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GEOGRAPHY

Geological–Geomorphological Structure and Recent History of the Iranian Coast of the Caspian Sea

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The Iranian coast of the Caspian Sea is an element of the South Caspian Depression, which represents a spacious plain with a subtropical climate bordered in the south by the Elburs mountainous system. Its western, central, and eastern parts bear different names: Gilyan, Mazandaran, and Golestan plains, respectively. In structural terms, this region represents the Elburs foredeep filled with a thick sequence of Neogene–Quaternary sediments and separated from the Elburs fold system by a deep-seated regional fault.

The structure and development history of the Iranian coast are insufficiently investigated [4, 9]: all the available publications are mostly dedicated to their particular geological aspects [1–3, 5–8, 10–14]. The materials discussed in this communication were obtained on the Iranian coast of the Caspian Sea in 2005 and 2011 (Fig. 1). These investigations provided extensive data on the geomorphological structure and lithology of recent sediments.

GEOLOGICAL–GEOMORPHOLOGICAL STRUCTURE

The Iranian coast of the Caspian Sea is a spacious slightly seaward inclined lowland extending for over 600 km in the latitudinal direction and ranging from 1 to 60 km wide in its central part and in the Sefidrud and Gorgan river delta areas, respectively. The maritime part of this lowland represents a marine plain with altitudes of 27 to –20 m complicated by poorly expressed terraces and separated from the present-day beach by a system of coastal bars that surround lagoons. In the west and east, these coastal bars form large nehrungs, which separate Enzeli Lagoon and Gorgan Bay from the sea. In its central part, the lowland surface (aggradational [4]) is characterized by altitudes ranging from 0 to –20 m. Its southern part is marked by a narrow band of low foothills with local relicts of poorly expressed terraces and cliff. The maritime plain is covered by young lithology-variable sediments.

Based on the complex analysis of the available materials including the stratigraphic position of sediments in the section, the general geomorphological and hypsometric situation, the composition of molluscan fossils, the lithological–facies features, the radiocarbon age estimates, and the stratigraphy of sediments in neighboring well-studied areas of the Caspian Sea coast, the sedimentary section in the region under consideration is subdivided into the Khvalynian and Novocaspian horizons (Fig. 2).

The Khvalynian Horizon comprises the lower and upper Khvalynian beds. The lower Khvalynian beds form a thin marine-deposition cover of abrasion terraces on low foothills at altitudes of 15 to 50 m [4, 9]. The beds are characterized by a variable lithological–facies composition: clayey, sandy, and gravely–sandy sediments with the dominant role of red–brown clayey–silty varieties characteristic of the Khvalynian section through the entire Caspian region. They are barren of molluscan shells, although some authors note *Didacna* finds [9]. These sediments are underlain by coarse-grained alluvial–proluvial facies. The upper Khvalynian beds constitute the basal part of the section in the back part of the coast, where they crop out in walls of river valleys. Similarly to the lower Khvalynian strata, these sediments are barren of molluscan fossils, being darker and coarser. Based on radiocarbon dates available for Khvalynian sections in other areas of the Caspian region [6], the age of the lower and upper Khvalynian sediments in the Iranian coast may be estimated as ranging from 16.0 to 11.5 and from 8.2 to 7.2 ka, respectively.

The Novocaspian Horizon includes the Mangyshlakian, Dagestanian, lower and upper Novocaspian, and Recent beds. The Mangyshlakian Beds, which reflect the significant Caspian Sea regression, are widespread on the Iranian coast constituting the surficial part of the maritime plain section (upper 0 to –20 m).

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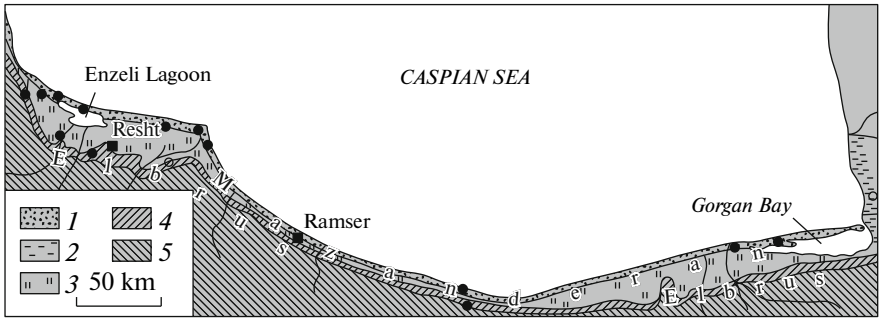

Fig. 1. Iranian coast of the Caspian Sea. (*1*) Novocaspian terrace with recent beach; (*2*) desiccated shores; (*3*) late Khvalynian alluvial–proluvial–marine plain; (*4*) piedmonts with dominant early Khvalynian terraces; (*5*) mountainous relief. Dots indicate sites of complex investigations.

With respect to their lithological–facies composition, these sediments are dominated by coarse-detrital alluvial and alluvial–proluvial varieties, which fill buried river valleys and form spacious fans overlying the terraced surface of the late Khvalynian plain. Noteworthy are frequent finds of large differently rounded boulders of Elburs bedrocks. The subordinate role belongs to loess-like and eolian facies and buried soils.

The Dagestanian Beds of the section are conditionally defined proceeding from their occurrence at the base of marine Novocaspian sediments and lack of *Cerastoderma glaucum*. They are represented by gray–lilac sands with whole *Didacna cristata* shells, which grade laterally into compact caked pant remains overlying Mangyshlakian boulder gravel with pebbles.

The lower Novocaspian Beds are developed at altitudes of –25 to –20 m. They are composed of lithology-variable terrigenous sediments with intercalations of organogenic mud with plant remains and indications of insignificant hiatuses in the form of buried soils and eolian sediment reworking. These beds yielded several close radiocarbon dates of approximately 2.4 ka [12]. The upper Novocaspian Beds were developed in the coastal part of the plain at altitudes of –25 to –26 m, where they constitute a low marine terrace and nehrungs that separate lagoons from the sea. These sediments yielded radiocarbon dates ranging from 0.3 to 1.0 ka [7, 12]. Recent sediments were deposited in the transitional shore–sea zone being represented by beach, abandoned cliff, river channel and floodplain facies, eolian varieties, and soils.

As a whole, the Novocaspian section of the Iranian coast is characterized by a uniform lithological–facies composition with dominant marine, fluvial, eolian, and pedogenic sediments. Marine facies are the most diverse being represented by coastal-marine (facies of shoals with calm low-energy hydrodynamic environments and beach) and lagoonal sediments. The lagoonal sediments are recorded at different hypsometric levels being most frequent at altitudes of –20 to –22 m and –25 to –26 m in basal parts of the lower and upper Novocaspian beds, respectively.

The Novocaspian sediments are saturated with paleontological remains. They contain 11 molluscan species of the Cardiidae family with representatives of the genera *Didacna* Eichw. and *Cerastoderma* Poll. being most abundant. The first genus is an endemic taxon for the Caspian Sea, which is characterized by rapid evolutionary development at the species and subspecies levels. The second genus is represented by immigrants from the Black Sea, which are characterized by a Mediterranean origin and which colonized the Caspian Sea during the Holocene Novocaspian epoch. The Novocaspian molluscan assemblages differ from their coeval counterparts populating other Caspian coasts (Table 1) by the dominant role of crassoid *Didacna* representatives, in addition to *Cerastoderma glaucum*, and the occurrence of species indicating slightly brackish-water environments.

The species cited in the table form the Novocaspian molluscan fauna. The analysis of their bed-by-bed distribution through the section (Table 2) shows that they form three assemblages: Dagestanian, Novocaspian, and Recent. The Novocaspian assemblage is represented by two subassemblages, which occupy different stratigraphic positions in the section.

The defined fossil different-composition and different-rank assemblages combined with complex data on sediment lithology provide the basis for stratigraphic subdivision of sections and paleogeographic reconstructions of the Iranian coast of the Caspian Sea.

Recent History of the Iranian Coast of the Caspian Sea

The South Caspian Depression, which includes the Iranian coast, existed as early as the Pliocene, when it was flooded by the Akchagylian and Apsheronian transgressions. The recent geological history of the coast corresponds to the terminal late Pleistocene–Holocene marked by the formation of the present-day coastal topography. It includes several substantially different stages: Khvalynian, Mangyshlakian, Novocaspian, and Recent.

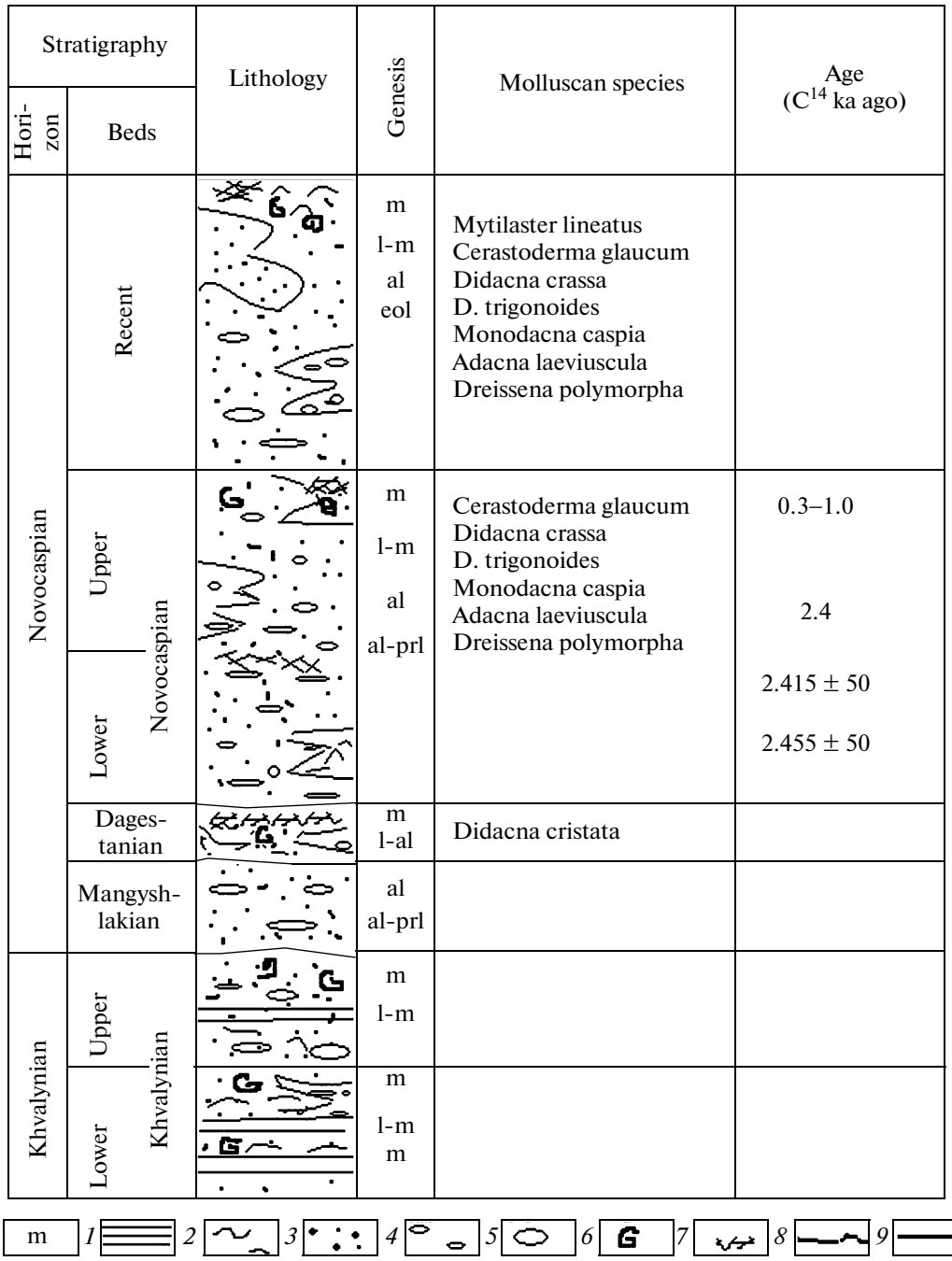

Fig. 2. Composite section of Recent sediments in the Iranian coast of the Caspian Sea. (*1*) Genesis of sediments: (m) marine, (l-m) lagoonal, (al) alluvial, (al–pr) alluvial–prolluvial, (eol) eolian; (*2*) clay; (*3*) silt; (*4*) sand; (*5*) gravel pebble; (*6*) boulders; (*7*) shells; (*8*) plant remains; (*9*) erosional surface (hiatus); (*10*) facies transition.

The *Khvalynian stage* (terminal late Pleistocene–initial Holocene) includes the early and late Khvalynian epochs. During the early epoch, the entire coast and low foothills up to altitudes of +50 m were flooded by the early Khvalynian transgression. The latter produced a system of abrasion terraces at altitudes of 14, 25, 35, and 48–50 m [4, 9] with a thin marine-deposition cover and well-developed cliff with surf niches. Judging from the lithological–facies composition of marine sediments and their position in the section, the coastal zone of the Khvalynian sea was characterized by calm depositional environments with accumulation of mud and clays in lagoons, which were subsequently replaced by high-energy hydrodynamic conditions of the shoal (pebble gravel, sands).

The next epoch corresponded to the late Khvalynian transgression, which flooded the entire maritime plain to altitudes of 0 m. It was separated from the previous transgression by a short erosion episode, which is reflected in the incision subsequently filled

Table 1. Molluscan fossils from Novocaspian sediments from different areas of the Caspian basin

Molluscan species	Area of the coast								
	South-western	Apsheron Peninsula	Western		North-western	Northern	Eastern	South-eastern	Iran
			Azerbaijan	Dagestan					
D. crassa									
D. baeri									
D. barbotdemarnyi									
D. longipes									
D. trigonoides									
D. pyramidata									
D. praetrigonoides									
D. parallella									
D. cristata									
D. protracta									
D. profundicola									
Monodacna caspia									
Adacna vitrea									
A. laeviuscula									
Hypanis plicatus									
Cerastoderma glaucum									
Mytilaster lineatus									
Dreissena polymorpha									
Dr. rostriformis									
Dr. caspia									

Note: Color intensity indicates the relative abundance of particular species in sediments: the more intense the color, the higher the abundance.

with river alluvium, and formation of deltas. The upper Khvalynian sediments outcropping in the back part of the maritime plain at altitudes of –20 to –40 m imply that at the transgression onset they accumulated mostly in calm relatively deepwater environments of estuaries and lagoons, which subsequently gave way to shallow-water high-energy hydrodynamic conditions at the end of the depositional process. The late Khvalynian surface is terraced [9]. At the same time, due to universal development of the Mangyshlakian alluvium, terraces are practically indistinguishable in the present-day topography except for that reflecting the maximal transgression.

A remarkable feature of Khvalynian sediments developed on the Iranian coast is the absence of molluscan shells in them. All along the coast of the Caspian Sea, Khvalynian sections are recognizable and divisible based on molluscan assemblages [6]. On the Iranian coast, thorough examination of coeval sections was in vain. What factors could suppress molluscan development on the Iranian coast during the Khvalynian transgression, which reached the Elburs piedmonts? It is clear that coastal areas of the basin received fresh cold waters at that time, which deteriorated the ecological conditions of the *Didacna* habitat, although no brackish-water and freshwater molluscan species were found either. It is conceivable that the fine-grained composition of Khvalynian sediments and their high accumulation rates were largely responsible for suppression of molluscan assemblages.

The *Mangyshlakian stage*, lasting from 7.2 to 6.4 ka, was extremely important for the formation of the Iranian coastal topography. During this regressive epoch marked by the sea level fall by 100 m, the practically entire Caspian shelf became desiccated and subjected to intense erosion, which resulted in basin deepening and widening. When regression terminated, the valleys were filled with coarse-detrital alluvial and proluvial material. After their filling, such coarse-detrital sediments formed fans of mountainous rivers, which prograded to watershed areas. This process resulted in development of the continuous cover of coarse-grained fluvial sediments over the desiccated surface of the late Khvalynian plain up to altitudes of 0

Table 2. Assemblages and subassemblages of the Novocaspian molluscan fauna from the Iranian coast

Molluscan species	Beds			
	Dagestanian	Lower Novocaspian (−24 to −20 m)	Upper Novocaspian (−24 to −25 m)	Recent
D. crassa				
D. trigonoides				
D. pyramidata				
D. praetrigonoides				
D. cristata				
Monodacna caspia				
Adacna vitrea				
A. laeviuscula				
Cerastoderma glaucum				
Mytilaster lineatus				
Dreissena polymorpha				
Complexes	Didacna cristata	Cerastoderma-Didacna		Mytilaster-Cerastoderma
Subcomplexes		Didacna-Dreissena	Cerastoderma-Didacna cristata	

Note: See Table 1.

m. The sole exception is the Astara area, which retained a partially water-filled lagoon.

As was mentioned, the coarse-detrital Mangyshlakian sediments include many large boulders up to 1.0–1.5 m across. These relatively well rounded blocks are characterized by variable lithology (from metamorphosed rocks and granites to recrystallized limestones and sandstones of Elburs) are distributed from low foothills to the sea shore. Where do these rock blocks come from and how they were transported? The first speculative explanations imply glaciers, pack ice, and river transport. At the same time, the analysis of these boulders shows that they have another, not fluvial or glacial origin. The foothills and maritime plain are lacking indications of young glacial activity. Practically no floating ice, which would be able to transport coarse-detrital material from mountains and their piedmonts through the basin, occurred on shoals of Holocene seas in the subtropical zone. Such an idea is also inconsistent with the roundness of boulders. It is conceivable that these boulders resulted from a combination of two processes: gravitational landslide and mudflows. They both supplied rock blocks to channels of large rivers, which transported them through the maritime plain toward the seashore. These blocks were transported by rivers during strong floods along the northern slope of the Elburs Mountains. The downward movement of boulders with simultaneous rounding was probably determined by the removal of pebbly material from under them and powerful pressure of the water flow. These processes lasted hundreds to thousands of years, which is quiet sufficient for boulders to reach the Caspian seashore.

The *Novocaspian stage* lasting approximately 5 kyr corresponded to the terminal phase in development of the coast during the last Caspian transgression. The transgression was characterized by multistage patterns, which is reflected in the structure of marine sections and coastal topography. The section is composed of alternating terrigenous and coastal-marine sediments, which constitute two levels of the marine Novocaspian terrace separated by lagoonal mud deposited during the lower sea level. Lagoons became widely developed after the Mangyshlakian regression. The taxonomic composition of molluscan assemblages from lagoonal sediments indicates that they represented desalinated isolated or semi-isolated basins. With development of the Novocaspian transgression, depositional environments in the coastal zone were successively replaced by settings with more intense hydrodynamics and accumulation of coarse pebbly and sandy–gravely material and, then, calmer conditions with deposition of well-sorted sands on spacious shoals. Judging from abundant molluscan assemblages, the Novocaspian sea represented a brackish-water basin with salinity close to that in the present-day southern Caspian Sea.

The Novocaspian terrace occupies an extended band of the coast up to the altitude of −20 m. It is accretion–erosional in origin with the base represented by Mangyshlakian pebble gravel in its back part and of the accretion-type composed of facies-variable sediments in the shore part. Its upper level (−20 to −24 m) is marked by mobile dunes and relicts of buried and recent soils. The Novocaspian terrace of the lower level (−25 to −26 m) is located in the coastal

zone adjoining the abandoned cliff and representing a system of joint (overlapping) coastal bars separated by narrow lagoonal depressions. It was formed during the last significant sea level rise. This epoch was marked by the final formation of the large Mordob and Miankal nehrungs, which separate the Enzeli Lagoon and Gorgan Bay from the sea. The complex structure of sections in these nehrungs [7, 13] implies their formation to be a multistage process with deposition breaks and migrations of the main nehrung body. This was accompanied by the formation of the present-day Sefidrud River delta system, although the valley proper and its delta were formed considerably earlier. Their relicts are recognizable in space images at altitudes above 0 m on the early Khvalynian plain. The delta relicts reflecting the Mangyshlakian regression are established on shoals of the Caspian shelf [3]. Large volumes of sedimentary material transported by the Sefidrud River are responsible for frequent migrations of creek and main river channels. For example, in the Holocene the river changed its direction six times [3].

The *Recent stage* reflects the present-day natural process on the Iranian coast of the Caspian Sea: primarily its dynamics and trend. The stable structure of the coast and its brief recent history allow the main features of the recent natural process to be extrapolated to past epochs. The present-day shoreline is slightly differentiated and consists of two arcual northwestern and southeastern parts joining in the Sefidrud River mouth area [4]. The shores are mainly represented by marine-deposition and eroded types. The offshore part of the low Novocaspian terrace is intensely eroded. The high sedimentation rates are recorded only in areas of large deltas, which prograde toward the shelf owing to intense sediment supply. For instance, the rate of Sefidrud River mouth progradation is approximately 15 m/year; in the period of Caspian Sea level fall in 1950–1977, it was as high as 27–53 m/year [10]. The greater share of sedimentary material transported by the river to the offshore mouth area is quickly distributed over the underwater slope, where the sedimentation rate amounts to 10–25 mm/year [13]. This is also evident from the structure and composition of present-day bars that isolate lagoons from the sea and indicate the prevalent transverse transport of terrigenous sediments delivered by rivers into the sea [4]. The recent epoch is marked by insignificant fluctuations of the Caspian Sea level accompanied by changes in coastal processes: the desiccation zone and beach became wider and eolian reworking of sands in the coastal zone intensified during the period of the Caspian Sea level fall in 1950–1977, while its subsequent rise in 1978–1995 was marked by enhanced abrasion of the low marine terrace, onshore migration of the recent coastal bar, and reduction of the area occupied by the adjacent lagoonal depression.

The above-mentioned peculiar features in the geological–geomorphological structure and recent development history of the Iranian coast of the Caspian Sea were mainly determined by the position of this narrow zone at the transition between the Alpine Elburs mountainous system and the southern Caspian basin, which is characterized by different-scale cyclicity and hydrodynamic activity. Such a situation was responsible for the intense supply of terrigenous material to the coastal zone and high rates of its reworking and deposition to produce different forms of surface and underwater topography. These processes complicated by various factors, which rapidly changed in space and time, are well reflected in development of river deltas, nehrungs, and the low terrace consisting of a system of beaches and coastal bars.

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