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TWO APPROACHES TO STUDYING THE OCEANOSPHERE

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Аннотация

Изучение аналитических закономерностей развития отдельных компонентов океаносферы заложено в океанологии программой первой океанологической экспедиции на «Челленджере» в конце XIX в. Отечественная географическая школа решает проблемы, актуальные как в области физической географии, так и океанологии: изучение взаимодействия компонентов природы, выделение и описание природно-территориальных комплексов региональной и локальной размерности. Успешное комплексное изучение, освоение и охрана природных ресурсов береговой зоны и шельфа Мирового океана требуют использование как аналитических океанологических, так и комплексных географических методов исследований.

Ключевые слова: аналитические исследования, комплексные исследования, береговая зона и шельф, природные территориальные комплексы, принципы районирования, концепция подводного ландшафта, программа комплексного изучения ландшафтов.

Abstract

The study of analytical patterns in the evolution of individual components of the oceanosphere was laid down in oceanology by the programme of the first oceanological expedition aboard the Challenger at the end of the 19th century. The national geographical school solves problems that are relevant both in physical geography and oceanology: the study of the interaction of the components of nature, and the identification and description of natural territorial complexes of regional and local scales. Successful integrated study, development and protection of natural resources of the coastal zone and the shelf of the World Ocean require the use of analytical oceanological and integrated geographic research methods.

Keywords: Analytical studies, integrated studies, coastal zone and shelf, natural territorial complexes, zoning principles, underwater landscape concept, integrated landscape study programme.

Introduction

The expedition aboard the steam-sailing corvette *Challenger* (1872-1876) performed the programme of detailed component-by-component study of the World Ocean nature. This expedition initiated the formation of oceanology – a complex of scientific disciplines about physical, chemical, geological and biological processes in oceans. The structure of oceanology, laid down in the late 19th century, retains the analytical approach to studying the World Ocean to our days.

In geography, the concept of comprehensive studies was laid down by V.V. Dokuchaev. He wrote that there is no doubt that the knowledge of nature – its forces, elements, phenomena and bodies – made such gigantic steps during the 19th century that it is often called the century of natural science. However, V.V. Dokuchaev pointed out that mainly individual bodies and phenomena were studied rather than their relationships, not the genetic, eternal and always natural relationship that exists between forces, bodies and phenomena, between dead and living nature. L.A. Zenkevich (1970) noted the expediency of creating an integral direction in oceanology, based on the V.N. Sukachev's doctrine of biogeocenosis. However, this proposal remained unimplemented. In international experience, an integrated approach to the study of

life is known as an ecosystem approach. (A.Tansley, 'The use and abuse of vegetational terms and concepts', 1935, Ecology 16: 284–307)

The coastal zone and the shelf correspond to an area of interaction between main geospheres of the Earth: the atmosphere, hydrosphere, lithosphere and biosphere. Therefore, there is a high dynamism of natural processes, the formation of various natural complexes and a high diversity of bottom biocenoses there. The coastal zone and the shelf are an arena of rich mineral and biological resources, their intensive consumption, which has a devastating effect on coastal ecosystems and landscapes.

Problems of comprehensive studying underwater margins of the continents are related to the fact that they are not accessible to direct visual perception. In the mid-20th century, tools for airborne surveying the shallow seabed and methods for deciphering airborne images were developed (Guryeva, Petrov, Sharkov, 1976) in the course of geological mapping and exploration of oil and gas fields off the Azerbaijan coast. The use of scuba gear allowed explorers-divers to implement the whole range of work performed by a geographer on land: photograph and describe the relief, soil, bottom biocenoses, and take samples. Subsequently, this experience made it possible to describe and map landscapes of shallow marine areas of the Black, Caspian and Far Eastern seas, to develop the theory and methods of landscape-bionomic studies of the coastal zone and the shelf (Petrov, 1989; 2004; 2008). The shallow depth available for airborne surveying of the shallow seabed has been overcome in recent decades by the widespread use of ultrasonic sonar imaging, which is capable of providing an image of the seabed of the entire shelf. When interpreting and summarizing the data obtained from the interpretation of sonar images of the shelf, it is advisable to use the method of landscape interpretation of airborne images of the shallow seabed. The paper describes the application of the geographical approach to the study of the coastal zone and the shelf: principles of detailed zoning of the coastal zone and the shelf, the concept of the underwater landscape. In conclusion, a programme of comprehensive landscape bionomic studies of the coastal zone is proposed.

Principles of detailed zoning of the coastal zone and the shelf

Principles of global zoning of shallow marine areas were developed in the early 21st century by American oceanologists M. D. Spalding, G. Allen, H. Fox and N. S. Davidson (Spalding et al., 2007). The authors distinguish 12 realms, 62 provinces and 232 ecoregions (sea basins).

The proposed system of zoning units reflects major global features of life in the ocean. However, the assessment of biodiversity, productivity, use and conservation of biological resources requires the development of a more detailed system of units for zoning marine ecoregions (Petrov, 2020; 2022). Let us define principles of detailed zoning of sea basins.

The landscape and bionomic features of the coastal zones and the shelf reflect the influence of three factors: geological and geomorphological aspects, the depth and position of the coastal zone in the system of units of geographical zonality.

Geological and geomorphological structure (morphostructures) of the coastal zone and the shelf. Changes in the relief, the effect of abrasion and sedimentation are an important factor in changing the bionomic conditions in the coastal zone and on the shelf. Morphostructural features of continental margins, the latest and recent tectonic movements are of great importance in these processes. In the Neogene-Quaternary, the morphostructures evolved from planetary to local, which specified major topographic features of marine margins of platforms and orogens. The morphostructures control the relief of the coast, the contour of the coastline, and the considerable steepness of the underwater slope. There are longitudinal coasts, in which fold axes are located along the coastline, and transverse coasts, where fold axes are normal to the coast. Growing longitudinal coasts are characterized by the formation of a coastal cliff, an abrasion underwater coastal slope, a steep coast, and a narrow shelf. Off the transverse-type coast, 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 underwater coastal slope. The abrasion-sculptural underwater coastal slope corresponds to a particular biotope of rocky soils dominated by attached biological forms (sessile biota).

Thick sequence of Quaternary deposits is accumulated in place of tectonic troughs, and morphostructures of accumulative plains and coasts are formed. On the underwater slope, confusion of sea, directed normally towards the coast, results in transverse movement of sediments and their grading. At depths inaccessible to the action of waves, thin sandy-silty material drifted from the coastal zone is deposited. The propagation of waves at right and oblique angles to the coastline controls the alongshore sediment flow. Submarine coastal ridges and other forms of accumulative relief are typical landforms there. In the upper part of the continental slope, within the active influence of the wave field, mainly mobile forms live

on sandy deposits; in the lower part, where the impact of waves is weakened, a biotope of sandy-silt deposits is formed dominated by hydrobionts (infauna) burrowing into the ground.

The following size range of morphostructural zoning units is proposed: regions, counties and underwater landscapes.

Vertical zonation. With increasing depth, rapid change in bionomic conditions, the nature of biotopes and bottom biocenoses takes place, so it is proposed to subdivide the shelf into three belts. The upper belt includes the coastal zone (submarine nearshore slope). It is located within the wave impact, has a seasonal rhythm (first of all, warming up during the warm period of the year) and light intensity sufficient for the macrophyte communities. The intermediate belt is located below the thermocline, the wave activity is weakened, the seasonal rhythm is not very pronounced, and the light intensity is low. Single multicellular and some unicellular algae are found there. Due to the weakened hydrodynamics in this belt, fine silty material rich 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. There, hydrodynamic activity increases, sculptural forms of relief are formed, and the diversity of sessile fauna assemblages increases.

Geographic zonality. The temperature regime is the primary factor of zonality. In the early 20th century, W. Setchell (Setchell, 1917), studying geographical patterns of underwater vegetation distribution, identified stenothermal assemblages of bottom seaweeds, characterized by the fact that they were confined to the water, the temperature regime of which differed by 5–10 °C. Recently, it was established that temperature gradients are related to the individual evolution and life cycles of hydrobionts, for which values of 0, 5, 10, 15, 20, 25°C are typical. These thermal boundaries are proposed to be used for identifying geographic belts and zones. For example, in the Northern Hemisphere, in the cold zone, there are Arctic and subarctic zones with biologically active water temperatures in summer of 0–5 and 5–10 °C respectively. In the temperate zone, boreal and nemoral zones with biologically active temperatures in winter of 0–5 and 5–10 °C, respectively, are identified. In the warm zone, there is a tropical zone with biologically active temperatures in winter above 20 °C.

Within shallow marine areas, boundaries of surface and seabed zones merge; below the transient layer, natural zones of the same type with the zones identified on the sea surface are

not traced. An important additional characteristic of thermal zones is the salinity of sea water. The salinity value below 24.69 $^{0}/_{00}$ (Knipovich boundary) separates seas with normal salinity from brackish water basins. This boundary separates marine biota from brackish water biota that is accompanied by a sharp decrease in the species diversity of marine biota.

The concept of the underwater landscape of the coastal zone

Landscape science of the coastal zone and the shelf is based on the theoretical provisions of the Russian Dokuchaev-Berg geographical school. The development of landscape studies in the coastal zone and on the shelf requires a clear definition of the concept of underwater landscape, its morphological structure and properties of landscape-forming factors, as well as consideration of the underwater landscape as the main initial unit of landscape zoning of shallow marine areas (Petrov, 2020; 2021).

The underwater landscape of the coastal zone (ULCZ) is a relatively homogeneous section of the coastal zone, which differs qualitatively from adjacent areas in its structure, i.e. with monotypic geological setting, relief, soils, hydroclimate (temperature, salinity, currents, wave processes) and with monotypic hydrobiont assemblages. Underwater landscape of the coastal zone is the smallest initial taxonomic unit of landscape zoning; it does not intersect boundaries of higher rank taxa, belongs to one natural zone, lies within the upper belt of the shelf, and is limited by one regional morphostructure.

Each underwater landscape is characterized by a peculiar combination of intralandscape natural systems (facies, landforms), which are biotopes of bottom biocenoses. ULCZs cover the coastal land affected by surf – supralittoral; land flooded at high tide – littoral; and the seabed to a depth, where the wave impact fades and the light intensity is insufficient for the formation of macrophyte communities – sublittoral (upper shelf belt). Deeper, ULCZs are replaced by landscapes of the elitoral zone (intermediate belt of the shelf).

The natural factors that control the richness and diversity of landscapes of shallow marine areas include: the relationship of hydrological conditions with the meteorological regime of the atmosphere, a pronounced seasonal rhythm of natural processes; water mobility, which controls abrasion, lithodynamics, and sediment accumulation, and also contributes to good aeration, the influx of nutrients, and the spread of anlages of organisms; the penetration of solar radiation, which supports the photosynthesis of phytoplankton and phytobenthos; river discharge, which result in strong variability in the seawater salinity, its enrichment with

biogenic and organic substances (solid runoff takes major part in feeding along the coastal sediment flow); great species diversity and richness of life forms, which contribute to the high density of occupation of various ecological niches; the influence of the Pleistocene regression with which relict landforms and facies of bottom sediments, broken areals of organisms, and the influence of the Holocene transgression (which controls the youth of underwater landscapes) are associated.

The concept of the underwater landscape assumes that:

- the landscape of the seabed is isolated in a section of the earth's crust, which has generally the same geological structure;

- as a rule, it is associated with the evolution of one regional morphostructure;

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

- subaquatic light, temperature and wave processes change with depth, that controls the vertical subdivision of the coastal zone;

- the variety of bedforms, soils, hydrological settings control the diversity of biotopes and, accordingly, the diversity of seabed biocenoses.

All these facts serve as a basis for identifying a system of morphological units of intra-landscape differentiation.

Seabed natural complexes (SNCs) associated with typical forms of relief, soils, and hydrobiont assemblages have, as a rule, a peculiar appearance; therefore, in the landscape science they are called morphological units of intralandscape subdivision.

Basic units of the horizontal subdivision are the *facies* and the *landform*.

The underwater facies is the smallest elementary seabed natural complex. It corresponds to a specific biotope associated with one form of microrelief or one element of mesorelief (top, slope, foot of the bank), and is located in a certain depth interval. The facies is composed of one lithological variety of recent sediments or is confined to a rock outcrop of homogeneous petrologic composition and occupied by one biocenosis. The facies assemblage forms an underwater landform.

The underwater landform is a seabed natural complex related to a certain mesoform of relief, with pronounced boundaries. The differentiated evolution of local structures results in the formation of two types of landforms. On the structures, which underwent uplifting, the seabed is eroded, and abrasion-sculptural landforms are formed: the alongshore cliff belt, and underwater banks and reefs far from the coast. On the structures, which experienced subsidence, sedimentary seabed leveling occurs and accumulative-type landforms appear. In areas of active lithodynamics, underwater landforms are represented by coastal bars, underwater spits, etc.

Ground properties are an important environmental factor of these landforms. There are communities of attached biological forms associated with rocky grounds, and communities of organisms burrowing into loose bottom, which habitus has adaptive traits caused by the fact that they lived in different types of soil.

The vertical differentiation of shallow marine areas reflects the height of the surf impact, the rhythm of tidal phenomena, the weakening of waves, and the decrease in subaquatic light with depth. These factors influence the entire set of environmental conditions that control the distribution of seabed biocenoses. The bathymetric profile is the basis of the conjugate series of benthic natural assemblages. Facies, landforms, and entire landscapes are subject to a regular change with depth.

Vertical zones are main units of subdivision of underwater landscapes with depth: *supralittoral*, *littoral* (*pseudolittoral*), *sublittoral*.

The next unit into which zones are subdivided vertically is called a floor. In the supralittoral, the floors reflect the height of the surf impact; in the littoral, tidal rhythms; and in the sublittoral, the weakening of the effect of waves on the seabed and the decrease in subaquatic light. Sometimes the floors can be subdivided into steps, which 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 for the vertical subdivision of landscapes of the coastal zone resembles a spring, compressed at the beginning and stretched at the end.

The concept of morphological units occupies a special place in studying underwater landscapes. They are the major target of marine and submarine investigations and mapping.

The landscapes are identified based on the analysis of regular spatial combinations of the morphological units.

Programme of comprehensive studying landscapes of the coastal zone

The programme of comprehensive studying landscapes of the coastal zone involves the solution of the following tasks:

1. To elicit morphostructural features of coasts, nature of differentiated most recent and recent tectonic movements; emphasize morphostructures controlling coast relief, dimensions and shape of the sea basin; show lines of the most recent active dislocations, which affect the formation of longitudinal and transverse coasts.

2. To provide insights into the influence of fluctuations in the level of the World Ocean and inland seas in the Pleistocene and Holocene on the formation of the present-day bottom relief of shallow marine areas; determine relief features of coasts and the underwater coastal slope of abrasion and accumulative types; indicated areas with an active and dead cliff, the depth of the rock belt and the role of continental runoff in the formation of its lower boundary; describe features of the biotope of rocks and stones and related life forms of hydrobionts; determine relief features of coasts and the accumulative-type submarine nearshore slope; specify the role of wave processes in the grading of sediments on the submarine slope and along the coastal sediment flow in the formation of offshore bars and other forms of accumulative relief; to characterize features of biotopes of mobile sand drifts and sandy-silty accumulative plains and related life forms of hydrobionts.

3. To assess the environmental role of hydrological conditions in the study area; determine the seawater salinity, identify brackish water areas with the salinity below the Knipovich boundary; identify the temperature regime of shallow marine areas; indicate the depth of the transition layer; study sea currents, showing the places of upwelling and downwelling; determine the local tide regime and the intensity of wind-driven waves.

4. To perform comprehensive study of the coastal zone and the shelf, using up-to-date methods of remote sensing, marine and underwater studies; draw boundaries of underwater landscapes and map their morphological structure based on morphostructural geomorphological and hydrological features; characterize underwater landforms and dominant facies; record their position in the system of units of the vertical seabed subdivision.

5. To determine the place of underwater landscapes in the system of units of morphostructural, zonal and vertical zoning; determine the areal of landscapes-analogues.

The implementation of landscape bionomic studies of the coastal zone and the shelf according to the proposed programme will ensure the uniformity of the work and comparability of results obtained.

Conclusion

1. Oceanology studies analytical patterns of evolution of some components of the oceanosphere.

2. Geography studies the hierarchical system of geographical landscapes, which resulted from the interaction between components of geospheres; principles of natural regionalization; landscapes as main initial units of zoning and targets of field studies.

3. Successful comprehensive study, development and protection of natural resources of the coastal zone and the shelf of the World Ocean require the use of analytical oceanological and comprehensive geographical research methods.

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