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MORPHOSTRUCTURAL PRINCIPLE OF DETAILED MARINE ECOREGIONS' ZONING: CASE STUDY OF THE CASPIAN SEA NEAR AZERBAIJAN

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Abstract

Concepts concerning the major role of tectonic movements in the formation of morphostructures that caused the environmental features of the coastal zone are substantiated. Landscapes correspond to regional morphostructures, and morphological units of horizontal landscape dissection correspond to local morphostructures. The general landscape map of the Caspian coastal zone near Azerbaijan and the map of the Absheron underwater landscape are given; natural features of the underwater landforms highlighted on the map are discussed.

Keywords: coastal zone, tectonic movements, morphostructures, underwater landscapes, morphological structure, Middle Caspian, Azerbaijan.

Introduction

Principles for zoning world's marine ecoregions were developed by M. D. Spalding, G. Allen, H. Fox, and N. C. Davidson (Spalding et al., 2007). The proposed zoning system reflects the most extensive global features of life in the ocean; The initial unit of zoning is an ecoregion (sea basins). However, the demands of science and practice require the elaboration of a more detailed system of zoning units of the seas. The paper discusses principles of detailed regionalization of a marine ecoregion based on the example of the Caspian coastal zone near Azerbaijan.

1. Tectonics as a major factor in the detailed regionalization of ecoregions.

Changes in the type of the relief, processes of abrasion and sedimentation are an important factor in changing bionomic conditions in the coastal zone and on the shelf. The leading role in these processes belongs to morphostructural features of continental margins, the latest and recent tectonic movements. In the Neogene-Quaternary, morphostructures evolved from planetary to local, which specified main features of the relief of marine margins of platforms and orogens. The morphostructures control the topography of the coast, the contour of the coastline and the steepness of the underwater slope. There are longitudinal coasts, fold axes of which are located along the coastline, and transverse coasts, when fold axes run normal to the coast. Growing longitudinal coasts are characterized by the formation of a coastal cliff, an abrasive underwater coastal slope, a steep coast, and a narrow shelf. On the transverse coasts, the axes of growing folds continue into the sea to form a system of capes, islands and bays; the shelf is wide. An abrasion-accumulative terrace with numerous reefs and banks in place of local folds is formed on the submarine nearshore slope. The abrasion-sculptural submarine nearshore slope is a special biotope of rocky bottom, dominated by attached biological forms (sessile biota).

In the place of tectonic troughs, a thick layer of Quaternary sediments accumulates and morphostructures of accumulative plains and coasts are formed. On the underwater slope, waves directed normal to the coast cause lateral movement of sediments and their grading. Fine sandy and silty material carried out from the coastal zone is deposited at depths inaccessible to the wave action. The propagation of waves at right and oblique angles to the coastline results in the alongshore sediment flow. Underwater coastal swells and other forms of accumulative relief are typical there (Zenkovich, 1962). In the upper part of the underwater nearshore slope, within the active impact of the wave field, mainly mobile forms live on sandy sediments; in the lower part, where the impact of waves is weakened, a biotope of sandy-silty deposits is formed; it is dominated by hydrobionts burrowing into the ground (infauna).

The following size range of morphostructural zoning units is proposed: *counties, districts, and regions (landscapes)*. With increasing depth, there is a rapid change in bionomic conditions, the nature of biotopes and bottom biocenoses, so, the shelf is proposed to be subdivided into 3 belts. The *upper belt* includes the coastal zone (underwater nearshore slope). It is exposed to wave action, has seasonal rhythms (mainly warming during the warm season) and sufficient light for the evolution of macrophyte assemblages. The *intermediate belt* is located below the thermocline layer, the wave activity is weakened, the seasonal rhythm is weakly expressed, and the illumination is low. Single multicellular and some unicellular algae occur there. Due to weakened hydrodynamics in this belt, fine silty material enriched in detritus is deposited and a diverse infauna is formed. The *lower belt* corresponds to the inflection of the seabed profile towards the continental slope. Hydrodynamic activity increases there, sculptural relief forms are formed, and the diversity of sessile fauna groups grows.

It is shown below how the formation of morphostructures and underwater landscapes is related to the tectonic structure of the Caspian coast near Azerbaijan.

The Caspian coastal zone near Azerbaijan is structurally formed by alternating large megastructures - synclinoria and anticlinoria, continuing from land to seabed (Sharkov, 1964). To the north, there is the vast Kusaro-Divichinsky Synclinorium, which opens wide towards the deep-sea part of the Middle Caspian Basin; further, the coastal zone, including the Absheron Peninsula and the Absheron Archipelago, is confined to the eastern submergence of the axis of the Greater Caucasus Megaanticlinorium. To the south, there is an accumulative plain in place of the Jeirankechmes Synclinorium, separated from the vast Lower Kura Megasynclinorium by Gobustan anticlinal zones submerging into the sea, which lead to the formation of shallow waters and islands of the Baku Archipelago.

The presented materials show a clear dependence of regional features of the nature of the Azerbaijan onshore and offshore zones on inherited differentiated evolution of megastructures. This justifies identifying corresponding landscapes (Fig. 1).

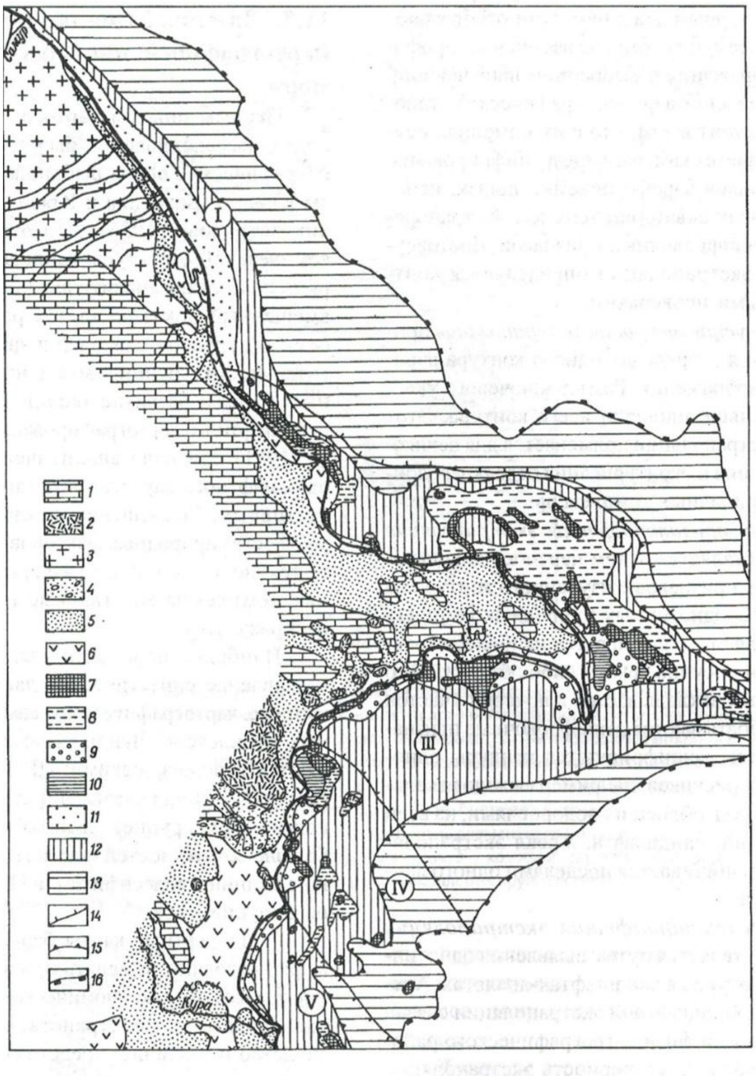

Fig. 1. Landscape map of the Caspian coastal zone near Azerbaijan.

1-6 – coastal landscapes: 1 – low-hill terrains (spurs of the Main Caucasian Range), overgrown with sagebrush and saltwort-sagebrush semidesert vegetation on grey-brown alkaline soils; 2 – areas of intense mud volcanic activity; 3 – alluvial-proluvial foothill plains (Shollar Plain), overgrown with lowland mixed forests and meadow, mainly post-forest vegetation along with shrubs and glades on alluvial-meadow-forest non-carbonate soils; 4 – large mountain river fans (Pirsagat River fan), overgrown with sagebrush and saltwort-sagebrush semidesert vegetation on grey-brown alkaline soils; 5 – abrasion-accumulative plains (Khvalynian marine terraces), overgrown with sagebrush and saltwort-sagebrush semidesert vegetation on grey-brown alkaline soils, on the Absheron Peninsula – ephemerous forb-and-grass semi-desert vegetation; 6 - abrasion-accumulative plains (Novocaspian and recent marine terraces) with aeolian sandy relief forms and coastal salt marshes. The vegetation is represented by psammophyte and saltwort groups; 7-13 - dominant landforms of the coastal zone of the sea: 7 - cliffs and rocks; 8 – shell fields; 9 – underwater meadows of sea grasses; 10 – plains covered with a crust of recent lithified sediments; 11 – band of coastal sandy-shelly deposits with underwater beach barriers; 12 – shelly-silty plains of the lower level of the sublittoral; 13 –

shelly-silty plains of the upper floor of the eulittoral zone; 14 – boundaries of littoral zone landscapes: I – Samur landscape; II – Absheron landscape (landscape of the Absheron Archipelago); III – Jeirankechmes landscape; IV - landscape of the Baku Archipelago water area; V- Kura landscape; 15 – lower limit of the sublittoral zone; 16 – shelf edge

2. Underwater landscape concept

Studies of the coastal zone and shelf, based on the general theory of landscape science, took shape in Russia in the mid-20th century (Gur'yanova, 1959, Petrov, 1989, 2020). However, the evolution of underwater landscape science was to a certain extent hampered by the lack of a conceptual apparatus that would naturally be included in the theory of oceanology. First of all, it is necessary to recognize that landscape is a general concept applicable to the studies both on land and on the seabed.

The diversity of underwater landscapes of the coastal zone depends on a number of factors. Hydrological conditions are related to the climate and meteorological regime of the atmosphere, which feature the seasonal rhythm of natural processes in the coastal zone.

Penetration of solar radiation supports photosynthesis of phytoplankton and phytobenthos. The mobility of water controls abrasion, lithodynamics and sediment accumulation, and also contributes to good aeration, the influx of nutrients and the distribution of the rudiments of organisms. The discharge of liquid and solid land runoff causes strong variability in the salinity of the sea water and leads to an enrichment of nutrients and organic substances. Great species diversity and richness of life forms lead to high population density of various ecological niches.

The underwater landscapes of the coastal zone and shelf are influenced by the Pleistocene regression, which resulted in the formation of relict landforms, the presence of subaerial deposits and the disjunction of habitats of hydrobionts, and the Holocene transgression led to the underwater landscape rejuvenation.

Main properties of underwater landscapes of the coastal zone are as follows:
- the seabed landscape is located in a block of the earth's crust characterized by similar geology; it is, as a rule, associated with the evolution of one regional morphostructure;

- each landscape is characterized by a certain set of lithological variances in recent bottom sediments or bedrock outcrops, which control the nature of the sculptural micro- and mesoforms of the underwater relief;

- underwater illumination, temperature and wave processes change with depth, which causes

the vertical subdivision of the coastal zone;
- the variety of relief forms, seabed, and hydrological settings control the diversity of biotopes and, accordingly, the diversity of bottom biocenoses.

All these factors serve as the base for identifying a system of morphological units of differentiation within the landscape. Characteristics of the morphology of underwater landscapes include a description of units of horizontal and vertical subdivisions. The basic units of horizontal subdivision of underwater landscapes are facies and landforms. Submarine facies is the smallest elementary bottom natural complex. It represents a specific biotope associated with one form of microrelief or one element of mesorelief (knoll, slope, foot of a bank), and is located in a certain depth interval. The facies is composed of one lithological variety in recent sediments or is confined to a rock outcrop of homogeneous composition and occupied by one biocenosis. A set of facies forms an underwater landform. The underwater landform is a natural complex associated with a specific mesoform of relief and has clear limits. The differentiated evolution of local structures leads to the formation of two types of landforms. On structures experiencing uplift, the bottom is eroded, and abrasion-sculptural type landforms are formed: a coastal belt of rocks, offshore underwater banks and reefs. Complicated morphology of the landscape, a wide variety of biotopes and associated biocenoses appear. Structures experiencing subsidence are characterized by sedimentary leveling the bottom and the formation of accumulative-type landforms. In areas of active lithodynamics, underwater landforms are represented by offshore beaches, underwater spits, etc. In a calm hydrodynamic environment, in areas of continuous sedimentation, monotonous sandy-silty plains are formed. Sea ground properties are an important environmental factor of these landforms. Assemblages of attached biological forms associated with rocky bottom and assemblages of organisms burrowing into loose soil are well known; their habit reflects adaptive characteristics caused by the way of life on different types of seabed.

The vertical differentiation of shallow marine waters reflects the height of the surf impact, the tidal rhythm, the wave weakening and the fading of underwater illumination with depth. Processes of relief formation, sedimentation, as well as the entire set of environmental settings that control the distribution of bottom biocenoses are influenced by these factors. The bathymetric profile is a basis for a conjugate series of bottom natural complexes. Facies, landforms, and entire landscapes are subject to regular changes with depth. Vertical zones are main units of underwater landscape subdivision with depth. In the upper shelf belt there are three vertical zones: supralittoral, littoral (pseudolittoral), sublittoral. The outer sublittoral zone extends deeper, belonging to the intermediate shelf zone. The next unit, into which zones are subdivided vertically, is proposed to be called a floor. In the supralittoral, they reflect the height of the surf impact; in the littoral zone, tidal rhythms, in the sublittoral zone, the weakening of the wave impact on the seabed and the fading of underwater illumination. Sometimes within the floors there are steps that differ in the composition of bottom biocenoses. The size of the intervals of vertical subdivisions varies with depth from centimeters to tens of meters; in general, the system of units of the vertical subdivision of landscapes of the coastal zone resembles a spring, compressed at the beginning and stretched at depth.

The concept of morphological units occupies a special place in studying underwater landscapes. They are the direct target of marine and underwater studies and mapping. Regular spatial combinations of morphological units are similar to a genome, which is responsible for the stability of the landscape as a whole.

3. Landscape-bionomic mapping of the Absheron Archipelago

The Absheron Peninsula and the shallow waters of the Absheron Archipelago are formed on the eastern continuation of the Greater Caucasus Megaanticlinorium. The Absheron Archipelago water area represents a landscape where the distribution of landforms of various types is controlled by the geology and geomorphology (Sharkov, 1964). The bottom of vast shallow waters is accessible for high-resolution airborne and space photography, so landforms of various types receive a characteristic image due to which their outlines are easily interpreted and transferred onto the base of marine maps (Gur'yeva, Petrov, Sharkov, 1976).

Interpretation and mapping features are shown using the case study of underwater cliffs and rocks that are formed in place of local structures experiencing uplift. Diving operations in key areas made it possible to establish that on airborne images dark details correspond to rocky ridges overgrown with algae, and the light tone corresponds to sand and shell deposits (Fig. 2a). Using simple transformations, an airborne image can be presented in graphical form as a map of bottom natural complexes (Fig. 2b).

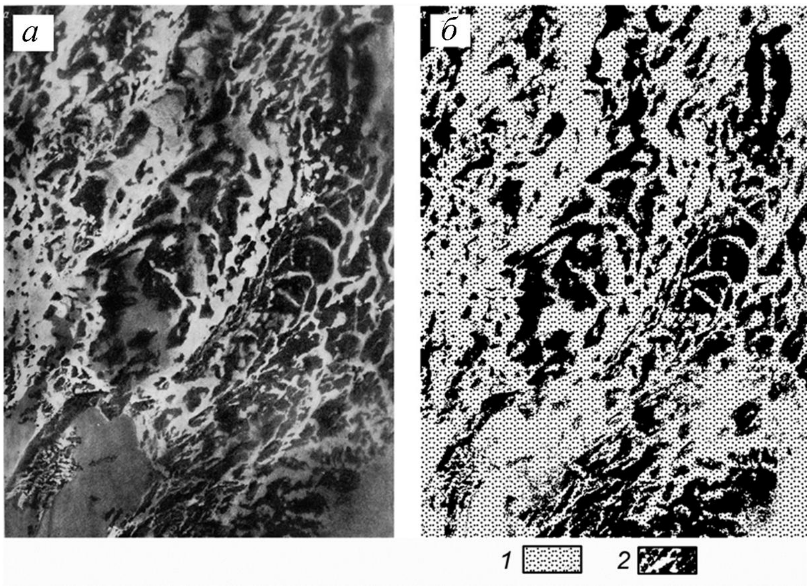

Fig. 2. Landform of cliffs and rocks with assemblages of lithophylic hydrobionts, evolved instead of an anticlinal fold: a – airborne image (scale 1: 15,000): dark elements of the image correspond to ridges overgrown with algae, light elements correspond to leveled areas of the bottom covered with sand and shell sediments; b – map of bottom natural complexes: 1 – leveled sections of the bottom covered with sand and shell sediments, 2 – rocky ridges overgrown with algae

After the interpretation of airborne photographs in the process of marine and underwater studies, the landscape-bionomic map of the water area of the Absheron Archipelago was compiled (Fig. 3). Let me show the close relationship between the formation and distribution of major types of underwater landforms with the geology and geomorphology of the seabed (Fig. 4).

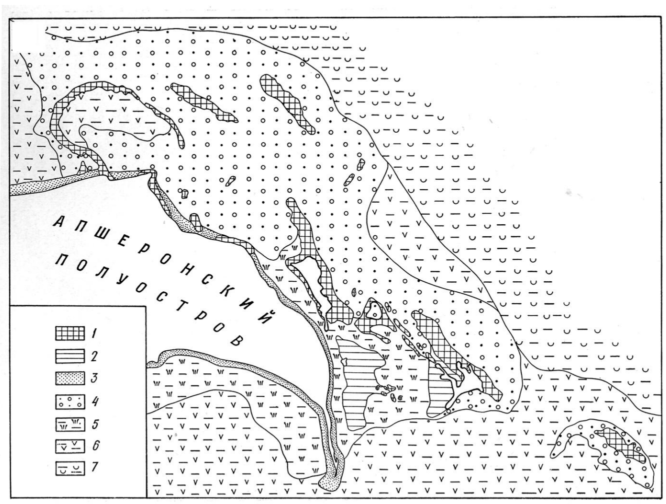

Fig. 3. Landscape-bionomic map of the Absheron Archipelago.

Legend. Underwater landforms: 1 – cliffs and rocks, 2 – plains covered with lithified crust, 3 – offshore beaches, 4 – shell fields, 5 – sea grass meadows, 6 – muddy plains of the coastal zone, 7 – offshore silty plains at depth over 20 m

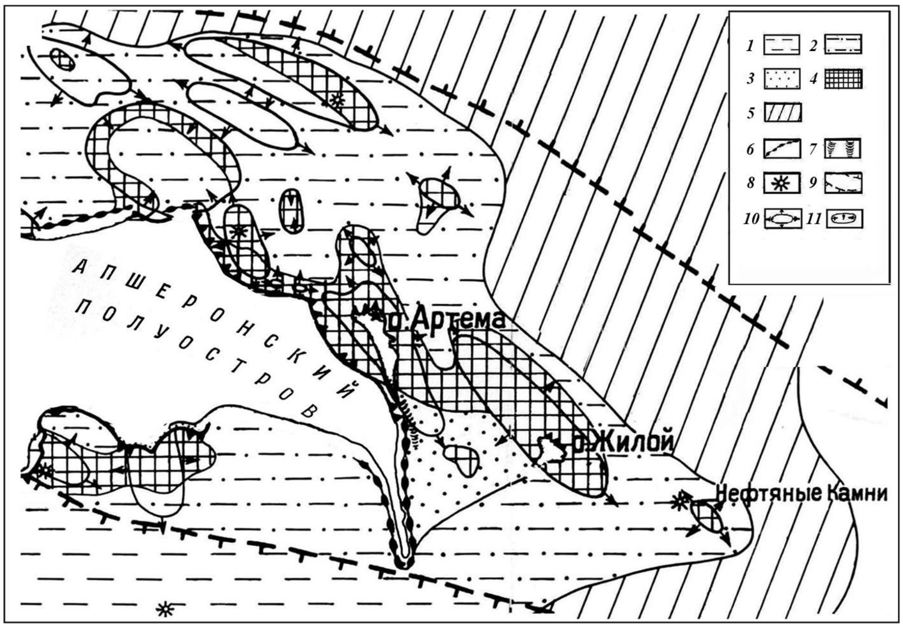

Fig. 4. Geomorphological map of the Absheron Archipelago according to V.V. Sharkov (1964). Legend: 1 – accumulative plains, 2 – abrasion-accumulative plains, 3 – accumulative plains under the protection of coastal ledges, 4 – abrasion sculpture-ridge relief, 5 – accumulative plains of non-wave accumulation, lower part of the shelf, 6 – underwater coastal sand bars, 7 – underwater sand spits, 8 – underwater cones of mud volcanoes, 9 – boundaries of the underwater continuation of the Greater Caucasus Megaanticlinorium, 10 – growing local anticlinal uplifts expressed in relief, 11 – inverted forms of relief confined to local synclines

Thus, the outlines of the abrasion-accumulative plain (see Fig. 4, symbol 2) coincide with the outlines of the shell fields (see Fig. 3, symbol 4); the outlines of the abrasion sculpture-ridge relief (see Fig. 4, symbol 4) and growing local anticlinal uplifts expressed in the relief (see Fig. 4, symbol 10) coincide with the outlines of landforms of cliffs and rocks (see Fig. 3, symbol 1), etc.

Brief description of the underwater landforms shown on the map (see Fig. 3) are given below.

4. Underwater landforms of the Absheron Archipelago

The landscape and bionomic features of the Absheron Archipelago are associated with the following main types of underwater landforms: cliffs and rocks; shell fields; plains covered with lithified crust; sea grass meadows; silty plains of the coastal zone and offshore silty plains at a depth of over 20 m. Let us discuss features of bottom zoocenoses typical of the above types of underwater landforms. The zoobenthos of the coastal zone immediately below sea level in all areas is dominated by the eurytopic bivalve mollusk *Mytilaster lineatus*. Uncontrolled invasion and mass reproduction of this species in the 20–30s of the 20th century led to the extinction of a number of native species and a change in the zoobenthos structure (Zarbalieva et al., 2016). The introduction of the bivalve mollusk *Abra ovata* enriched the infauna of seagrass meadows and silty plains of the coastal zone (Zenkevich, Birshtein, Karpevich, 1945).

Landforms of cliffs and rocks consist of abrasion-sculptural forms of relief, caused by outcrops of layers of strongly cemented bedrock and fragments separated from it (see Fig. 3, symbol 1). They are a biotope of lithophilic hydrobionts: algae and invertebrate animals (Fig. 5).

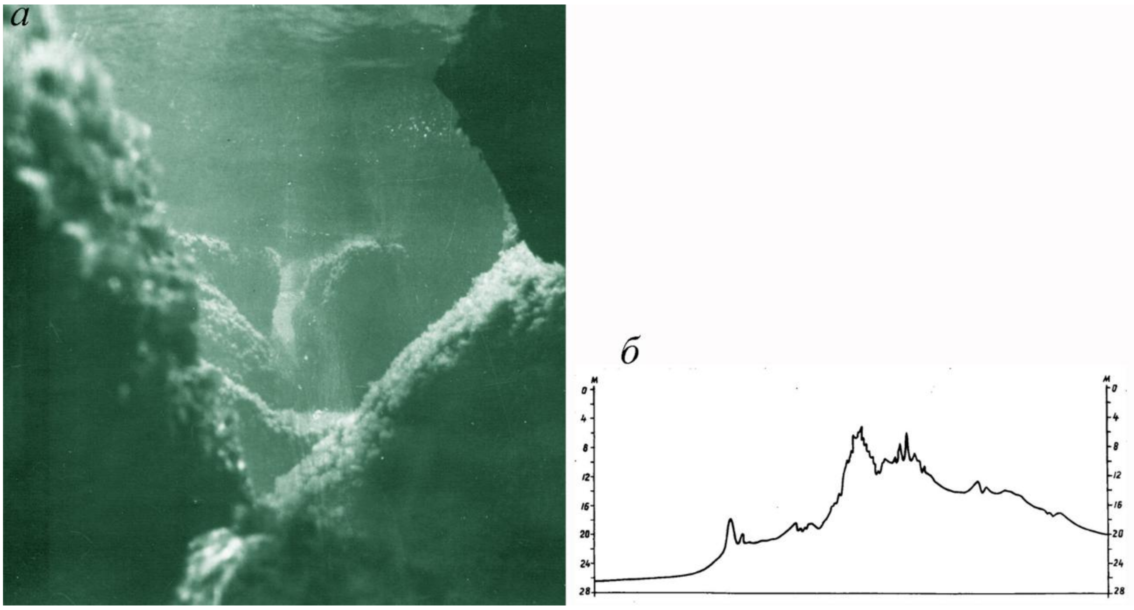

Fig. 5. Landform of cliff and rocks: a) the top of a bank in the upper sublittoral, overgrown with algae, phytocenosis Cladophora + Enteromorpha + Ceramium elegans + Laurencia caspica (underwater photo); b) bank profile

Diatom-eating *Theodoxus pallasi*, gastropods settle en masse among algae thickets. Just below sea level, under a cover of algae, rocks and cliffs are completely covered with a brush of bivalve mollusks *Mytilaster lineatus*. As the depth increases, the cover of algae disappears and the biocenosis habit in the lower sublittoral zone is dominated by the brush Mythelastra and the barnacle crustacean *Balanus improvisus*, which overgrows mollusk valves. (Fig. 6).

Fig. 6. Landform of cliffs and rocks. A brush of bivalve mollusks *Mytilaster lineatus*, overgrowing rocky surfaces in the lower sublittoral (underwater photo): 1 – *Mytilaster lineatus*, 2 – barnacles *Balanus improvisus* overgrowing mollusk valves

The *landforms of the shell fields* are represented by sandy-shell sediments covering the abrasion-accumulative plain (see Fig. 3, symbol 4). They occupy the largest area in the landscape of the Absheron Archipelago. The sedimentary cover forms there without the participation of the fluvial terrigenous material removal from the Absheron Peninsula. The accumulation of a thick sedimentary layer is hindered by the inherited uplift of the eastern continuation of the Greater Caucasus Megaanticlinorium, which has resulted in the formation of shallow water throughout the Absheron Archipelago. Main components of sediments are biogenic material (shells) and chemogenic sediments (oolitic sands and carbonate silts), as well as sediments resulting from bedrock abrasion.

Leveled bottom spaces covered with a thin layer of sandy-shelly sediment are combined with abrasion-sculptured forms. Shells play a leading role in the sedimentation, resulting from the crumbling of dead mollusk shells, which form a peculiar thanatocoenosis (description is given below). The sediments consist mainly of whole and broken shells, in some places mixed with detrital sand (Fig. 7). In some areas a variety of accumulation forms are produced under the influence of waves and currents. Under moderate hydrodynamic conditions in the lower sublittoral, dense populations of Mytilaster are formed on the bottom, and the red alga *Ceramium diaphanum* settles in separate clumps attached to shells.

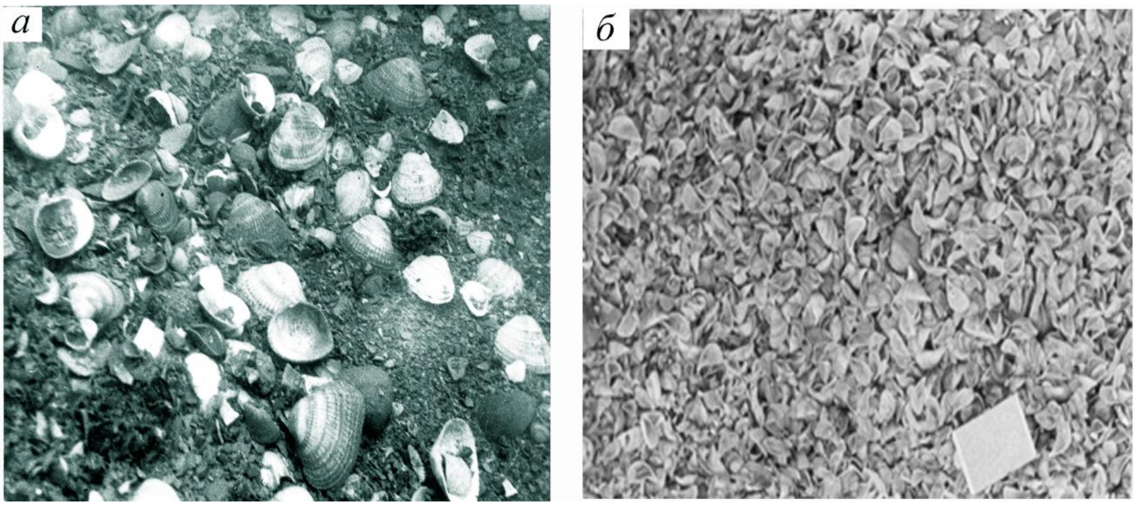

Fig. 7. Landform of shell fields: a) shell field formed by the valves of mollusks *Didacna, Hypanis, Dreissena elata, Mytilaster lineatus* (underwater photo); b) detritus sand (sample photo)

Landforms of seagrass meadows are formed in transparent water at a depth of 5–6 m, protected from waves and currents by coastal ledges, islands and rocky ridges (see Fig. 3, symbol 5). Herbaceous rhizomatous plants *Zostera minor* and *Ruppia maritima* are dominant life forms there. They form thickets with high, sometimes continuous density on sandy-silty bottom with an admixture of shells (Fig. 8). The algae Charophytic and red algae *Ceramium diaphaum* characterized by epiphytic lifestyle are accompanying species. *Mytilaster lineatus* settles in places on the bottom surface; mollusks *Abra ovata, Cerastoderma lamarcki* and worms *Nereis diversicolor* live in the seabed. The mollusks that are part of the biocenosis enrich the sediments with autochthonous shell material.

Fig. 8. Landform of sea grass meadows, Ruppia maritima–Zostera minor phytocenosis (underwater photo)

Plain landforms covered with lithified crust are formed at a depth of 2–5 m, under moderate wave action (see Fig. 3, symbol 2). The lithified crust consists of oolitic sand grains, whole and broken shells, bound by calcareous cement precipitated from seawater. The thickness of the crust varies from several to tens of centimeters. Lithified deposits are the newest formations, as evidenced by the presence in their composition of valves of mytilaster, a mollusk that arrived in the Caspian Sea in the 20s of the 20th century. The cementation crust rests horizontally on recent unconsolidated sediments. This landform represents a biotope of thickets of filamentous red algae *Ceramium diaphaum* and dense colonies of Mytilaster lineatus+Balanus improvises (Fig. 9) In areas exposed to wave action, various forms of accumulative relief composed of sandy-shelly sediments are formed on the levelled surface of the cementation crust.

Fig. 9. Plain landform covered with a lithified crust, an assemblage of red algae Ceramium diaphaum hiding the Mytilaster lineatus + Balanus improvises biocenosis, overgrowing the cementation crust

Landforms of silty plains of the coastal zone are formed in the process of silt accumulation (see Fig. 3, symbol 6), compensating for the inherited subsidence of local structures, as well as in shallow waters protected from waves and currents by coastal ledges, islands and rocky ridges.

Silt deposits (soft formations) are a biotope of infauna of mollusks, worms and crustaceans. Mollusks *Cerastoderma lamarcki, Abra ovata, Pyrgula* and worms *Nereis diversicolor, Oligochaeta, Hypania* prevail at a depth of 20–25 m. *Mytilaster lineatus* forms an idiosyncratic population on the bottom surface in some places; *Balanus improvises* settles en masse on the valves of the latter (Fig. 10). The high productivity of mollusks ensures the enrichment of sediments with autochthonous shell material.

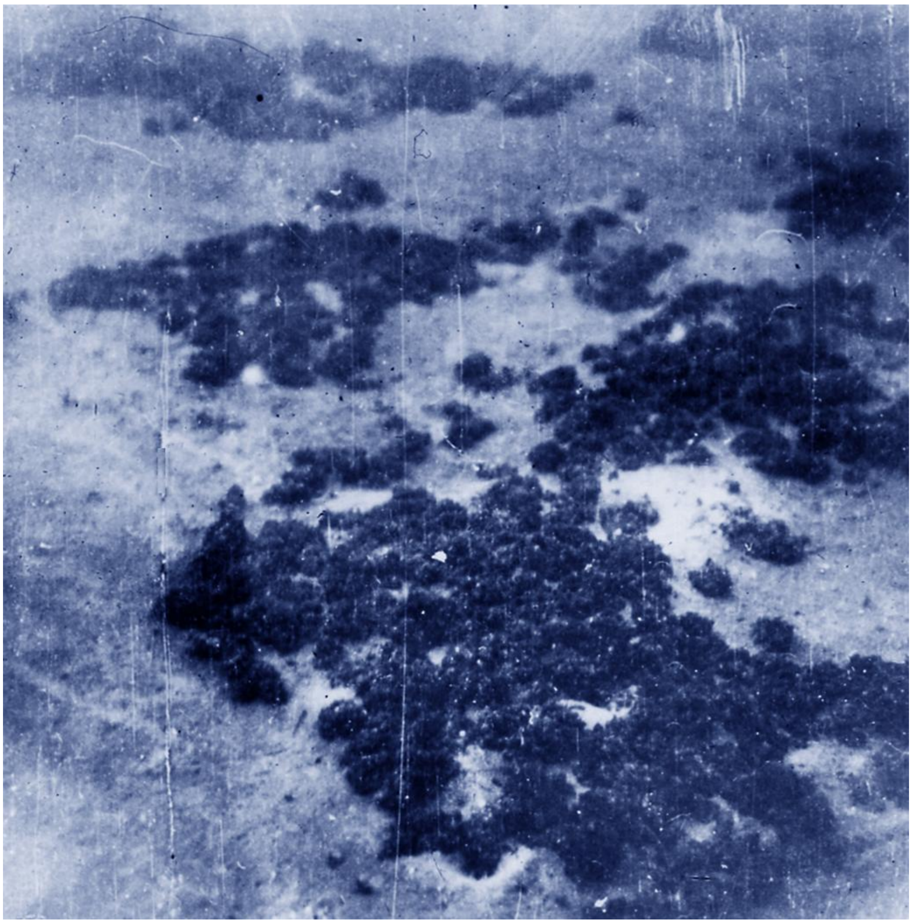

Fig. 10. Landform of silty plain in the lower part of the coastal slope, patches of mitelastra colonies on the bottom surface (underwater photo)

Silty plains extend beyond the coastal zone (see Fig. 3, symbol 7) without violent changes.

At depths more than 25–30 m in the offshore coastal zone, a landform of silty plains is formed, in which the mollusk *Dreissena rostriformis* acquires a dominant position; its valves dominate the thanatocoenosis of recent sediments. Worms *Oligochaeta* evolve en mass; a characteristic component is the amphipod *Corophium*, which settles in tubules.

5. Analogue landscapes

Analogue landscapes in the coastal zone and on the shelf of various marine ecoregions are formed on the same type of morphostructures, within the same vertical belt, in geographic zones with the same type of biologically active temperature and salinity regime. These landscapes have a characteristic combination of underwater landforms and associated groups of lifeforms of aquatic organisms. Underwater landforms of analogue landscapes are stations that can be used for the introduction of beneficial species either serve as biotopes favourable for the invasion of harmful species.

An example of introduction is the invasion of the polychaete *Nereis diversicolor* and the bivalve mollusk *Abra ovata* into the landform of sandy-silty grounds of the Caspian Sea from a similar landform in the Sea of Azov in the mid-20th century. The introduction of these species resulted in the enrichment of the fish food base of the Caspian Sea.

An example of catastrophic invasion is the introduction of unwanted invasive species into the Caspian, Black and Azov Seas. In the 20s of the last century, the mollusk *Mytilaster lineatus* was accidentally invaded into the Caspian Sea. It proliferated rapidly in rocky landforms of the Middle Caspian coastal zone, completely displacing from this biotope two endemic native species, *Dreissena elata* and *D. caspica. caspica*. In the 80s of the 20th century, the comb jellies *Mnemiopsis leidyi* appeared in the epipelagic waters of the Black and Azov Seas, and in the early 21st century in the North Caspian. It feeds on zooplankton, eggs and larvae of fish and bottom invertebrates. By actively reproducing, Mnemiopsis has cripple the fodder base of fish and reduced the ability of many benthic invertebrates to reproduce. As a result, fisheries declined sharply. In the early 1990s, the comb jellies *Beroe ovata*, which feeds on *Mnemiopsis leidyi*, also appeared spontaneously in the Black Sea. This invasion is positive, as the introduction of *Beroe ovata* led to a rapid decline in the Mnemiopsis population.

Thus, the applied value of the concept of analogue landscapes lies in the ability to predict the introduction of beneficial species and to foresee the risk of invasion of harmful species.

6. Conclusion

1. It is proposed to carry out detailed regionalisation of marine ecosystems by identifying territorial units that reflect features of the morphostructure of the continental margin and changes in bionomic environment with depth.

2. The main initial unit of zoning is the underwater landscape.

3. Each landscape has features of the morphology, which is revealed in the system of units of vertical and horizontal differentiation within the landscape.

4. Materials of detailed regionalisation of the coastal zone and shelf of marine ecoregions can be used to create a database, which will make it possible to identify analogue landscapes. The applied significance of their identification consists in the possibility of predicting the introduction of beneficial species and the risk of invasion of harmful species.

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