil Rocks).

These findings highlight the essential role of aquatic invertebrates in water purification processes, which include the filtration and removal of suspended particles and hydrocarbons, the formation of organically derived bottom sediments, and the preservation of food availability for benthic fauna.

Source: "Ecology of the Caspian Lake." Baku, "Adiloglu" Publishing house, 1994, pp. 194-197. Author: A.G. Kasymov

2.6 OIL ACCUMULATION IN AQUATIC FAUNA

Marine organisms are crucial for the self-purification of seawater from various pollutants. They absorb different elements from their marine surroundings and store them within their bodies. Numerous studies (Lee & Bensen, 1975; Lee, Sauerheber & Bensen, 1972; Stegman & Teal, 1973) have documented the capacity of marine animals to accumulate petroleum compounds alongside other substances.

O.G. Mironov (1973) indicated that green crabs and hermit crabs can accumulate petroleum hydrocarbons in their tissues. Black Sea mussels have also shown the ability to retain varying levels of petroleum in their bodies (Milovidova, 1975). G.M. Pyatakova (1975) observed that the mollusk *Mutilaster lineatus*, found in the Caspian Sea, can accumulate between 0.0003 and 0.037 mg/day of petroleum hydrocarbons. C.A. Bons (Burns, 1976) reported that the crab *Uca pugnax* accumulates hydrocarbons in its tissues and includes petroleum detritus in its diet.

T.L. Shchekaturina (1978) noted that the crab *Eriphia verrucosa* and the *mussel Mytilus galloprovincialis* can accumulate diesel fuel hydrocarbons. In mussels, the accumulation process starts with the uptake of lighter hydrocarbon fractions. In Black Sea crabs, hydrocarbon concentrations can reach 234.6 mg per 100 g of wet mass in the hepatopancreas, 49.9 mg in the gonads, and 18.2 mg in the remaining body.

Under experimental conditions, *Cerastoderma lamarcki* specimens measuring 7–15 mm, exposed to *Sangachal* crude oil at concentrations of 3.0–8.5 mg/L, filtered between 1.9 and 12.6 mL/h. At lower concentrations, the rate of petroleum accumulation was greater than at higher concentrations (Kasymov & Likhodeeva, 1984).

Larger specimens were observed to gather more petroleum compared to their smaller counterparts. For instance, *Cerastoderma lamarcki* individuals measuring 15 mm accumulated as much as 0.068 mg/g of petroleum, whereas those at 6 mm only gathered 0.028 mg/g. The quantity of petroleum retained per unit of body mass diminished as the toxicity of the petroleum solution increased. At a concentration of 3 mg/L, petroleum accumulation varied from 0.028 to 0.068 mg/g, but at 8.5 mg/L, it fell to a range of 0.0013 to 0.006 mg/g.

The *mollusk Mutilaster lineatus*, subjected to petroleum concentrations between 2.0 and 8.5 mg/L, accumulated petroleum in its tissues at levels ranging from 0.00015 to 0.052 mg/g (See Table).

Due to its greater toxicity, mollusks accumulated oil from the “Oil Rocks" field in lesser amounts compared to *Sangachal* crude oil. For example, at concentrations ranging from 3.8 to 9.0 mg/L, *Mutilaster* accumulated merely 0.003 to 0.037 mg/g of petroleum. Similarly, at concentrations between 4.5 and 10.25 mg/L, *Cerastoderma* retained 0.001 to 0.041 mg/g. Therefore, as the concentration of oil increased, both the filtration rate and the quantity of petroleum accumulated per unit of soft tissue mass diminished (Kasymov & Likhodeeva, 1984).

Table

FILTRATION RATE AND OIL ACCUMULATION IN MOLLUSKS (SANGACHAL OILFIELD)

Oil Concentration (mg/L)	Number of Specimens (ind.)	Body Length (mm)	Filtration Rate (mL/h)	Oil Accumulated per Unit Body Mass (mg/g)
2.0	Mytilaster lineatus			0.00500
3.5	6	18	23,0	0.01100
3.5	6	12	7.2	0.00450
3.6	10	19-22	7.6	0.05200
3.6	5	19-22	8.0	0.00580
3.6	3	16-18	9.0	0,00400
4.5	5	16	3.6	0,00440
5.0	5	13	3.4	0,00400
5.0	5	10	1.2	0.01000
5.6	5	15	15,0	0.00060
5.6	5	10	12.0	0.00070
6.0	5	19-21	4.5	0.00650
6.0	5	15-18	3.5	0.00560
6.0	5	12-14	2.0	0.00580
6.8	5	17	3.0	0.00400
6.8	5	10	1.5	0.00230
7.5	5	17	2.7	0.00015

8.5	6	12-13	3.8	0.01500
8.5	10	12-16	2.0	0,01800
	Cerastoderma lamarcki			
3.0	2	15	12.6	0.06800
3.0	2	6	2.4	0.02800
4.5	5	14	2.4	0.06000
4.5	5	10	6.4	0.02800
4.5	5	7	5.3	0.02500
8.5	5	19	6.6	0,00600
8.5	5	15	2.2	0.00470
8.5	5	14	1.9	0.00130

Therefore, marine bivalve mollusks are crucial for purifying seawater from petroleum pollution.

Research indicates that petroleum hydrocarbons can persist within marine organisms. For example, M. Blumer, G. Sauzé, and J. Sauss (1970) found that traces of petroleum could still be identified in bivalve mollusks even after an eight-month period. J.W. Anderson (1973) noted that mollusks were entirely cleared of petroleum within 24 to 52 days when placed in uncontaminated water, while V.U. Fossuto (1975) reported complete removal within 10 to 15 days.

Interestingly, higher concentrations of oil result in lower accumulation in mollusk tissues. In specimens exposed to *Sangachal* crude oil at concentrations of 2.3 and 9.5 mg/L, the petroleum content was measured at 0.016 and 0.0005 mg/g, respectively. When these mollusks were transferred to clean water, the oil levels in their tissues decreased steadily, demonstrating their ability to gradually eliminate petroleum contaminants in oil-free conditions. For instance, mollusks subjected to *Sangachal* oil at a concentration of 3.8 mg/L had a petroleum content of 0.0045 mg/g. After 7 days in clean water, this concentration fell to 0.0041 mg/g, and after 27 days, it further declined to a mere 0.00005 mg/g. In *Mutilaster* specimens measuring 8 mm in length and maintained in clean water for 57 days, petroleum was no longer detectable.

In mollusks filtering water that contains crude oil from the "Oil Rocks" field at concentrations between 1.5 and 9.0 mg/L, the quantity of accumulated petroleum ranged from 0.007 to 0.029 mg/g. In a *Mutilaster* specimen with a length of 13 mm, 0.026 mg/g of petroleum was found. After 6 days in clean water, this concentration decreased to 0.0036 mg/g, and after 47 days, it further declined to 0.000035 mg/g. Therefore, *Mutilaster* and *Cerastoderma* mollusks have the ability to extract petroleum from the water, accumulate it within their bodies, and later transport it to the seafloor. The petroleum from the "Oil Rocks" oil field remains in mollusk tissues for a longer period compared to petroleum from the *Sangachal* field.

Source: "Ecology of the Caspian Lake." Baku, "Adiloglu" Publishing house, 1994, pp. 198-202.
Author: A. G. Kasymov

2.7 ECOLOGICAL STATUS OF THE SEA

2.7.1 Pollution via River Inflows

The ecological health of the Caspian Sea is significantly influenced by the Environmental Conditions of the rivers that feed into it. This issue is undeniably one of the most critical aspects of the larger Ecological Crisis affecting the Caspian region, as nearly all rivers flowing into the Sea have, to some extent, become channels for the movement of pollutants.

The total average annual inflow of rivers into the Caspian Sea is around 300 cubic kilometers. The primary rivers that discharge into the Caspian include the Volga, Ural, Terek, Sulak, Samur, Kura, and Sefid-Rud. Among these, the Volga River stands out as the largest contributor, with an average annual discharge of approximately 250 km^3, representing 81.2% of the total river inflow to the Sea.

The Volga serves as the main source of pollution for the Caspian Sea. The bulk of the industrial capacity of the Russian Federation is situated within the Volga River basin. This river system is crucial, supplying 80% of the total freshwater inflow into the Caspian Sea.

Due to the extensive development along its banks, the Volga basin has faced numerous anthropogenic pressures. These pressures encompass hydrotechnical construction and hydropower generation, irrigation, industrial and domestic water consumption, as well as chemical, thermal, and acid pollution, timber floating, unsustainable fishing practices, encroachment into protected riparian areas, breaches of land use regulations, and rising amounts of uncontrolled surface runoff that carries pollutants. Consequently, as a result of these cumulative effects, nearly all rivers within the Volga-Caspian basin have experienced considerable transformation.

Human activities have significantly impacted the natural environment of the Volga River basin, effectively turning the Volga into Russia's primary wastewater repository. Annually, around 2.5 km^3 of untreated wastewater and 7 km^3 of inadequately treated wastewater are released into the basin through the Volga.

The average yearly toxic burden on the ecosystems of the Volga and its tributaries is five times greater than the equivalent toxic burden on aquatic ecosystems in other parts of Russia. The amount of contaminated wastewater entering the Volga basin represents 39% of the total volume of such discharges produced across the Russian Federation ("The Revival of the Volga", 1996).

Key pollutants found in the Volga basin include petroleum hydrocarbons, iron and copper compounds, and easily oxidizable organic materials. Approximately 85% of phenolic petroleum products, 80% of surfactants (both anionic and nonionic), along with the majority of heavy metals and DDT residues, are carried to the Caspian Sea via the Volga, Ural, Terek, and Kura rivers (Kosarev & Gulev, 1996).

The Kura River, along with its tributary the Aras—flowing through the regions of three South Caucasus nations (Georgia, Armenia, and Azerbaijan), as well as Iran and Turkey—accounts for 5.8% of all cadmium, 6.2% of biological oxygen demand (BOD), and 1.1% of hydrocarbons carried by rivers into the Caspian Sea. Comparable pollution trends are noted in the Ural and Terek rivers.

2.7.2 *Pollution from the Coastal Zone of the Caspian*

The Caspian region hosts around 200 significant cities and over 220 sources of industrial pollution (Kuksa, 1996). The estimated population living along the coastline is about 10 million individuals.

The rapid development of oil and gas extraction along the coast of the Caspian Sea – especially in the Astrakhan Region, the Republic of Kalmykia, and Kazakhstan – has greatly influenced the natural processes in the area. The extraction of hydrocarbon resources has led to the establishment of transportation corridors, extensive power transmission lines, oil and gas pipelines, water supply systems, residential developments, and various socio-cultural infrastructure projects.

In addition to the pollution of surface waters in the river basins that flow into the Caspian, there are many continuously operating coastal pollution sources that have a considerable impact on the marine environment. Every coastal city – without exception – acts as a source of pollution, particularly major urban centers like Astrakhan, Baku, Makhachkala, Türkmenbashy, and others, which release wastewater directly into the sea.

The natural environment of the Absheron Peninsula is marked by a significant level of oil pollution, especially in its coastal regions, where oil extraction has been ongoing for more than a century. The average concentration of petroleum hydrocarbons in the topsoil layer (0–5 cm) is 50 to 100 times higher than background levels (Azmetov & Aliyev, 1992).

The entire Caspian coastline of Turkmenistan, along with its adjacent coastal zone, falls within the Balkan velayat, which has its administrative center in the city of Nebit-Dag. This velayat covers a total area of 138,500 km² and has a population of 411,300, accounting for about 9% of Turkmenistan's overall population. The Türkmenbashy and Hazar (formerly Hasan-Kuli) etraps are located directly next to the Caspian Sea, along with regions governed by the municipal administrations (häkimliks) of Çeleken (Cheleken) and Nebit-Dag.

Historically, the economy of the Balkan velayat has been shaped by the natural resources found in the sea and its coastal areas. The oil and chemical industries began to develop with the extraction of fuel-energy and mineral resources in the Caspian littoral zone, leading to the establishment of industrial centers such as Türkmenbashy, Nebit-Dag, Beýikdaş (Beyikdash), Çeleken, Ekerem (Okaram), Kotur-Tepe, and others.

The primary source of bacterial contamination in Türkmenbashy Bay is the emergency discharge of domestic and municipal sewage from the city of Türkmenbashy. In Çeleken, the wastewater treatment facilities for domestic sewage are partially submerged, which worsens the sanitary and environmental conditions.

Forty percent of the coastal pollution that flows into the Caspian Sea comes from the shorelines of Azerbaijan and Iran.

The highest levels of petroleum hydrocarbons are released from the coasts of Azerbaijan, Iran, and Russia. The Iranian coast is mainly responsible for the discharge of phosphates and nitrates. Among the coastal cities, Baku is the leading contributor, representing 46% of all urban wastewater released into the sea.

2.7.3 Pollution Resulting from Sea Level Rise

The fluctuation of sea level, which varies significantly, is the most notable characteristic of the Caspian Sea, distinguishing it from other major inland water bodies on the planet.

Unlike many other parts of the world, where rising sea levels may become a concern for human activities in the future, the situation in the Caspian Sea region—especially in Azerbaijan—is already urgent. The increase in groundwater levels has changed the natural environmental conditions, resulting in the rise of new diseases among the local population residing in this coastal area.

Due to a 2.5-meter increase in sea level, around 300 oil wells, both abandoned and operational, in the Northern Caspian have been submerged, with water infiltrating approximately 600 more wells. The Bibi-Heybat oil field located on the Absheron Peninsula has been nearly completely flooded. A comparable scenario is evident along the Turkmen coastline, particularly near Cheleken Island and the Livanov Bank. Nevertheless, accurately assessing the amount of hydrocarbons that have entered the sea due to submersion remains a significant challenge.

Direct Oil Pollution. Undoubtedly, one of the most significant and dangerous sources of pollution in the Caspian Sea is oil. Oil contamination hinders the growth of *phytobenthos* and *phytoplankton* in the Caspian—primarily represented by *cyanobacteria* and diatoms—reduces oxygen production, and accumulates in bottom sediments. It is widely recognized that losses of oil and petroleum products during extraction, transportation, and usage can amount to as much as 2% of the total volume. Just a single gram of petroleum products can render 2,000 liters of water unsuitable for use.

An increase in the thickness of an oil film on the water surface to merely 0.1 mm disrupts gas exchange processes and poses a lethal threat to aquatic organisms. This degree of pollution can occur with the presence of as little as 1 gram of oil per square meter of surface water. Toxic concentrations of petroleum products are alarmingly low, at 0.01 mg/L for fish, 100 mg/L for macroalgae, and 0.1 mg/L for phytoplankton. Larvae and juvenile fish are particularly susceptible to such contamination (Kasymov A.G., 1994).

The effects of oil pollution are most prominently observed in waterfowl. When exposed to oil, feathers lose their water-repellent and insulating properties, which swiftly leads to the death of the birds. Instances of mass bird mortality have been repeatedly reported in the Absheron region. For example, Azerbaijani media reported that approximately 30,000 birds died in 1998 on the protected Gel Island near the village of Alat.

The closeness of protected areas and extraction wells presents a continual risk to the Ramsar-designated wetlands situated along both the western and eastern coasts of the Caspian Sea.

Between 1941 and 1958, while drilling in the "Neft Dashlary" ("Oil Rocks") oil field, uncontrolled surface oil eruptions, referred to as artificial gryphon formation, were documented in 37 wells. These gryphons were active for durations ranging from several days to as long as two years.

The amount of crude oil released during these occurrences fluctuated between 100 and 500 tons each day.

A Non-Exhaustive List of Incidents Involving Accidents and Oil Spills in the Northern Caspian Sea

1985–1986 – Tengiz Field: A disastrous blowout occurred at Well No. 37, leading to well control and mitigation efforts that spanned 398 days. Approximately 3.5 million tons of crude oil were incinerated, and around 900 tons of soot were emitted into the environment.

March 2000 – Sunkar Drilling Rig: An oil spill incident took place during offshore operations.

April 2000 – Sunkar Drilling Rig: An oil spill occurred during well testing at the East Kashagan prospect.

April 2001 – Sunkar Drilling Rig: An oil spill, along with a release of hydrogen sulfide (H_2S),

During both the pre-war and wartime phases of the Great Patriotic War (1941–1945), significant anthropogenic pollution was noted in the coastal shallow-water areas of Krasnovodsk Bay and Aladja Inlet, particularly after the relocation of the Tuapse Oil Refinery to this region. This environmental decline was marked by a substantial die-off of waterfowl, as local reports suggest that collectors of oil-contaminated birds, known as *mazutniki*, along with specially trained dogs, would retrieve between 40 and 200 such birds daily.

Primary Causes of Pollution of the Caspian Sea from Offshore Oil Operations:

Outdated drilling and well operation technologies;

Insufficient emergency response and blowout prevention equipment;

Carelessness in the management and disposal of industrial waste;

Deterioration of flowlines and main trunk pipelines;

Corrosion and lack of cathodic protection systems;

Coastal erosion induced by waves at pipeline landfall locations.

2.7.4 Introduction of Alien Species

Until quite recently, the risk associated with invasive species was not deemed significant in the Caspian Sea. In fact, the sea served as a testing site for the intentional introduction of non-native species intended to boost the fishery productivity of the basin. It is crucial to highlight that these introductions were largely grounded in scientific predictions. In certain instances, fish and their prey organisms were introduced at the same time – for instance, *mullet (Mugil spp.)* along with *Nereis (Polychaete worms).*

The scenario changed dramatically with the emergence of a substantial population surge of the comb jelly *Mnemiopsis leidyi.* According to information from the Caspian Fisheries Research Institute (CaspNIRKh), *Mnemiopsis* was officially documented in the Caspian Sea for the first time in the fall of 1999. However, unverified accounts of its presence trace back to the mid-1980s.

Mnemiopsis leidyi was first noted in the Sea of Azov roughly a decade earlier and, between 1985 and 1990, it wreaked havoc on both the Azov and Black Sea ecosystems. It was most likely introduced through ballast water released by vessels coming from the shores of North America. Its subsequent invasion of the Caspian Sea occurred with relative ease. This ctenophore primarily preys on *zooplankton*, consuming up to 40% of its body weight daily. In doing so, it drastically reduces the trophic base vital for the survival of native fish species in the Caspian. Due to its rapid reproductive rate and the lack of natural predators in the area, *Mnemiopsis* stands virtually unmatched among other zooplankton feeders. Additionally, by consuming the *planktonic larvae* of *benthic invertebrates*, it presents a significant threat to *benthivorous fish species*, including the highly *prized sturgeons (Acipenseridae).*

2.7.5 Overfishing and Poaching

Fisheries experts generally agree that the economic instability faced by the Caspian littoral states in the 1990s led to a significant underutilization of nearly all commercially valuable fish species, with the exception of sturgeons.

Nevertheless, an examination of the age distribution of the harvested fish (Tarasov, 2000) indicates that, despite the apparent lack of fishing activity, considerable overexploitation did occur—particularly concerning the *anchovy sprat (Clupeonella engrauliformis).* For example, in 1974, more than 70% of the sprat catch was made up of fish aged 4 to 8 years. By 1997, this age group represented only 2% of the catch, with the majority being fish aged 2 to

3 years. This suggests that the catch quotas for sprat were based on a significantly inaccurate estimation of total biomass, with discrepancies reaching several tens of percent. The precise reasons for these miscalculations by the scientific bodies in the sector remain a matter of speculation today. Potential contributing factors may include inadequate stock assessments and exploratory surveys, institutional pressures from fisheries authorities, the introduction of *Mnemiopsis leidyi*, and the unaccounted predation pressure from the *Caspian seal (Pusa caspica)*, whose hunting was prohibited in the early 1990s. Regardless of the underlying reasons, it is clear that a crucial, unidentified factor contributing to the decline of sprat stocks in the early 1990s was either overlooked or intentionally disregarded.

Catch quotas saw a steady increase until the close of 2001. The Total Allowable Catch (TAC) for 1997 was established at 210,000–230,000 tons, with an actual harvest of 178,200 tons. This shortfall was officially blamed on "economic difficulties." By 2001, the TAC was elevated to 300,000 tons. Even following the mass mortality event that impacted sprat populations, the Caspian Fisheries Research Institute (CaspNIRKh) projected a harvest of 107,000 tons for 2002 – effectively permitting ongoing exploitation of the species despite the evident and severe population decline. It is questionable whether even 10% of this quota could be realistically achieved.

This scenario raises doubts about the scientific credibility of the quota justifications that CaspNIRKh has provided over the years for all fish species. It highlights the pressing need to transfer the responsibility for establishing exploitation limits for aquatic biological resources to independent environmental and conservation organizations.

The most drastic repercussions of scientific errors in the fisheries industry were evident in the management of sturgeon populations. Indicators of an impending crisis were already visible in the 1980s. From 1983 to 1992, the catch of Caspian sturgeons plummeted by a factor of 2.6 – from 23,500 tons to 8,900 tons. In the following eight years, catches fell by another significant amount, dwindling to just 900 tons by 1999.

Poaching has only recently been acknowledged as a major contributor to the decline in sturgeon catches. In the 1980s and early 1990s, illegal fishing was deemed minimal when compared to state-sanctioned extraction.

The effects of illegal fishing on the decline of sturgeon populations require thorough examination. Estimates of poaching have surged significantly over the years: from 30–50% of the official catch in 1997, to 4–5 times the legal harvest in 1998, and as high as 10–15 times during the 2000–2002 timeframe. In 2001, the Caspian Fisheries Research Institute (CaspNIRKh) estimated that illegal catches reached 12,000–14,000 tons of sturgeon and 1,200 tons of caviar. These estimates were corroborated by CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) assessments and public statements from the Russian State Committee for Fisheries. Given the substantial market value of black caviar– ranging from $800 to $5,000 USD per kilogram in Western markets–media speculation about a so-called "caviar mafia" has emerged, purportedly controlling not only regional fisheries but also influencing law enforcement in the Caspian-bordering areas.

At a Moscow expert meeting, participants unanimously concluded that the primary threat to the survival of sturgeon populations in the Caspian Sea “originates from poaching, which has reached a mass scale in recent years.” Experts from CaspNIRKh estimated that in 2000, poachers in Azerbaijan, Kazakhstan, Russia, and Turkmenistan harvested at least 12,000–14,000 tons of sturgeon and placed over 1,200 tons of caviar into the market. In comparison, the total official catch reported by the four Caspian littoral states was less than 1,000 tons (as reported in *“Trud”* newspaper, February 14, 2001).

2.7.6 Eutrophication

The elevated pollution levels in the Caspian Sea and its tributaries have long sparked worries about the potential emergence of anoxic zones, even though this concern has not been prioritized among the most pressing environmental issues. Numerous studies have highlighted a considerable risk of algal blooms and hypoxia, especially in regions south of the Turkmen Bay. However, the most credible data regarding this matter originates from the early 1980s, and there have been no documented cases of fish kills or similar hypoxia-related incidents in the years since, complicating the ability to reach definitive conclusions at this time.

Nevertheless, significant disruption to the equilibrium between primary production and organic matter breakdown – caused by the introduction of *Mnemiopsis leidyi* – could result in major and potentially disastrous ecological shifts.

Although *Mnemiopsis* does not pose a threat to the photosynthetic processes of phytoplankton, it has a profound impact on the *degradative (heterotrophic) segment* of the cycle, particularly affecting the zooplankton–fish–benthos pathway. Consequently, it is anticipated that undecomposed organic matter will build up in the water column, fostering conditions that are conducive to the formation of hydrogen sulfide (H_2S) contamination in the lower layers. The toxic effects on the remaining benthic fauna could hasten the growth of anaerobic zones. Therefore, it is reasonable to predict the emergence of extensive anoxic regions wherever conditions permit prolonged stratification of the water column – especially in areas marked by the mixing of freshwater and saltwater, along with high levels of unicellular algal production.

The areas identified as high-risk align with regions of increased phosphorus input–particularly, the deepwater disposal sites in the Middle and Southern Caspian (areas affected by upwelling), along with the transitional zone between the Northern and Middle Caspian. In the Northern Caspian, locations with diminished dissolved oxygen levels have also been recognized; this issue is further aggravated during the winter months due to seasonal ice cover. Such circumstances are likely to heighten stress on commercially important fish species by raising the incidence of fish kills and obstructing migratory pathways.

Additionally, under these modified environmental conditions, predicting the changes in the taxonomic structure of phytoplankton communities remains challenging. In some instances, increased nutrient loading can lead to the emergence of *harmful algal blooms (HABs)*, including the phenomenon known as “red tides.” A pertinent example of this occurrence has been noted in Soymonov Bay (Turkmenistan).

Source: “Hydrometeorological Variability and Ecogeographical Problems of the Caspian Sea”. Baku, “Elm” Publishing house, 2007, pp.319-364. Author: R.M. Mamedov.

2.8 ANTHROPOGENIC IMPACT ON CASPIAN SEA ECOSYSTEMS

Ecological Characterization of the Caspian Sea. Investigations into the primary factors driving biological productivity in the Caspian Sea, along with a variety of related environmental challenges, have yielded a thorough understanding of the intensity and intricacy of Human-Induced pressures impacting both the Marine Ecosystem and its Extensive Drainage Basin over the last four decades and beyond. In this regard, it is important to assert with certainty that few, if any, Aquatic Ecosystems worldwide have experienced such extended and complex Ecological Deterioration as the Caspian Sea. The magnitude and variety of pollutants released into the basin are astonishing. Adding to this issue is the legacy of tens of thousands of classified seismic detonations – each involving explosive charges between 10 kilograms and 1.5 tons of TNT– conducted from the 1940s to the 1960s, which significantly disrupted the seabed across large expanses of the sea. Additional harm was caused by missile testing at designated military ranges in the open waters of the Southern Caspian and other areas. When evaluating the combined effects of these elements, one cannot help but be amazed at how the Caspian Sea has managed to persist as an ecological system at all.

In 1961, the author of this narrative was part of an experimental commission aimed at evaluating the effects of geophysical exploration activities – particularly, controlled underwater explosions – on marine life and the Physico-Chemical characteristics of the water surrounding the blast areas.

The results revealed that detonating explosive charges over 70 kilograms led to total mortality of fish species within a radius of about 85–100 meters from the epicenter. Around 60% of the fish biomass settled on the ocean floor. Planktonic organisms lost their viability, and the water column became laden with terrestrial particles and byproducts of combustion. Benthic sediments were mechanically disturbed and resuspended, resulting in a significant reduction in water clarity. The pH levels in the epicentral area decreased by 3–4 units. To this day, the absence of saprophytic bacteria in water samples taken after detonation remains a mystery.

It is widely recognized that the Caspian Sea is a naturally isolated basin, marked by alternating periods of low and high-water levels. However, during these fluctuations – and up until the 1940s – its Biological Productivity remained robust, with both its flora and fauna adapting consistently without losing taxonomic integrity. The qualitative structure of the ecosystem stayed stable (Derzhavin, 1939, 1951). Among the key factors driving ecological change in the Caspian Sea today are fluctuations in sea level and pollution.

As highlighted in various historical and contemporary sources (discussed in more detail in the following section), variability in water levels is a fundamental aspect of the Caspian Sea's natural regime. It is clear that each phase of Regression and Transgression has influenced Ecosystem Stability; however, as previously mentioned, these changes did not lead to catastrophic outcomes for Aquatic Life.

On a Global Scale, significant ecological changes in the Caspian have primarily stemmed from the rising pollution levels affecting both the sea and its watershed. These detrimental effects have been exacerbated by a decline in Sea Level, Human Regulation of river inflows from major tributaries, and associated hydrological alterations.

A wealth of data is available concerning pollution in the Caspian Sea. This matter has been addressed by numerous experts and has been a topic of discussion at various symposia and scientific conferences. In response, several high-level policy resolutions have been enacted. However, the Caspian Sea continues to experience pollution, even with widespread acknowledgment – by all coastal nations – of the necessity to maintain its ecological integrity and ensure the purity of its waters. Variations in sea level mainly influence the shape of the coastline: they alternately increase or decrease the extent of shallow-water areas, modify hydrographic systems in river delta regions, and either enhance or diminish the movement and currents of the water body. These alterations also interfere with water exchange among the sea's sub-basins, change the distribution of sediment loads, and lead to a variety of other cascading environmental effects.

In contrast to the Southern and Middle Caspian, variations in sea level significantly affect the vast shallow-water region of the Northern Caspian. During periods of low water (1928–

1978), the main discharge of the Volga River was redistributed, with a diversion of flow towards its western area, resulting in a notable decrease in overall biological productivity in the eastern section. Simultaneously, the rise in salinity in water bodies cut off from the Volga's freshwater influence facilitated the spread of Mediterranean immigrant species, which began to supplant the native flora and fauna of the Caspian.

In the deep-water areas – specifically the Middle and Southern Caspian – these processes led to an increase in vertical circulation throughout the water column. It was observed that the upward movement of biogenic elements from deep accumulation zones into the surface euphotic layers supplied bacterioplankton with vital nutrients, while the deeper layers obtained both energy substrates and oxygen. This change in the dynamics of vertical water exchange facilitated the growth of *rhizophytes,* which replaced the native algal communities of the Caspian Sea (Salmanov, 1968, 1972). In the shallow coastal regions of river estuaries, a decrease in sea level changed sedimentation processes, particularly in the Northern Caspian. Heightened wave activity caused a decline in water clarity – averaging between 0.25 to 0.4 meters – leading to a Thinner Effective Euphotic Layer. This also encouraged the erosion of fine-grained sediments, interfering with the development of Benthic communities and other essential benthivorous food sources.

In recent years, the Caspian Sea has experienced significant transformations linked to rising water levels. The Erosion of newly flooded and waterlogged land has introduced large quantities of Allochthonous Materials into the sea, which include Biogenic Elements, Organic Matter, Terrigenous

Inputs, Hydrocarbons, Heavy Metals, and various other Substances.

The rising sea level has resulted in a notable change in the routes of fluvial sediment transport. This increase in water level has caused a decrease in the movement of detritus and terrigenous materials to deeper water areas, leading to their greater accumulation in river foredeltas and other regions of the continental shelf.

By 1995, the thickness of silt deposits in the Kura River channel near its mouth had risen by 1.2–1.4 meters compared to 1979. The backwater effect from the Caspian Sea resulted in a reduction of flow velocity by more than half, while the water depth increased by over 1 meter. Importantly, during winds from the northeast and southeast, seawater penetrates several kilometers upstream along the Kura River, which significantly hinders its discharge into the sea (Salmanov, 1996). In conclusion, both regression and transgression are crucial in influencing overall biological productivity and shaping the dynamics of production and destruction processes.

Among the various factors impacting the stability of the Caspian Sea Ecosystem, Human Activities – especially general pollution – are becoming increasingly significant. As noted earlier, this topic has been thoroughly explored in both scientific and popular literature; thus, a detailed discussion is unnecessary here. Instead, we will focus on listing the Primary Pollutants.

In terms of importance, the duration of consistent input, and the complex effects on both Fauna and Flora, as well as on the Physicochemical characteristics of water and bottom sediments, oil pollution holds a prominent position in the Caspian Sea. Oil and Petroleum Products were among the earliest pollutants to negatively impact the marine biocenosis.

Currently, oil pollution influences nearly the entire Caspian Sea basin, including the discharge points of all major inflowing rivers. While in the 1950s and 1960s, Oil Contamination was primarily limited to marine oil fields and areas receiving discharges from oil refineries and related industrial operations, since the 1980s, it has become widespread across the sea. It is crucial to highlight that one of the aims of our research was to ascertain the concentration of Petroleum Hydrocarbons in Caspian waters and evaluate the extent of their Biodegradation by Hydrocarbon-Oxidizing Bacteria (this will be elaborated on in the following sections).

Based on calculations gathered from all available sources, since the widely acknowledged discovery of Caspian oil, over 2.5 million tons of crude oil have been released into the sea. In 1969 alone, around 47,000 tons of oil were discharged into the sea along with ballast water from oil tankers, in addition to another 7,000 tons from bilge water of ships.

Regarding accidental spills, it is enough to mention just two significant events: after an incident on the eastern shelf of the Middle and Southern Caspian in the late 1960s, more than 4,000 tons of oil were spilled into the sea. For several months, over 20,000 tons of gas-oil condensates were released due to ongoing fires and active gryphons at the site. Even as recently as 1983, oil concentrations of 1.43 g/kg of silt were recorded at depths of 200 meters in sediments off the Southwestern Ccoast of Ogurchinsky Island; by 1995, at the boundary between the Middle and Southern Caspian (at a depth of approximately 270 meters), concentrations of 0.86 g/kg were noted. In Baku Bay, sediments are permeated with Petroleum Products down to 5-7 meters below the seabed. All ports along both the Western and Eastern shores of the Caspian have long been saturated with oil. To evaluate the extent of pollution from oil and other contaminants, *maximum permissible concentrations* (*MPCs*) are generally utilized as reference points. However, during our examination of water samples across extensive shelf regions in all three sectors of the Caspian Sea, we consistently detected oil concentrations that exceeded MPCs by several times.

Unlike many other pollutants, oil can be easily transported to remote areas, is relatively "*persistent*", and exhibits a wide range of chemical diversity. For the complete mineralization of just 1 kilogram of oil, the oxygen required is equivalent to that found in 400,000 liters of seawater (Zo-Bell, 1964).

Characteristic features of petroleum pollution encompass a variety of sources, infiltration into nearly all Environmental Components, extensive Spatial Distribution across vast marine regions, and accumulation in sediment at the bottom. The soluble and denser oil fractions in the water column easily adsorb other toxic substances, such as Heavy Metals, which aids in their transport and Bioavailability. These contaminants deteriorate water quality, adversely impact the Oxygen Regime, and disturb the balance between surface water layers and the atmosphere.

Oil contamination has significantly transformed the Environmental Conditions on the Western Shelf of the Southern Caspian. During a 15-year span from 1961 to 1976, the primary phytoplankton productivity in the waters surrounding the Apsheron-Baku Archipelago plummeted by a factor of 50.

Phytobenthos was eliminated over vast areas, stretching from northern Apsheron to the Kura River delta, throughout the expansive Krasnovodsk Bay, and around the Cheleken Peninsula. Areas affected by oil pollution are now nearly devoid of zoobenthos and have lost their significance as vital feeding grounds. Anaerobic Processes prevail in the bottom sediments of these regions. The Metabolic Byproducts of Anaerobic Microflora have led to the formation of unusual Redox Layers – zones where O_2 and H_2S coexist– conditions that are foreign to the Caspian Sea but typical of the Black Sea (Sorokin & Avdeev, 1991).

Chemical Pollution has significantly influenced the ecological conditions of the Caspian Sea. Its effects were especially evident during times of declining sea levels.

During those years, over 150 different chemical substances were identified among the Toxicants entering the Caspian Sea. In the 1970s, alone, large amounts of concentrated acids (Nitric, Sulfuric, and Hydrochloric) were released into the sea from the primary chemical production site of the former USSR– Sumgait city–totaling 45,000–50,000 tons each year. Additionally, a classified substance known as Nekal, which is more toxic and environmentally persistent than DDT, was discharged in quantities exceeding 15,000-20,000 tons annually. This highly toxic and environmentally durable compound remains largely unknown to the public; however, it can completely eradicate Invertebrates and Phytoplankton Populations even at a concentration of 0.01 mg/L (Salmanov, 1976).

Adverse ecological conditions are similarly noted along the coastal areas of the Eastern Shelf of the Middle and Southern Caspian, which face ongoing anthropogenic pressure from petrochemical complexes in Turkmenistan – especially around the cities of Türkmenbashy (previously known as Krasnovodsk), Cheleken, Alasha, and Hasan-Kuli – as well as from significant Petrochemical and Metallurgical industries, including Uranium Enrichment Plants in the Republic of Kazakhstan, particularly in the vicinity of Aktau and its surrounding regions.

There is substantial evidence indicating Environmental Degradation in the coastal waters adjacent to the cities of Makhachkala, Kaspiysk, Dagestanskie Ogni, and Izberbash (Salmanov, 1987; Kasymov, 1994; Stolyarov & Mamaev, 1992).

In the context of pollution in the Caspian Sea – especially in the northern basin – river discharge acts as the main channel for Allochthonous Materials (Granina, 1995; Katunin, 1995; Kovalenko, 1995; Kostrov, 1995). Rivers serve as conduits and repositories for Toxic Substances, transporting a diverse range of industrial and municipal wastewater discharges and emissions from the vast drainage basin of the Caspian Sea. Through river input, a variety of pollutants enter the sea, such as *pesticides, detergents, heavy metal salts, mineral and organic compounds, radionuclides, and more*. The cumulative effects of these inputs – through *chemical interactions, nutrient cycling, biochemical changes, and other related processes* – result in changes to Faunal and Floral Succession, create Synergistic Effects, and modify the Trophic Structure and Ecological Condition of the Caspian Sea.

Currently, all rivers transport organic matter and biogenic elements to the sea –inputs that, when considered alongside petroleum, chemical, and other pollutants, may seem relatively "harmless" However, in reality, these two factors are key contributors to the nearly irreversible anthropogenic eutrophication that is now impacting the entire Caspian Sea (which will be discussed in detail in later sections). It is well known that under the conditions of the Caspian Sea, one kilogram of biogenic elements can lead to the production of one metric ton of Bacterioplankton Biomass (Farb, 1984).

Organic matter originating from municipal and domestic sources is the first to experience biodegradation in the Caspian environment. Research has demonstrated that in Baku Bay, in the area receiving household wastewater, with an oxygen concentration of 9.3 mg O_2/L, oxygen is depleted within 8–9 hours during experimental biodegradation processes (Salmanov, 1987). Further studies indicated that within 4 hours, 92.3% of the initial dissolved oxygen is consumed, and within just 1 hour–39% is already depleted.

River discharge–currently the main factor contributing to rising sea levels–has experienced both quantitative and qualitative transformations. Over the last 15 to 20 years, the levels of biogenic elements and organic matter in the discharges from the major rivers flowing into the Caspian Sea have roughly doubled. For instance, in the primary river of the Caspian basin – the Volga – the yearly organic matter load surged from 2 million tons to 6 million tons during this timeframe. In the Kura River, this amount increased from 180,000 tons to almost 600,000 tons. These alterations provide a clear insight into the worsening Oxygen Conditions in the contact zones and surrounding marine regions of the Caspian Sea. Therefore, from the summarized information provided above, it is clear that a significantly critical ecological situation has emerged in the isolated Caspian Sea. Additional pollution and ongoing Human-Induced Pressure on the Marine Ecosystem present serious and escalating threats. In conclusion, it is important to highlight that one of the essential measures for restoring the Ecological Balance of the Caspian Sea is the enforcement of Stringent Sanitary Controls over river discharges. Extensive studies carried out in the catchment areas of the Volga, Kura, Ural, Terek, and other rivers have shown that natural self-purification processes are currently hindered across these systems (Salmanov & Mansurov, 1996; Ivanov, 1999; Popova, 1992; Bolshov, 1992). To effectively neutralize pollutants in rivers like the Kura – Aras system, the water flow needs to be increased by at least 15-20 times. For the Volga River, restoring its self-purification ability would necessitate an additional inflow at a river scale.

The Multicomponent Pollution affecting the Caspian Sea has emerged as a Crucial Factor in changing the Sanitary and Hygienic Conditions for numerous commercially significant species. Mass mortality incidents involving valuable fish species have become increasingly frequent. The Physico-Chemical and Biochemical impacts of Toxic Substances and Chemical Pollutants in Marine Environments are still not thoroughly researched. Due to ongoing contamination, certain fish populations are more frequently suffering from diseases caused by *parasites, pathogenic bacteria*, and *fungi* – resulting in extensive and often hard-to-measure damage. Prominent examples include Muscle Fiber Separation *(myopathy)* and the Rupture or Weakening of Egg Membranes, which have been demonstrated to arise from the combined effects of Petroleum and Pesticide Contamination (Lukyanenko, 1990; Altufyev, 1994). As noted by several researchers (Biserova et al., 1998;

Ivanov, 1999), many aquatic organisms in the Caspian Sea carry a variety of parasites that can pose health risks to Humans, such as *Anisakidae, Pseudoamphistomidae, Eustrongylides,* among others. Pathogenic bacteria like *Proteus, Vibrio spp.,* and *Proteus vulgaris* have also been identified in both seawater and fish tissues.

Contemporary Scientific and Theoretical Perspectives on Water Balance Variations and Sea Level Predictions for the Caspian Sea. It is now firmly established that variations in the water balance – specifically, the cyclic nature of the Caspian Sea's level regime – are intrinsic to its hydrological characteristics and represent a consistent, recurring phenomenon. It is no coincidence that some of the earliest historical references to the variability of the Caspian Sea level can be found in the writings of ancient Greek and Roman scholars (Lenz, 1836; Guel, 1956; Shlyamin, 1962). Accounts by Herodotus and Aristotle, from the 6^{th}–5^{th} centuries BCE, along with records compiled by Patroclus in the early 2^{nd}–4^{th} centuries BCE, demonstrate an early recognition of sea level fluctuations. In essence, there is a substantial historical record that chronicles the changes in the Caspian Sea level. This leads us to infer that the Caspian region has undergone Hydrological and Environmental events that were at least as dramatic as those we witness today. As noted by L.N. Gumilev (1980), changes in sea level were among the factors contributing to the decline of the Khazar people and the fall of the formidable empire they had built. Even in the present day, the cyclic nature of the Caspian Sea's level inflicts considerable harm on the coastal states and affects hundreds of thousands of residents in the coastal areas. Each phase of transgression or regression results in significant alterations to the ecological stability of coastal biocenoses, modifies river estuarine systems, either expands or reduces the sea's surface area, changes its trophic status, and initiates a variety of other Hydroecological Impacts. For these reasons, comprehending the factors that influence sea level changes and creating dependable forecasting models have historically been pivotal to scientific research and discussions among *hydrologists, oceanographers*, and *climatologists* (Apollov, 1935; Berg, 1934; Svitokh, 1991; Varushenko, 1987; Mamedov, 1998; Shnitnikov, 1957, et al.).

This issue is clearly a specialized area of study. Nevertheless, since our research was carried out during both the Regression and Transgression Phases of the Caspian Sea level cycle – periods that had a direct impact on our results – it is fitting to provide a brief overview of the existing Scientific and Theoretical Viewpoints concerning the factors behind the fluctuations in Caspian Sea levels. The literature indicates that starting in 1926, the sea level, which was previously noted at –26 meters (in relation to the Baltic Sea datum), began to decrease sharply, reaching –29.02 meters by 1977. However, in 1978, the level began to rise–an unexpected development for many experts–and by the end of 1994, it had returned to –26.5 meters above sea level (Mamedov, 1996; 1998). A wealth of *geological, paleogeographical, archaeological,* and *historical research* on the Caspian Sea, along with extensive long-term observational data gathered from its shores, suggests that the sea exhibits a complex hierarchy of level fluctuations. Each recorded sea level reflects the cumulative impact of various overlapping oscillatory patterns, which either enhance or diminish the dominant trend over a specific time frame.

It is important to note that the current sea level of the Caspian does not represent its historical states. Based on existing research, the total duration of highstand phases throughout the Geological History of the Basin was three to four times longer than that of lowstand periods (Svitokh, 1991). This finding is derived from data acquired through absolute dating and the examination of ancient sedimentary deposits from the Caspian (Svitokh & Yanina, 1996). Radiocarbon dating of Caspian sediments performed by S.A. Veliev (as referenced in Mamedov, 1996) has shown that over the last 4,000 years, changes in sea level have followed a distinct rhythm with cycles of approximately 200–250 years, and broader cycles occurring every 450–500 years. According to this model, the sea level of the Caspian Sea tends to rise gradually for 200–250 years, followed by a decline of a similar duration. Two consecutive rhythmic phases create a complete cycle, which is typically marked at both the beginning and end by a notably low sea level of around -35 meters.

As noted by R.M. Mamedov (1996), the most significant period for comprehending the dynamics of the modern Caspian Sea is the last 500 years, during which numerous alternating transgressive and regressive phases have been documented.

It has been determined that various factors affect the level of the Caspian Sea, including the amount of river and underground inflows; the Equilibrium between Precipitation on the sea's surface and evaporation; sedimentation rates and the diagenetic alteration of basin deposits; as well as neotectonic and seismic activities; coastal topography, among others. These are the main factors that directly influence fluctuations in sea level. These processes are also closely related to and influenced by larger natural phenomena on a planetary or regional scale – such as Atmospheric Circulation Patterns, Climatic Cycles, Solar activity, the Caspian region's location within the broader Morphotectonic Structure of Eurasia, and its ongoing Geodynamic Processes.

Currently, in addition to natural factors, Human Activities – particularly the *irreversible extraction of river discharge* – have significantly increased their effect on the Sea's Hydrological Regime.

It is important to note that the exact degree to which each of the previously mentioned factors affects fluctuations in Caspian Sea levels is still unclear. This ambiguity represents a Key Area of disagreement among scholars regarding the reasons behind sudden changes in sea level and the Dependability of Long-Term Predictions.

A Comprehensive Analysis of Extensive Empirical Data concerning sea-level changes and the hydrological patterns of incoming rivers over the last 160 years supports the Theory that fluctuations in Caspian Sea levels are influenced not by local conditions, but by Broader Atmospheric Phenomena – particularly, the strengthening of *anticyclonic circulation patterns* (Eygesson, 1957). Furthermore, it has been found that during times of increased solar activity, sea levels typically decrease, while periods of diminished solar activity are associated with rising sea levels.

The Role of Geological Factors in the Dynamics of Caspian Sea levels has been largely dismissed by various researchers, who have shown a considerable gap between the possible extent of Geological Influences and the scale of observed Hydrological

Changes. For example, although annual variations in sea level can exceed 10 cm, the rate of tectonic uplift or subsidence, as indicated by shoreline deformation, is usually only a few millimeters annually. Likewise, the yearly rate of marine mud-volcanic sediment accumulation does not surpass several millimeters.

A thorough examination of all the causes and factors affecting the fluctuations in the Caspian Sea level leads us to conclude that the primary and most significant factor contributing to the Instability and Extent of these changes is Hydrometeorological in nature. Nevertheless, for minor fluctuations, the influence of geological and other factors cannot be completely disregarded. Overall, however, the effect of geological factors is significantly less, by two orders of magnitude, compared to Hydrometeorological causes (Svitoch, Yanina, 1996). Notable findings are presented in a study by R. Mamedov and his associates (1996). Their calculations suggest that the current changes in the Caspian Sea level are predominantly influenced by variations in the components of the Water Balance, especially river runoff and apparent evaporation. The contributions from these components are nearly equal, each representing about 40%. Their quantitative analysis reveals that Hydrometeorological factors are responsible for roughly 85-90% of the level fluctuations in nearly all instances. Additionally, it was found that Anthropogenic Factors affect the Caspian Sea level through mechanisms such as reservoirs, irreversible water extraction for irrigation, the presence of oil films on the surface, and similar impacts. Overall, their evaluation estimates the influence of Anthropogenic factors on changes in the Caspian Sea level to be between 3-5%.

The forecasts made by R. Mamedov and his team suggested that the Caspian Sea level would continue to rise until 1997, reaching a level of -26.3 meters, followed by a decrease until 2000. After that, an increase of about 1.3 meters is anticipated, with the level expected to reach approximately -25.2 meters by 2025.

Source: "Ecology and Biological Productivity of the Caspian Sea." Baku, Ismail" Publishing house, 1999, pp. 62-71.
Author: M.A.Salmanov

2.9 OIL AND THE ECOLOGY OF THE CASPIAN SEA

The problem of marine and oceanic pollution caused by crude oil and petroleum products has become increasingly significant due to their complex and systemic effects on aquatic life. It is therefore not surprising that these pollutants are now recognized as *emerging ecological factors* (Mazmanidi, 1997). In this context, the Caspian Sea holds a uniquely important position. As a closed and endorheic basin, it has historically undergone earlier and more severe direct interactions with Oil and Petroleum Products than any other inland water body. Consequently, Oil has effectively turned into a *persistent allochthonous substrate* within the Caspian marine ecosystem.

Crude Oil and its Derivatives represent a Complex Natural Mixture of Hydrocarbons, along with Organic Compounds that contain *sulfur, nitrogen, oxygen, and other heteroatoms*. Based on the predominance of certain Hydrocarbon Classes, oils are classified as *methanic*, *methano-naphthenic, naphthenic, aromatic*, and others. It is particularly significant that over 250 different *sulfur-bearing compounds* have been discovered in

Crude Oil, many of which are found in heavy, high-boiling fractions (Khotimsky et al., 1977). Moreover, Crude Oil includes *carboxylic acids, esters, ketones, phenols, and trace metals*. Although the Complete Chemical Makeup of crude oils is still not fully characterized, more than 400 individual Hydrocarbons have been identified so far (Mazmanidi, 1997). The existence of these varied compounds underscores the extensive and potentially enduring ecological consequences of oil when it is released into Aquatic Environments, including the Caspian Sea. The toxicity of petroleum has been acknowledged for a long time, and it is primarily influenced by its Molecular Structure and Physicochemical Properties.

As early as 1900, I.D. Kuptsis conducted experiments that revealed the Main Toxic substances – termed the "oil poison" complex– consist of low-boiling saturated Hydrocarbons and Naphthenic Acids, which migrate from Crude Oil into Aquatic Ecosystems (Mazmanidi, 1997).

In recent years, numerous researchers have highlighted that the most dangerous elements of Petroleum for Aquatic life are its Water-Soluble Fractions, especially Phenolic Compounds (Lee et al., 1972; Moore & Dwyer, 1974). The topic of Petroleum Pollution in the Caspian Sea is thoroughly examined in Chapter IV. It is important to mention that although there is a substantial amount of literature on this subject, most publications only offer broad overviews of Oil Pollution in the Caspian.

Furthermore, there is a notable deficiency of empirical evidence concerning the *"in situ"* degradation of Petroleum in Marine settings, particularly regarding the function of Microbial Communities as Key Biodegraders. Current research on Hydrocarbon Oxidation processes is, firstly, frequently inconsistent and, secondly, limited to specific Geographic areas such as particular ports and bays within the Caspian Sea (Tsiban, 1976; Popova & Novozhilova, 1968; Efendiyeva, 1978).

In light of the critical nature of the problem and the many recorded cases of Oil and Petroleum Pollution in the Caspian Sea, our study aimed to quantify the presence and evaluate the Physiological Activity of Hydrocarbon-Oxidizing Bacteria found in both the water column and the sediment at the bottom. Furthermore, we conducted a partial analysis of Hydrocarbon levels in Environmental samples gathered from various locations across the Surface of the Caspian Sea (Salmanov, 1968, 1975, 1987, 1995, 1997, 1998).

It has been established that the degree of Petroleum Biodegradation in the Caspian Sea is primarily determined by the Physicochemical Structure of the Oil itself and the specific characteristics of the Local Marine Environment. Seasonal variability, the chemical composition and concentration of the Hydrocarbon Substrate, as well as the physicogeographical features of individual water bodies, play a significant role in the Natural Elimination of Oil in marine conditions. Numerous experimental studies have investigated the Degradation Dynamics of various oil types using both mono- and mixed cultures of Hydrocarbon-Oxidizing Bacteria. It was found that *paraffinic, sulfur-rich, and high-octane petroleum compounds* undergo mineralization at different rates even under identical Environmental conditions. Under natural Caspian Sea conditions, the detected Oil is typically *"weathered,"* or aged, since the lighter fractions of freshly spilled oil tend to volatilize from the water surface within the first 24 hours. Moreover, a portion of the oil also dissolves into the water column over a relatively short time span. The rate and extent of Evaporation and Dissolution are highly variable and depend on several Environmental factors, including *oil film thickness, wind speed and direction, wave dynamics, water circulation patterns, ambient temperature, and others*. According to some studies, up to 80% of gasoline and 22% of kerosene can volatilize from the water surface within the first 24 hours, depending on Air Temperature. In contrast, *fuel oil (mazut)* losses over the same period do not exceed 0.3% (Wilkinson, 1979).

Source: "Ecology and Biological Productivity of the Caspian Sea." Baku,Ismail" Publishing house, 1999, pp. 311-312.
Author: M.A. Salmanov

2.10 ANTHROPOGENIC EUTHROPHICATION AND ITS ECOLOGICAL CONSEQUENCES IN THE CASPIAN SEA

It is important to highlight that finding an open water body free from Anthropogenic influences is quite challenging. The impact of Human Activities on Aquatic Ecosystems triggers a complex series of events: in certain instances, it hinders the growth of plant and animal life, while in others, it instigates ecological successions that lead to the rapid increase of both Autotrophic and Heterotrophic Microorganisms. Regardless of its form, such pressure disrupts the functional stability of Aquatic Ecosystems.

The phenomenon of Anthropogenic Eutrophication affecting *oceans, seas, lakes, reservoirs, and rivers* has been thoroughly examined in scientific studies. The Caspian Sea is no exception to this trend. Although it is one of the most significantly and persistently affected Aquatic Environments, there is still a lack of comprehensive research on Anthropogenic Eutrophication in the Caspian Sea and its related consequences.

Earlier sections have outlined the general pollution issues facing the Caspian Sea. However, the particular impacts and long-term effects of the influx of Allochthonous Substances into the sea have not been extensively researched. Nevertheless, it is clear that the severe pollution of the surrounding area and the Marine Environment over the last fifty years has dramatically changed the Ecological Stability of the Caspian Sea as well as influenced the course of its Biological Development.

It is widely recognized that the Eutrophication of aquatic ecosystems is mainly caused by the influx of biogenic elements and easily degradable organic matter. In the Caspian Sea, the breakdown of pollutants further enhances the enrichment of both the water column and the sediments at the bottom with metabolic by-products, which are then integrated into the overall biogeochemical cycling within the basin.

The main sources of Biogenic Elements – especially Organic Matter from Domestic and Agricultural activities – include *river inflows, urban areas, and settlements* scattered throughout the catchment. The response of the Hydro Ecosystem to these nutrient inputs varies and depends on several Natural and Human-Induced Characteristics of the Caspian Sea, such as the makeup of *dissolved organic matter, salinity, water circulation patterns, current dynamics, bathymetry, thermal stratification, and other elements.* Long-term studies have shown that human-induced changes in nutrient loading inevitably influence the structural organization of the Marine Ecosystem. This encompasses heightened levels of Biological Productivity, alterations in the species composition of Biological Communities, disruption of Trophic Interactions, and modifications in the Physical and Chemical characteristics of the water. In every instance, Anthropogenic Eutrophication of the Caspian Sea results in an increased Trophic Status, meaning a rise in the rate of Autochthonous Organic Matter Production.

The situation in the Caspian Sea is characterized by Imbalance. It is widely recognized that naturally balanced ecosystems maintain a stable Equilibrium between the production and breakdown of Organic Matter, as well as between the Release and Consumption of Oxygen. However, the disruption of this Equilibrium in specific eutrophic areas of the Caspian Sea has resulted in various Biological and Chemical Changes. These alterations are particularly noticeable in the Aquatic Zones of river estuaries and in regions that receive continuous point-source discharges, where an Overabundance of readily Bioavailable Organic Matter from both Allochthonous and Autochthonous Sources leads to respiration rates that exceed the rate of Oxygen replenishment. This issue is especially significant in the deeper layers of the water column within the deepwater regions of all three basins of the Caspian Sea (Salmanov, 1998).

It is important to highlight that the large-scale Human-Induced Eutrophication of the Caspian Sea commenced in the northwestern and northeastern regions of the Northern Caspian during the early 1960s (Salmanov, 1968, 1987). Before this time, the process of Anthropogenic Eutrophication in the

Northern Caspian was somewhat limited due to a decrease in suspended particles and lower concentrations of mineral nitrogen and phosphorus, which resulted from the development of a series of reservoirs along the Volga and other significant rivers – a situation noted by L.A. Barsukova (1971). During the 1970s, it is significant to mention that Eutrophication in the regions surrounding the Belinskiy and Volga-Caspian shipping canals, Agrakhan-Kizlyar Bay, Makhachkala coastal area, and the western section of the Northern Caspian remained confined and primarily occurred in the summer months. In the western shelf, Algal Blooms were only detected in specific locations southeast of the Apsheron Peninsula, within the shallow waters of the Baku Archipelago, and in the Kura region of the Southern Caspian (Salmanov, 1975, 1981, 1987). Notably, by 1983, as the Eutrophication process progressed, the previously mentioned "hotspots" merged into a continuous area of phytoplankton blooms. By the early 1990s, these blooms had become a constant presence along the entire western shelf, stretching from the Volga River delta to Astara, and had expanded longitudinally to reach the midline of the deepwater Southern Caspian.

In the eastern shelf of the Caspian Sea, localized phytoplankton bloom events were documented solely in the early 1990s, mainly around Kulaly Island, the southeastern part of the Ural River delta, and the shallow coastal areas of Peschany and Sagyndyk bays, as well as near the cities of Aktau and Bektash. In the eastern region of the Southern Caspian, enhanced phytoplankton growth – lasting for almost the entire year – was noted in the vicinity of the Cheleken Peninsula, and within the Turkmen and Krasnovodsk bays, extending outward to the 200-

meter isobath along the Hasan-Kuli, Ogurchinsky, Ulsky, and Okarem cross-sections.

Table 1

Years	Phosphorus, kt		Nitrogen, kt		Silicic acid, thousand tons	Organic matter million tons
	Mineral	Organic	Mineral	Organic		
1960-1970	1.6	14,3	60,3	140,4	430,0	[illegible]
1970-1975	2,8	24,0	91,8	286,0	534,0	3,4
1976-1980	5.6	61,5	68,7	276,0	443,0	3,9
1981-1985	7.3	40,8	138,0	367,0	384,0	6,4
1986-1990	14,1	28,4	182,0	380,4	467,0	6,3

Long-term fluctuations in the flow of biogenic elements and Organic Matter from the Volga River (Astrakhan) (Katunin et al., 1992; Zenin, 1965)

As mentioned earlier, the initial Anthropogenic Eutrophication was detected in the Northern Caspian, mainly due to the discharge of the Volga River, which is rich in biogenic elements and Organic Matter (see Table 1). Nonetheless, it is important to recognize the contributions of other rivers – specifically the Terek, Sulak, and Ural – in the Eutrophication processes occurring within the river – sea interaction zones. According to Table 1, over a span of 20 years, the total discharge of phosphates, nitrogen, and Organic Matter from the Volga River has, on average, tripled. The increase in *nitrogen and phosphorus load* during this period is estimated to be around 389 thousand tons. Given the established coefficient that indicates 1 kg of phosphorus or nitrogen in the conditions of the Caspian Sea can potentially lead to the production of over 1,000 kg of bacterioplankton biomass (Sharapov, 1979), the magnitude and severity of Anthropogenic Eutrophication in the Caspian Sea become clearly evident.

It is crucial to recognize that Anthropogenic Eutrophication in the northeastern region of the Northern Caspian primarily takes place within the mixing zone of the Ural River's water mass. In this region, primary production saw an increase of 2.5 to 3 times from 1983 to 1989, reaching levels of 4.4–5 mg C/L (Salmanov, 1991). A.A. Bolshov et al. (1992) noted that most biogenic elements, such as phosphorus and nitrogen, are consumed in the lower reaches of the Ural River. However, except for the southeastern area of the Ural Depression, Eutrophication has been observed throughout the entire Northern Caspian basin. Eutrophication in the Northern Caspian has been escalating annually, leading to increased biologically and biochemically Mediated Oxygen Consumption in the water column. For instance, during the summer months from 1971 to 1983, primary production rose by 7 million tons, while the decomposition rate of Organic Matter in bottom sediments increased by 2.6 million tons.

The composition of *phytoplankton* in the Northern Caspian, both quantitatively and qualitatively, is greatly affected by the discharge volume of the Volga River, mainly due to the impact of freshwater inflow and subsequent desalination. Although the discharge volumes during 1983-1984 aligned with long-term averages, there was an increase of approximately 58 km^3 from 1985 to 1988, resulting in a salinity reduction of 2.2‰ below the mean annual values typical of the post-regulation phase of the Volga's flow.

This alteration in salinity facilitated the vigorous growth of freshwater and brackish-water phytoplankton species (Labunskaya, 1992). Table 2 provides average data for the spring–summer seasons spanning 1984-1986.

Table 2

Year	Spring		Summer	
	million cells/L	mg/L	million cells/L	mg/L
1984	2,6	2,0	5,8	2,5
1986	8,0	4,3	45,4	14,16

Phytoplankton Population and Biomass in the Northern Caspian Sea

In the spring, before the blooming conditions begin, freshwater diatoms are the primary constituents of the Phytoplankton Community, especially in areas influenced by Riverine Desalination – most notably *Stephanodiscus hantzschii*. Further to the south and southeast, as the impact of freshwater lessens, Marine Phytoplankton Species take over – such as *Skeletonema costatum, Rhizosolenia fragilissima*, and *Rhizosolenia calcar-avis*. The extensive growth of the entire Phytoplankton Community is noted during the summer months. At this time, in regions affected by river inflow, *Cyanobacteria (blue-green algae)* emerge as the main bloom-formers. In the western section of the Northern Caspian, their biomass can reach levels of 40–45 mg/L, largely due to the growth of *Aphanothece normanii f. subsalsa*.

During the blooms of *Cyanobacteria*, *green algae*, and *diatoms, filamentous chains* and *aggregates* are created, which significantly impair water clarity and reduce overall Oxygen levels.

Our studies have indicated that the resulting *colonies* and *aggregates* are primarily made up of *Phytoplankton forms* that are nearing the end of their vegetative cycle. These aggregates are frequently encrusted with or surrounded by *macroorganisms*. Importantly, millions of *Saprophytic Bacteria* were released from suspensions containing isolated *Aphanizomenon* cells (Salmanov, 1981).

It is widely recognized that Eutrophication causes significant destabilization of the Caspian Sea ecosystem, mainly due to the buildup of easily mineralizable organic compounds and a rise in the number of biodegraders. In such scenarios, both the water column and the sediments at the bottom become enriched with algal metabolites and intermediate decomposition products produced by microbial activity. During the early phases of Eutrophication, photosynthetic activities are more prominent than the degradation of organic matter. In simpler terms, gross primary production in the eutrophic areas of the sea initially surpasses one. However, as Autotrophic Biomass increases, the System undergoes a transition, and Decomposition processes start to take precedence. As a result, the heightened Oxygen Consumption by Aerobic Heterotrophs leads to a Deficiency of Oxygen. Additionally, in Hypoxic environments, further Oxygen is utilized in redox reactions that involve the by-products of anaerobic Organic Matter degradation.

It is important to highlight that the oxygen deficiency noted in the northern and central deepwater areas of the Caspian Sea, as well as in the delta and fore-delta regions and along the Dagestani coast during the summers of 1969 and 1971, was temporary in nature. Nevertheless, subsequent observations made in late summer and autumn of 1988 indicated that in parts of the Northern Caspian where phytoplankton blooms occurred, oxygen deficiency in the bottom waters continued from June until the first half of October. The possibility of the expansion and intensification of bottom-water hypoxia during the summer stagnation period has also been observed by D.N. Katanin, N.V. Ivanova, and others (1992). Their research showed that the average size of hypoxic zones in the Northern Caspian reached 7.8 thousand km^2 in June and 13.8 thousand km^2 in August.

The Anthropogenic Eutrophication of the Northern Caspian has significantly changed the hydrochemical conditions as well as the qualitative and quantitative makeup of *bacterioplankton* in both the water column and the bottom sediments. Over a span of 20 years (1968-1988), the total count of microorganisms in the surface water layers – averaged across the region – has surged by an order of magnitude in areas of persistent Eutrophication. Moreover, notable changes in the structure of the microbial community were recorded. For instance, over 80% of the Saprophytic Bacterial colonies that emerged during this timeframe were comprised of non-spore-forming types, in contrast to 1968 when they made up no more than 50%. The northern section of the Caspian Sea is shallow, and thermal stratification generally occurs only in specific areas and for brief periods. However, in the bottom layers – and often even in surface waters – of eutrophic regions, the prevalence of anaerobic forms, such as obligate anaerobes including sulfate-reducing and denitrifying bacteria, can reach concentrations of 250–500 cells/mL. It is noteworthy that as early as 1971, incidents of fish mortality (mass die-offs) were documented near the Belinskiy Canal and in the deltas of significant Volga

River branches, where Hydrogen Sulfide was found at depths of 2.4-3.6 meters in concentrations between 1.2 and 2.3 mg/L. In the sediments of these same locations, the density of anaerobic bacteria reached between 41,000 and 66,000 cells per gram.

The heightened discharge of the river – mainly from the Volga – and the resulting influx of biogenic elements along with Allochthonous Organic Matter pose an Ecological Risk not just to the exceptionally sensitive Northern Caspian region, but to the entire Caspian Sea. Indeed, concerning indicators of Human-Induced Eutrophication and its effects have been noted across the shelf zones of the sea (as elaborated below). It is important to highlight that the biogenic inflow, which has emerged as the main catalyst for Human-Induced Eutrophication, does not only lead to the overgrowth of phytoplankton and the creation of substantial bacterioplankton biomass. Significantly, the shift from aerobic degradation of dissolved Organic Matter – both Autochthonous and Allochthonous – to anaerobic processes has two critical consequences: firstly, it diminishes the rate of Organic Matter breakdown; and secondly, it promotes the release of phosphorus from sediment into the euphotic layer, thus boosting photosynthetic activity. Collectively, these processes exacerbate the disparity between Synthesis and Degradation, driving the system towards a Hypertrophic Condition and resulting in organic pollution within the marine environment.

As previously mentioned, the bulk of Biogenic Inflow reaches the Northern Caspian, where it is primarily integrated into the biotic cycle. The biomass resulting from both primary and secondary production includes *phosphorus, nitrogen, and* *various other biogenic elements*. Consequently, when predicting the Organic Matter Balance and evaluating the extent and impacts of Anthropogenic Eutrophication in the Northern Caspian – and the Caspian Sea overall – it is crucial to consider the internal reserves of the Sea itself. To understand the importance of this aspect, it suffices to note that the Phosphorus Concentration in the dry biomass of Bacterioplankton and Phytoplankton is approximately 2% and 0.6%, respectively (Kuznetsov, Romanenko, Kuznetsova, 1974; Bylinkina, 1980). Therefore, taking this into account, along with the regeneration of biogenic elements and their ongoing supply through river discharge, it becomes clear that Anthropogenic Eutrophication in the Northern Caspian is nearing an almost irreversible condition. Additionally, with the increase in Biological Oxygen demand and the growth of Hypoxic zones, it can be inferred that the Ecological Situation in the Northern Caspian is critical.

In the Central Caspian, Anthropogenic Eutrophication processes have been observed almost everywhere. These processes are particularly pronounced along the Western Shelf, where they lead to increased Biological Consumption of dissolved oxygen (Table 3).

It is important to highlight that the Eastern Shelf of the Central Caspian was historically marked by a lack of Mineral Nitrogen and Phosphorus Compounds. For example, during the 1960s and 1970s, from early spring to autumn, no detectable levels of Nitrate, Nitrite, or Phosphate were found in the water (Salmanov, 1968, 1987). In contrast, since 1983, even during the active growth period of *bacterioplankton*, average concentrations of Nitrogen and Phosphorus in these areas have consistently ranged from 28 to 50 µg/L.

Furthermore, there has been a rise in the annual average concentrations of these elements. For instance, when comparing 1988 to 1992–1993, nitrogen and phosphorus levels in areas south of Bautino increased by a factor of 2.5–3, nearly reaching the Southern Caspian boundary. Consequently, the eastern shelf of the Central Caspian has seen significant phytoplankton growth, achieving bloom stages that were previously uncommon in this area. It is important to note that Algal Blooms are more intense and last longer in the coastal waters of Bautino–Eraliyevo. In the southern and western parts of the central sector, the mass proliferation of bacterioplankton remains relatively low. It is typical for phytoplankton blooms to commence in early spring with a significant increase in diatoms, continuing until late autumn. During the summer months, these blooms also include cyanobacteria and green algae, especially in the western regions. Over a span of 20 years (1969–1989), the average annual phytoplankton production in the western shelf quadrupled, reaching 8.5–9.1 gC/m^2 per day, while the Organic Matter decomposition rate increased from 0.58 to 1.96 mg C/L per day, respectively. These alterations are even more significant on the eastern shelf–in the Urdjuk-Eraliyevo region–where, over a 30-year span (1964–1993), primary production surged by an order of magnitude, and the Organic Matter decomposition rate in the water column rose more than sixtyfold.

Table 3

Cross-section	1963	1968	1975	1981	1988	1997
Makhachkala	2,3	2,6	3,7	6,6	7,4	12,3
Kaspiysk	2,4	3,4	4,8	7,9	8,4	9,7
Izberbash	1,4	3,2	3,8	6,4	7,3	8,8
Derbent	3,1	4,1	5,3	8,4	7,9	11,7
Samur	3,3	4,4	5,6	9,4	10,3	14,7
Khudat	0,6	0,9	3,6	5,8	7,4	10,3
Khachmaz	0,9	1,3	4,2	8,3	9,6	12,1
Yalama	0,7	0,9	1,9	3,8	6,2	9,7
Kilyazi	0,6	1,3	2,0	4,3	6,3	8,6
Average	1,7	2,5	4,0	6,8	7,9	10,1

Average Daily Rates of Organic Matter Decomposition (g C/m²) Throughout the Summer Season

In the central region of the Middle Caspian, the average annual Photosynthetic production of *phytoplankton* rose by 70% during the same timeframe, while the decomposition rate of Organic Matter – both in the water column and in bottom sediments – has doubled.

As previously highlighted in earlier sections, there has been a notable change in the sea's oxygen regime, especially in its deeper zones. This change is mainly due to the mineralization of organic matter. The findings from the dissolved oxygen measurements are shown in Table 4.

Table 4

Depth, m	1965	1975	1985	1995
0,5	9,1	9,0	9,3	9,6
50	8,4	7,3	7,1	6,8
100	7,3	6,8	6,3	6,0
150	6,9	6,3	6,0	5,4
200	6,2	5,7	5,3	5,0
300	6,0	5,3	5,0	4,4
400	5,8	5,0	4,7	4,0
500	4,6	4,2	4,0	3,3
600	4,2	3,9	3,6	3,0
700	3,3	3,1	2,7	2,0
780	2,9	2,6	1,8	1,1

Variations in Dissolved Oxygen Levels (mg O_2/L) in the Deepwater Zone of the Middle Caspian (Station 5, Khachmas–Bektash Cross-section) Throughout the Summers of 1965, 1975, 1985, and 1995

In the western shelf of the Caspian Sea, extending from the Sumgayit coastal zone to the Alyat area, at depths of 25-35 meters (isobaths), the extensive growth of phytoplankton, as well as phyto- and zoobenthos, has been inhibited for more than 30 years. The main factor contributing to the decline of the dominant species of lower flora and fauna in this area has been widespread pollution, as elaborated in the relevant sections. However, significant Anthropogenic Eutrophication is also present in the Southern Caspian. In this region, the process remains stable primarily in designated contact zones, which have a continuous link with the inflow of polluted waters. The nature of Eutrophication in the western part of the Southern Caspian is markedly different from that in the Middle Caspian, as the area of maximum phytoplankton growth has migrated to deeper offshore regions. It is important to note that phytoplankton decline in relatively shallow waters has been recorded in the Sumgayit, Pirallahi, Shikhov, and Karadag – Alyat cross-sections. In the Kura, Kur-Kosin, Lankaran, and Astara sectors, Anthropogenic Eutrophication – similar to that observed in the Middle and Northern Caspian – has started to develop in coastal regions. Additionally, it is significant that in areas where the physiological activity of algae is diminished, both the population of microorganisms and the rate of biological oxygen consumption in the water column reach their peak levels. Long-term studies of Phytoplankton primary production in the Western Shelf indicate that the foundation for overall Biological Productivity in this area develops under quite complex ecological conditions.

Between the 10-25 m isobaths – from the Sumgayit transect to the Ust-Kura region – phytoplankton degradation was consistently observed from 1960 to 1989. During this timeframe, the total number of microorganisms in these sections of the Caspian Sea increased by a factor of 2-4, while the population of Saprophytic Bacteria surged by 5-10 times. Additionally, a general rise in the biological consumption of dissolved oxygen was noted across the region (refer to Table 5). Importantly, in the waters of Baku Bay, the Shikhov coastal zone, and the Kura area, dissolved oxygen levels are completely depleted within 8-18 hours.

Table 5

Section Site	Direct count				Saprophytic Bacteria				BOD_1 (Biochemical Oxygen Demand (1-day))			
	1962	1972	1982	1992	1962	1972	1982	1992	1962	1972	1982	1992
Baku Bay	4,80	8,40	14,80	18,10	4,60	11,00	19,00	34,00	4,60	6,70	7,40	9,00
Shikhov	3,20	4,90	8,10	9,20	2,70	6,60	14,00	23,00	3,20	4,10	5,20	6,30
Sangachal	2,60	2,90	3,60	4,30	1,60	2,00	3,40	7,80	1,40	1,60	2,30	3,20
Alat	3,10	3,80	4,10	5,30	2,70	3,60	4,70	8,40	1,20	1,40	1,70	2,90
Kura River Delta (or: Mouth of the Kura River)	9,40	11,00	16,00	21,00	5,90	8,70	11,40	23,40	4,30	5,70	7,40	8,60
Lankaran	2,90	3,80	4,90	6,30	1,40	2,30	4,40	6,80	2,20	2,70	3,30	4,20
Astara	2,10	2,90	3,70	4,80	1,30	1,60	1,80	9,60	2,10	2,80	3,7	4,40
Average	4,00	5,60	7,90	9,90	2,80	5,10	8,40	16,10	2,70	3,60	4,50	5,50

Long-Term Variations in Total Microorganism Abundance (million/mL), Count of Saprophytic Bacteria (thousand/mL), and Water Oxygen Consumption as BOD_1 (mg O_2/L per day) during Summer

In the western shelf of the Southern Caspian, Human-Induced Eutrophication has been on the rise, especially in regions south of the Kura River estuary. In this area, persistent Algal Blooms have been spreading southeastward into the central deepwater basin, where, by 1997, both the average daily primary production rate and oxygen consumption had surged tenfold compared to 1982. In the Eastern Shelf of the Southern Caspian, these phenomena have become almost irreversible, particularly in the regions south of Turkmen Bay. Throughout the year, the waters near Hasan-Kuli show significant phytoplankton growth and rapid changes in the composition of dominant species. While from 1983 to 1986 the extent of Algal Blooms was confined to the 25-30 m isobaths, by 1987 it had expanded to the 200–250 m isobaths, moving northwest and north toward the Ulsky–Ogurchinsky cross-section. Interestingly, in the Eastern Shelf of the Southern Caspian, the Anthropogenic Eutrophication process has progressed from both the Turkmen Bay in the north and the Hasan-Kuli area in the South, effectively converging from opposite directions. In this area, Oxygen Deficiency in bottom waters was first noted in the summer of 1986 at a depth of 120 meters in the border zone with the Islamic Republic of Iran. In the following years, Hypoxic conditions spread over a much larger area of the Central Basin, extending Westward and Northeastward. In the western part of the Southern Caspian, the Hypoxic Zone now includes the entire water area of the Small Kyzylagach Bay, the slope region of the Kura depression, and the Western Section of the deepwater basin.

It is important to note that before 1975, dissolved oxygen was found throughout the entire water column, including the bottom layers, in the open waters of the Southern Caspian. For example, in water samples collected from the deepest zones (900–996 meters), Oxygen Levels varied from 1.9 to 1.6 mg O_2/L, respectively. The presence of Hydrogen Sulfide – identified by its odor and black coloration – in sediments accounted for no more than 18-22% of a hundred samples gathered. In contrast, in 1996, Hydrogen Sulfide was found in 43 out of 56 sediment samples.

The ongoing Hypoxia in the deepwater zone of the Southern Caspian is demonstrated by the fact that factors such as vertical stagnation, water exchange, and thermal stratification do not aid in the replenishment of oxygen in bottom waters. Findings from winter surveys conducted in 1972 and 1995 confirm that hypoxic conditions in the deep zones have become a permanent issue, persisting even during the colder months. There is no doubt that this situation is a direct result of Eutrophication and represents a significant threat to the ecological health of the Southern Caspian Sea.

The ecological impacts of Human-Induced Eutrophication in the Caspian Sea are also evident in the shallowing of the *trophogenic* layer in areas affected by blooms and in the rapid growth of *anaerobic bacterial communities*.

Numerous assessments of water clarity carried out over time and across various regions have shown that, in the last two decades, the depth of the euphotic zone in the Northern, Middle, and Southern Caspian Sea has diminished by an average of 1.2, 2.5, and 3 meters, respectively. At the same time, a change in the depth of thermal stratification has been noted: in the Middle and Southern Caspian, the thermocline has ascended by 3 to 5 meters compared to its usual historical level.

Significantly, the biomass of *bacterioplankton* within the thermocline has risen considerably. In the 1960s and 1970s, the quantity of *Saprophytic Bacteria* in the thermocline layer was 35-40% greater than that in surface layers; however, data from 1987, 1993, and 1997 reveal that their concentration now exceeds that of heterotrophs in surface waters by 1.5 to 2 times. Clearly, the 40% rise in oxygen consumption within the water column is linked to increased microbial activity–particularly, the mineralization of organic matter.

It is important to highlight that anaerobic bacteria–such as *denitrifying, sulfate-reducing, methanogenic, and anaerobic* *cellulolytic bacteria*–were historically isolated from sediment samples. They were generally not found in the water column, except in specific, heavily polluted bays and inlets (Salmanov, 1970, 1972, 1987). Nevertheless, in the last 8–10 years, these bacteria have emerged as common constituents of the *bacteriocenosis* in the bottom water layers at depths exceeding the 75-100 meter isobaths. Furthermore, it has been demonstrated that increased primary production and heightened rates of Organic Matter decomposition – resulting in a corresponding decline in oxygen saturation – positively influence both the abundance and diversity of anaerobic bacterial communities in the Caspian Sea.

Source: "Ecology and Biological Productivity of the Caspian Sea." Baku, "Ismail" Publishing house, 1999, pp. 332-346.
Author: M.A. Salmanov

2.11 STRATEGY FOR ENVIRONMENTAL MONITORING IN THE CASPIAN SEA

Marine oil production in the Caspian Sea commenced in 1824, specifically in the Absheron Peninsula region. Prior to this, oil was extracted from shallow wells near Baku, which accessed surface layers. In the 1890s, industrial drilling of inclined wells reaching up to 200 meters offshore was conducted along the coasts of California and Virginia (USA). The initial offshore drilling platforms and piers were established in the 1920s off North America's coast, in the Caribbean, and in various other locations. In 1934, cluster drilling was introduced in the Caspian Sea close to Pirallahi Island (Baku), and by 1935, the first offshore steel structure for drilling was erected there. By 1972, a total of 1,880 steel platforms and causeways had been built in the Caspian Sea (Orujev, 1974). Since that time, Oil Pollution along the Caspian coastline has been noted, negatively impacting both the diversity and population of Marine Life. Consequently, the implementation of advanced technologies in oil extraction within the Caspian was initiated to safeguard valuable fish populations. Thus, it is essential to focus on the ecological consequences of Human Activities during offshore oil extraction in the Caspian Sea. It is vital to avert adverse impacts of offshore oil operations on the biological resources of the Caspian, particularly given that around 90% of *hydrobionts* reside in the Coastal Zone that extends up to 250 km from the shore. Clearly, Oil Pollution inflicts considerable damage on aquatic organisms, resulting in reduced productivity and fish yields. As noted by Patin (1997), the following *pollutants* have an impact on *Marine Ecosystems* and *hydrobionts*:

1. *Pollutants* with mechanical impacts include suspended solids, surface films, solid waste, and more. These materials harm respiratory, digestive, sensory organs, and various other systems.

2. *Eutrophication-causing substances* consist of mineral compounds of nitrogen and phosphorus, organic matter, etc. These result in extensive phytoplankton blooms, leading to ecosystem dysfunction.

3. *Substances* with saprobic effects, such as wastewater rich in easily degradable organic matter, lead to oxygen depletion, fish mortality, and other adverse phenomena.

4. *Toxic substances*, including heavy metals, chlorinated organic compounds, dioxins, and furans, adversely impact reproduction, feeding, and respiration in Marine Life.

5. *Mutagenic substances* like benzo[a]pyrene, other polycyclic aromatic hydrocarbons, radionuclides, and various mutagens induce carcinogenic, mutagenic, and teratogenic effects. Oil and petroleum products are classified as complex group toxicants, exhibiting both toxic and mechanical effects on living organisms.

Almost every phase and operation of Hydrocarbon Exploration and Extraction generates discharges of *liquid, solid, and gaseous waste,* which negatively impacts marine biological resources. Drilling activities release significant amounts of drilling fluids and cuttings. Among these, oil-based drilling fluids pose particular risks to marine *hydrobionts.* Cuttings that are saturated with such fluids have severe detrimental effects on marine organisms.

Another contributor to marine pollution is the formation of sand *(oil sludge)*, which is obtained alongside Crude Oil. Typically, this sand is treated to remove oil before being released into the sea; in certain instances, it is burned or taken to land for proper disposal.

During the drilling and oil extraction processes in the Caspian Sea, the bottom sediments and seawater become contaminated with drilling sludge. A significant quantity of Persistent and Toxic Hydrocarbon Compounds, along with other dangerous substances, is released into the Marine Ecosystem. Research indicates that the amount of drilling waste discharged into the sea is approximately 1,000–5,000 m^3 for each well drilled. For instance, in the North Sea, 22,000 tons of oil, in addition to 100,000 tons of chemical additives and 4,900 tons of potentially harmful substances (including biocides, corrosion inhibitors, detergents, demulsifiers, oxygen scavengers, etc.) were released into the marine environment solely through drilling muds (Davies, Kingston, 1999).

Each chemical used in drilling operations serves one or more Chemical-Technological purposes. For example, Barite is utilized to manage and regulate Hydrostatic pressure within the borehole; emulsifiers, along with sodium and calcium chloride solutions, assist in maintaining an isotonic balance between the drilling zone, the reservoir formation, and the circulating drilling fluids. To avert corrosion of drilling pipes, substances such as *sodium sulfite, ammonium bisulfite, zinc carbonate*, and other *inhibitors* are introduced into the borehole.

In addition to hydrocarbon pollution, particular concern is caused by *biocides*, which are used to suppress microbial activity in drilling fluids and pipe circulation systems. Among them, water-based drilling fluids – prepared with seawater or freshwater and additives such as c*austic soda* and *other reagents* – are considered the safest. However, all drilling waste contains elevated concentrations of *heavy metals (mercury, lead, cadmium, zinc, chromium, copper, etc.),* which accumulate in these wastes.

Formation waters also have a detrimental impact on *marine hydrobionts*. These waters contain *dissolved salts, organic compounds, petroleum hydrocarbons, heavy metals, suspended solids,* and *drilling reagents*. Moreover, formation waters may mix with extracted oil, gas, and with injected seawater during extraction processes. For example, formation waters from oil fields in the Gulf of Mexico were found to have high concentrations of *benzene* and *toluene* (10–31 mg/kg) and *corrosion inhibitors* (Davies, Kingston, 1999). In the Tengiz oil field in the Northern Caspian region, the content of petroleum products in formation water exceeds 25 g/L (Stradomskaya, Semenov, 1991).

Formation waters naturally contain radionuclides like *radium-226 and radium-228*. Over time, these *radionuclides* can accumulate and form localized areas of Radiological Risk.

In general, drilling and oil extraction operations in the Caspian Sea lead to the discharge of various toxic substances into the Marine Ecosystem, ultimately disturbing the Biological Equilibrium in the shelf zone and resulting in reduced fish catches. Thus, it is crucial to devise new strategies to prevent and alleviate the adverse effects of oil and gas extraction on Marine Life.

Oil contamination in the marine environment consistently raises alarms due to its potentially detrimental impacts on marine plants and animals. Toxic levels that can lead to mortality – especially in *fish eggs, larvae, and young marine creatures* – are usually lower than those that affect adult organisms. The early stages of Development are particularly susceptible to Oil Pollution, although adult organisms undergoing Morphological and Physiological Changes can also be significantly affected.

Ecotoxicological research indicates that lethal impacts of oil on *macrobenthic* organisms occur when Oil Concentrations in bottom sediments are between 1,000 and 7,000 mg/kg. In contrast, sublethal and threshold effects manifest at concentrations ranging from 100 to 1,000 mg/kg. For the most Toxic Components and Fractions of Oil, particularly *polycyclic aromatic hydrocarbons* (PAHs), such effects can occur at even lower concentrations, specifically between 10 and 100 mg/kg (Patin, 1997). Benthic and Demersal fish species residing in contaminated bottom sediments are especially susceptible. At PAH concentrations in sediments as low as 3-5 μg/kg, bottom-dwelling fish may exhibit visible signs of tissue and organ damage, including *tumors* and other *carcinogenic* or *mutagenic* conditions. The upper limit of the no-effect (safe) concentration zone for dissolved petroleum hydrocarbons in seawater is estimated to be approximately 10^{-3} mg/L. The concentration range from 10^{-3} to 10^{-2} mg/L can be conditionally classified as a zone of reversible threshold effects. Within this range, no significant biological impacts are generally observed in marine environments. Therefore, this interval can be viewed as intermediate between no-effect levels and the zone of clear sublethal effects. Consequently, acceptable concentration limits for *petroleum hydrocarbons* in marine water should be within the 10^{-3} to 10^{-2} mg/L range. For fishery water bodies, the *maximum allowable concentration* (MAC) for dissolved petroleum products is set at 0.05 mg/L. However, there is a current proposal to reduce the MAC for dissolved petroleum hydrocarbons in seawater to 0.01 mg/L (Patin, 1997).

On September 20, 1994, the initial oil contract was executed in Baku for the development of the Chirag, Azeri, and Gunashli oil fields, encompassing a total area of 432.4 km². Subsequently, agreements were made for additional fields, such as Karabakh (1996), Shah Deniz (1996), Dan Ulduzu and Ashrafi (1997), along with Lankaran-Deniz, Talysh-Deniz, Kurdashi, Oguz, Nakhchivan, Alov, and others.

In the Azerbaijani sector of the Caspian Sea, from 1990 to 2001, oil production varied between 1,234.57 to 6,919.4 thousand tons, with Chirag contributing 85.2% of the total offshore oil production. The *State Oil Company of Azerbaijan* (SOCAR) produces about 1,821.4 thousand tons annually, which represents 14.76% of all oil extracted from the sea. Oil loss during offshore operations is estimated to be around 1.17-1.34 thousand tons, while onshore losses are approximately 0.39 thousand tons. Consequently, some crude oil inevitably enters the marine environment, adversely impacting fish populations and their food organisms.

Thus, oil companies need to focus on environmental monitoring, both after drilling operations and during extraction activities. Considering that nearly 90% of the Caspian Sea's aquatic organisms reside in areas close to offshore oil fields, ongoing environmental monitoring in these areas is crucial.

In the Caspian Sea, native species are predominant in terms of biodiversity. These species exhibit a high sensitivity to oil pollution. The activities of oil exploration and extraction in the Caspian Sea have the potential to severely disrupt the Ecosystem in the Shelf Zone, possibly leading to the decline or extinction of important commercial fish species, particularly *sturgeon, herring,* and others.

Environmental monitoring serves as a Crucial Subsystem of Comprehensive Environmental Oversight. It includes the Observation, Assessment, and Prediction of Human-Induced Changes in the Ecological conditions of oil extraction areas throughout the entire duration of Offshore Field Development. The aim is to avert critical situations, such as excessive levels of *oil, petroleum products, chemical agents*, and other *hazardous substances* in the water, as well as Air Pollution that exceeds acceptable limits, all of which threaten Human Health and Marine Life, including *fish, forage invertebrates, the Caspian seal,* and *bird populations*. To tackle these issues, it is essential to gather multi-faceted data through both seasonal and one-time surveys. This necessitates the creation of an *environmental management system,* which should be a vital part of the Overall Management Strategy for oil extraction at specific offshore fields. The foundation of such a system is the Environmental Monitoring of the surrounding ecosystem. It is widely recognized that the majority of oil wells are situated near the migratory paths of valuable fish species, such as *sturgeon* and *herring*, as well as routes utilized by *migratory waterbirds*. These include species that winter along the Azerbaijani Caspian coast (e.g., *red-crested pochard, mute swan, great white pelican*) and others that breed in the area (e.g., *little gull, common tern*).

The migratory paths of various species of migratory birds – such as flamingos, greylag geese, ducks, northern shovelers, white-winged scoters, and others – also traverse areas near oil platforms and derricks.

Given this situation, it is essential to perform environmental monitoring prior to and following drilling activities, as well as during the process of oil extraction, focusing on the following parameters stated below:

Dissolved oxygen levels

Seafloor sediments

Hydrocarbons

Heavy metals

Phytoplankton

Zooplankton

Macrobenthos

Bird populations

Fish and seals

Atmospheric emissions

Radiological (radionuclide) contamination

In evaluating the risks associated with marine pollution, it is crucial to take into account not only the toxic characteristics of pollutants but also: the quantities released into the Marine Ecosystem; the routes and extent of their spread; their behavior and transformation in seawater; and their potential for bioaccumulation in Marine Life.

He has delivered numerous presentations at international scientific conferences and is currently engaged in research on the ecological characteristics of water resources across different regions of Azerbaijan.

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