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Remote Monitoring and Mapping of the Shallow Seabed

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Abstract.

Natural factors, technical means for remote monitoring and methodology for interpreting remote sensing images are discussed. Natural factors that determine the monitoring conditions include hydrometeorological regime, topography, soil, and thickets of submerged aquatic vegetation. Submarine topographical features, soils and associated seabed biocenoses form regular combinations that make the base of morphological landscape units (submarine landforms and facies). The latter, having specific physiognomic features, serve as the main target of photography in airborne and satellite images.

The technique for remote monitoring the shallow seabed involves the use of equipment installed on aircraft, unmanned airborne vehicles (UAVs) and satellites; shipborne ultrasonic (sonar) survey is a special type of monitoring.

The fundamentals of the methodology for using remote sensing images were developed on the basis of interpreting large-scale airborne photographs of the shallow seabed.

The landscape method of image interpretation is based on the use of regular relationships between components of environment: through the identification and characteristics of targets

appearing in the images, a logical conclusion is made about the presence and properties of objects and phenomena that are not directly displayed in the images, but associated with them via natural connections. There are the laboratory stage, submarine studies, and extrapolation of interpreting features. Elementary airborne photographic standards are fragments from airborne photographs, which characterize images of seabed nature complexes (SNC) of key areas. Standards are used to extrapolate interpreting features to images of the same type. The inter-landscape extrapolation is performed by studying analogous landscapes and transferring the established interpreting features to unvisited water areas.

In conclusion, a programme of comprehensive landscape-bionomic studies is proposed. Remote monitoring and mapping of the shallow seabed based on the proposed programme will ensure uniformity of work and comparability of the results obtained.

Keywords: *remote monitoring, sea shallow areas, natural factors, technical means, interpretation, landscape method.*

Introduction

The importance of sea shallow areas in the history of human civilization is great. Sea coasts are the most populated areas with active human activities and developed infrastructure. Large port complexes and hydrotechnical protective structures have been built in the coastal zone. Electrical and telegraph cables and product pipelines are laid along the seabed; exploration and production of oil and gas is carried out there, placer deposits are developed. Mariculture farms aimed at growing algae, invertebrates and fish has been extensively developed. At the same time, the coastal zone of the sea is of great recreational value.

Current oceanographic studies gradually acquire the environmental focus that became particularly distinct in European countries and the USA in 2001. Under the auspices of the Intergovernmental Oceanographic Commission, UNESCO, and the Scientific Committee on Oceanic Research, the first international research programme was established, which launched the creation of the international association of marine scientists studying geological, biological and oceanographic processes as indicators of benthic habitats (GEOHAB = geo & habitat, https://geohab.org/). Taking into account the fragility of marine ecosystems, marine environmental policy programmes have been developed in the European Union and the

United States. In 2008, the European Union adopted the Marine Strategy Framework Directive in the field of marine environmental policy (Directive 2008/56/EC, https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32008L0056). The adopted strategy is aimed at developing the monitoring of the marine environment, which is a valuable heritage that requires the protection of biodiversity necessary for maintaining favourable environmental conditions. The US Geological Survey has proposed a 10-Year Science Strategy (2020-2030) for the study and protection of coastal and marine resources (https://geonarrative.usgs.gov/cmhrp/). This programme is aimed at the conservation of biodiversity and increase in the biological productivity of marine communities. Russia has developed a system of laws aimed at studying the rational use and protection of shelf resources.

Aerospace methods are effective for studying and mapping the seabed in the photic zone; at greater depths, in the aphotic zone, ultrasonic sonar survey is used. The paper deals with natural, technical means for remote monitoring and methods for interpretation of aerospace photographs. In conclusion, a programme for comprehensive landscape-bionomic studies of the shallow seabed is proposed.

Nature conditions for remote monitoring of the shallow seabed

Transparency of the water is a necessary condition for obtaining a seabed image. It is highest in tropical latitudes. In temperate and arctic regions, it is much lower. An assessment of the prospects for remote monitoring of the shallow seabed is given in Table. 1. It follows from the table that depths up to 20-25 m are available for surveying at least in 50% of the shallow seabeds of the World Ocean.

Table 1 Prospects for remote monitoring the shallow seabed (according to L. K. Lepley, 1968)

Water transparency (Secchi depth), m	Percentage of total coastline length	Distribution
0-5	15	In the mouth areas of large rivers, that draining humid areas.
5-20	50	Typical for coastal waters of temperate and arctic regions. They can also be seen in the tropics, where the upwelling of deep waters occurs.

Deeper than 20	35	Tropical regions (where there is no upwelling of deep waters), Mediterranean Sea
Deeper than 30	5	Lesser Antilles, eastern Mediterranean, Southwest Pacific islands.

In general, main natural factors that specify monitoring conditions are as follows: hydrometeorological regime, the topography of the coastal zone of the sea, morphostructures that experience the recent and current differentiated movements, and the morphological structure of submarine landscapes.

Hydrometeorological regime. The main feature of seabed monitoring is that the sun's rays that form the image must pass through the water column twice, which reduces the brightness and contrast of submarine objects. The adverse effect of water increases with the deterioration of its transparency and an increase in the depth of the sea; the faster the depth increases and the worse is the transparency, the lesser is the depth and width of shallow seabeds available for monitoring. It has been empirically established that, on average, the depths available for display are one-third greater than the transparency of the sea, measured by a standard Secchi disk. Thickets of submarine vegetation, which are formed only when there is sufficient light for photosynthesis, are an indirect indicator of the depths available for photography. For example, on the coast of the Kola Peninsula (Barents Sea), this depth is 15 m.

The influence of the water column on the image quality has a pronounced spectral course: the greatest image contrast is achieved in the green part of the spectrum. Flecks of sunlight on the sea surface obscure the image of the seabed. The area covered with the flecks of sunlight depends on the intensity of waves and the height of the Sun above the horizon. Shooting is recommended to be carried out at a relatively low standing of the Sun and excitement of no more than 2 to 3 points.

Thus, the meteorological and hydrological regimes of water areas and their seasonal changes largely control the possibilities of monitoring. The situation is favorable when the weather is clear, visibility is good, the sea surface is calm and clean (free of ice, oil films, etc.), water transparency is high.

Topography of the coastal zone of the sea. The topography, depth and area of the coastal zone are the main parameters that should be taken into account when planning monitoring. The closest to the average position of the lower boundary of the coastal zone is the 30 m isobath. Shallow marine areas bounded by this isobath are most accessible for monitoring (Table 2).

Table 2 Areas of shallow marine waters (thous. sq. km)

Seas	**Depth steps, *m***		
	0-20	20-50	0-50
Sea of Azov	-	-	41
Northern part of the Black Sea	17	30	47
Caspian	148	52	200
Eastern Baltic Sea	25	30	55
Barents	44	68	112
Sea of Okhotsk	61	98	159
Northern Sea of Japan	8	16	24

Morphostructures. Recent and current differentiated movements play a leading role in the topography formation of marine margins of platforms and orogens. Morphostructures control the topography of the coast, the contour of the coastline, and the considerable steepness of the submarine slope. There are longitudinal coasts, characterized by fold axes located along the coastline, and transverse coasts, where the axes of the folds run along the normal to the coast. Growing longitudinal banks are characterized by the formation of a coastal cliff, a steep submarine abrasion coastal slope. Only a narrow strip of shallow marine areas is available for monitoring. Near the transverse-type coasts, the axes of growing folds continue into the sea to form a system of capes, islands, and bays. A significant area of shallow water is available for monitoring. Stony reefs, banks, etc., overgrown with algae and invertebrates, combined with flat areas composed of sand and shell sediments, make a contrasting pattern that is easily recognizable during monitoring.

A thick sequence of loose Quaternary sediments is formed in the place of tectonic troughs as well as shores with a sandy beach and a wide submarine accumulative plain. In general, submarine accumulative plains give a monotonous image, gradually merging with the water column. At a depth of up to 5 meters in the zone of active wave action, the image of submarine coastal ridges, spits and other accumulative forms of topography is clear.

Morphological structure of submarine landscapes. Submarine topography features, soil, and associated seabed biocenoses form regular combinations that represent a basis of seabed natural complexes (SNC). In landscape science, they form a system of intralandscape morphological units – facies and landforms (Petrov, 1989). The latter have characteristic physiognomic features and serve as the main object of the image in airborne and space photographs.

Let us study a landscape map of the Absheron Archipelago as an example (Fig. 1).

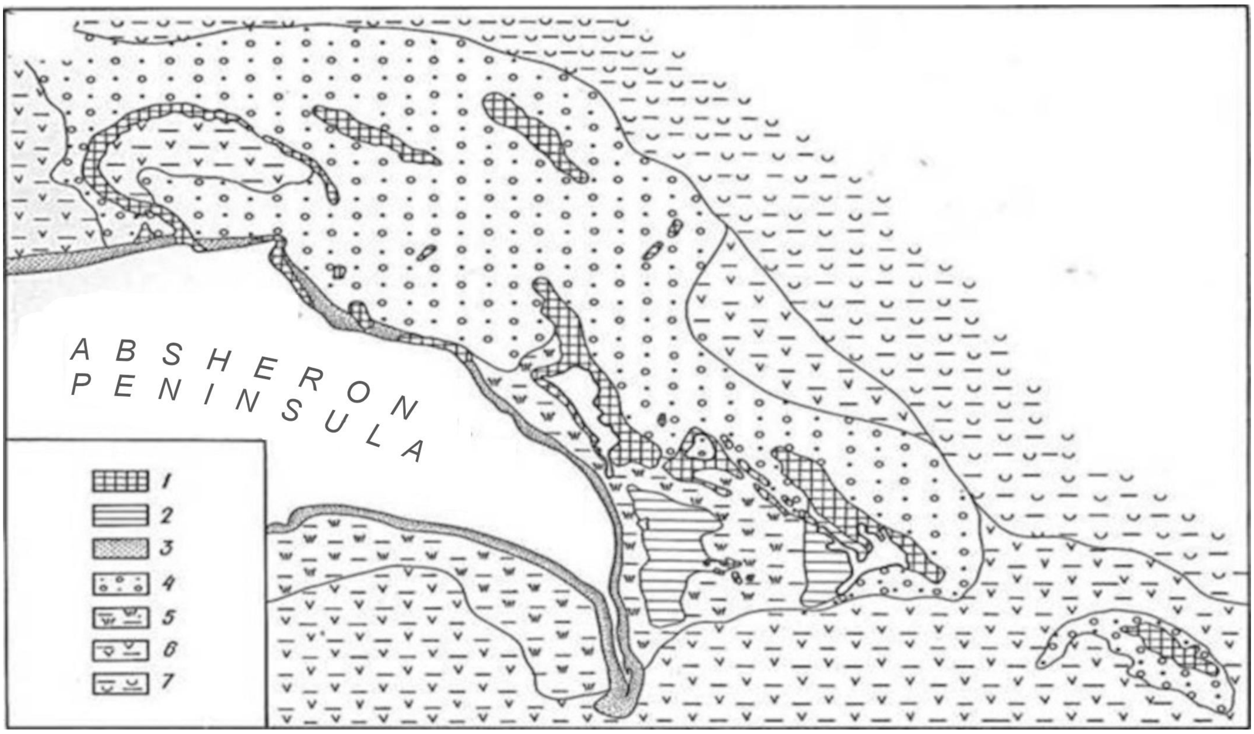

Fig. 1 Landscape map of the Absheron Archipelago (Caspian Sea).

Legend. Submarine landforms:

1 – Cliffs and stones; 2 – plains; covered with lithified crust; 3 – longshore bars; 4 – shell fields; 5 – seagrass meadows; 6 – muddy plains of the coastal zone; 7 – muddy plains outside the coastal zone at a depth of more than 20 m (Gur'eva, Petrov, Sharkov, 1976).

A brief description and typical airborne photographs of some landforms are given below.

Landforms of cliffs and stones are represented by abrasion-sculptural forms of topography, caused by outcrops of layers of strongly cemented rock in bedrock occurrence. In the airborne photograph (ABP), they receive a representative image reflecting the strike of the layers that outline the anticline fold wing (Fig. 2).

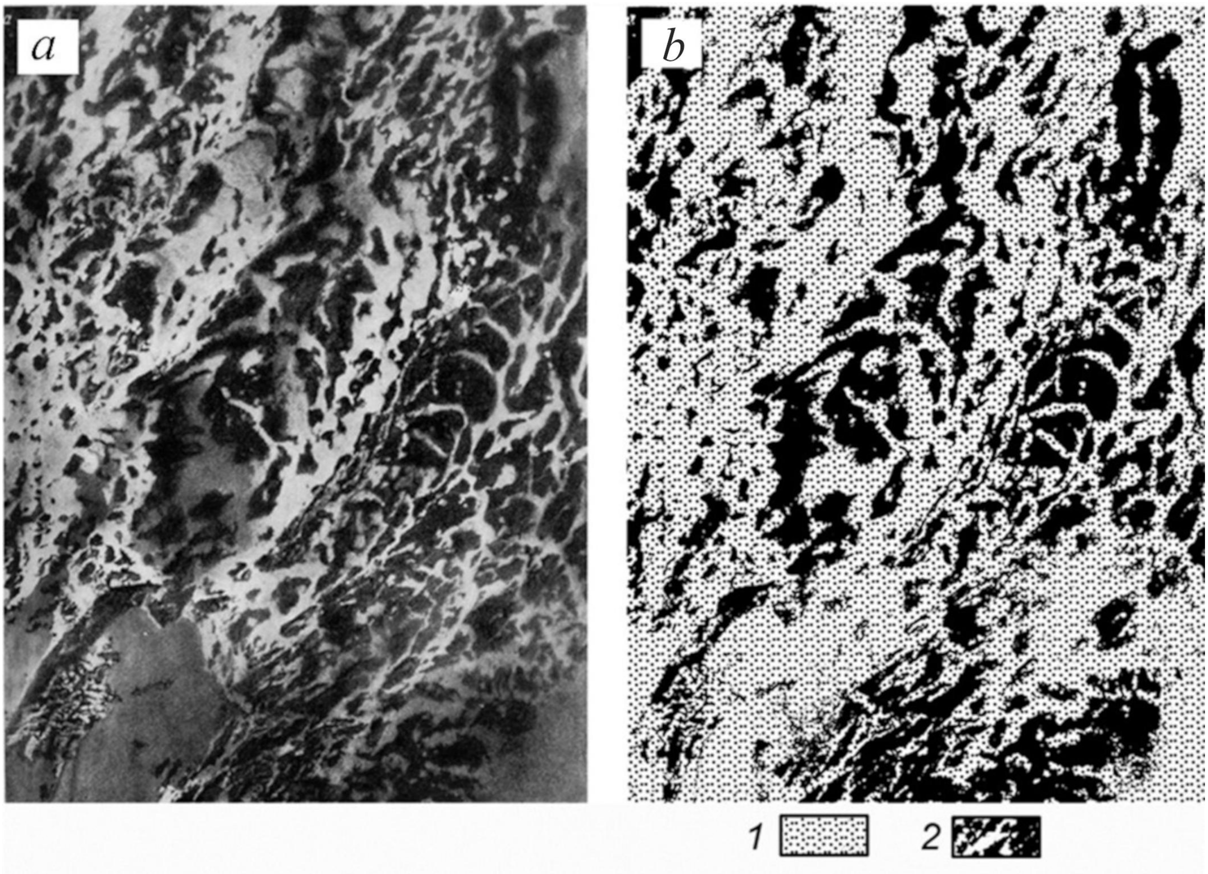

Fig. 2 Airborne image of landforms of cliffs and stones and its geological interpretation. Absheron Archipelago (Caspian Sea)

(a) Image of rocky ridges outlining the anticline fold wing. Airborne survey, scale 1:15,000; (b) transformation of airborne image into a graphical form, the basis of a geological map. *1* – recent sediments, sandy-shelly banks; *2* – bedrock layers outlining the anticline fold wing (Gur'eva, Petrov, Sharkov, 1976).

Landforms of cliffs and stones are a biotope of lithophilic hydrobionts: algae and invertebrates (Fig. 3).

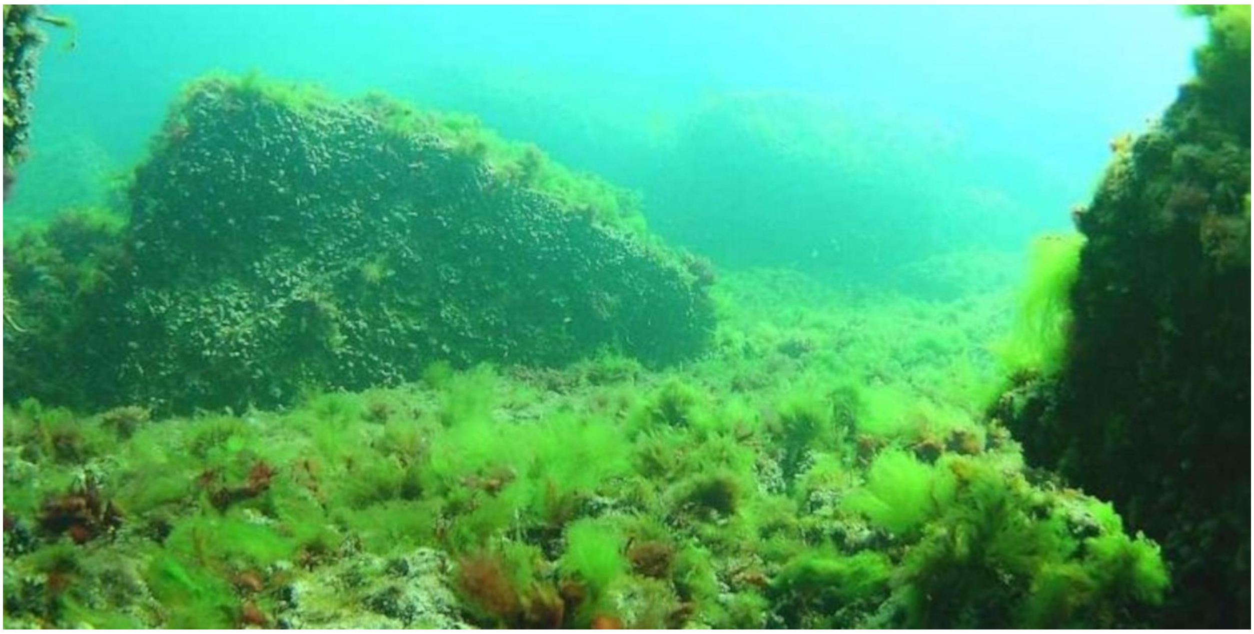

Fig. 3 Area of cliffs and stones: the top of the bank, overgrown with algae. Phytocenosis of green algae Cladophora + Enteromorpha and red algae Cerannum elegans + Laurencia caspica (underwater photo. From:https://travel2baku.com/ru/ru-this-is-azerbaijan-diving-azerbaijan/)

Landforms of the seashell fields are represented by sandy-shelly banks covering the abrasion-accumulative plain. On airborne photographs they have a monotonous light grey image, complicated by accumulative landforms (Fig. 4).

Fig. 4 Image of a seashell field complicated by flat submarine bars. Absheron Archipelago (Caspian Sea). Depth is 10 m. Airborne survey, scale 1: 15,000 (Gur'eva, Petrov, Sharkov, 1976).

Seashell fields occupy the largest area in the landscape of the Absheron Archipelago (Fig. 1). Due to the absence of the coastal runoff and the influx of terrigenous material from land, the main component of the sediments is autochthonous biogenic material – seashell (Fig. 5).

Fig. 5 Seashell field landforms: valves of mollusks Didacna, Hypanis, Dreissena elata, Mytilaster lineatus (underwater photo by K. Petrov)

Seagrass landforms are formed in transparent water at a depth of up to 5-6 m, protected from waves and currents by shore cusps, islands, and stone ridges. They have a representative image in the ABP (Fig. 6).

Fig. 6 Seagrass landforms. Absheron Archipelago (Caspian Sea). Depth is 6 m. ABP, scale 1:5,000 (Gur'eva, Petrov, Sharkov, 1976).

Seagrass landforms are dominated by *Zostera minor* and *Ruppia maritima* creeping stem grasses, forming thickets with high, sometimes complete density on sand-silt soils with an admixture of shells (Fig. 7).

Fig.7 Seagrass meadow landform, Zostera minor phytocenosis (underwater photo. From:https://www.shutterstock.com/ru/video/clip-1092936653-undersea-landscape---pov-scuaba-diving-over)

Technical facilities for remote monitoring

Technical facilities for remote monitoring of the shallow seabed include equipment installed on aircraft, unmanned airborne vehicles (UAVs) and satellites; a special type of equipment is shipboard ultrasonic (sonar) imaging.

Airborne survey (ABP). The beginning of the scientific and practical application of ABP in Russia dates back to the 60s of the 20th century, when there was a need for geological study and mapping of the shallow seabed of the Absheron Archipelago (Caspian Sea) for oil field explorations. The technical facilities and environmental conditions of ABP were developed at the Laboratory of Airborne Methods in the USSR Academy of Sciences (Gur'eva, Petrov, Ramm, Sharkov, 1968; Gur'eva, Petrov, Sharkov, 1976).

The survey was carried out with long-focus airborne cameras (f = 40 mm) with an angle of view of about 80°. A highly sensitive contrast aerofilm sensitized to the green part of the spectrum was used. The AS-1 isochromatic aerofilm used in fluoroscopy met these requirements. In the process of shooting, a yellow light filter JhS-12 (and when shooting from a height of more than 1000-1200 m - a light filter JS-18) was used; polarizing light filters were used for other purposes: with their help, the image of sun glare on the sea surface was completely or partially extinguished.

Orthogonal airborne survey was carried out at a scale of 1:5000-1:10000. The images were assembled into print laydowns and on their basis composite photographs were made, which covered large areas of shallow seabed (Fig. 8).

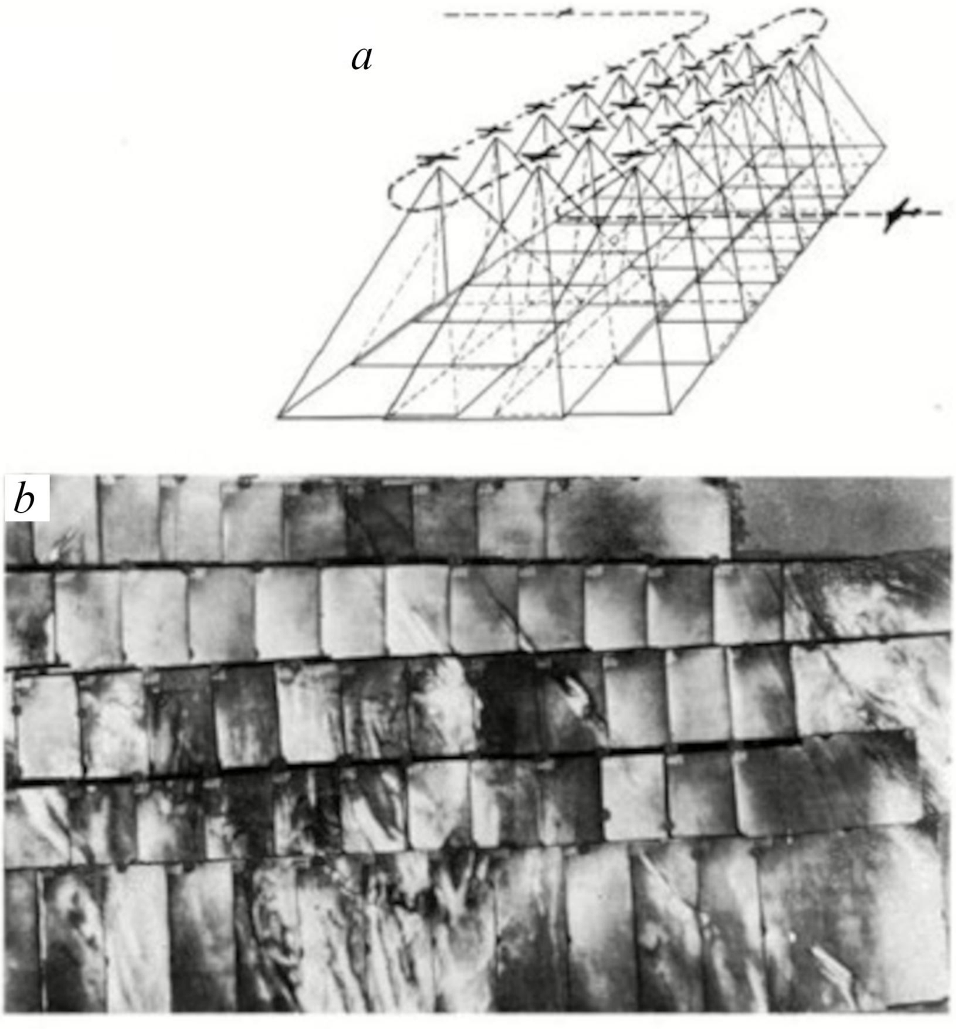

Fig. 8 Map of orthogonal ABS *(a)* and print laydown *(b)* (Gur'eva, Petrov, Sharkov, 1976).

In addition to shooting on black-and-white film, experience was gained in using multispectral films. The latter are characterized by high sensitivity in both the visible and infrared spectral bands. In spite of the fact that the water column absorbs infrared radiation, an important additional feature for interpreting multispectral images appears: it is colour, for interpreting surface objects (Fig. 9).

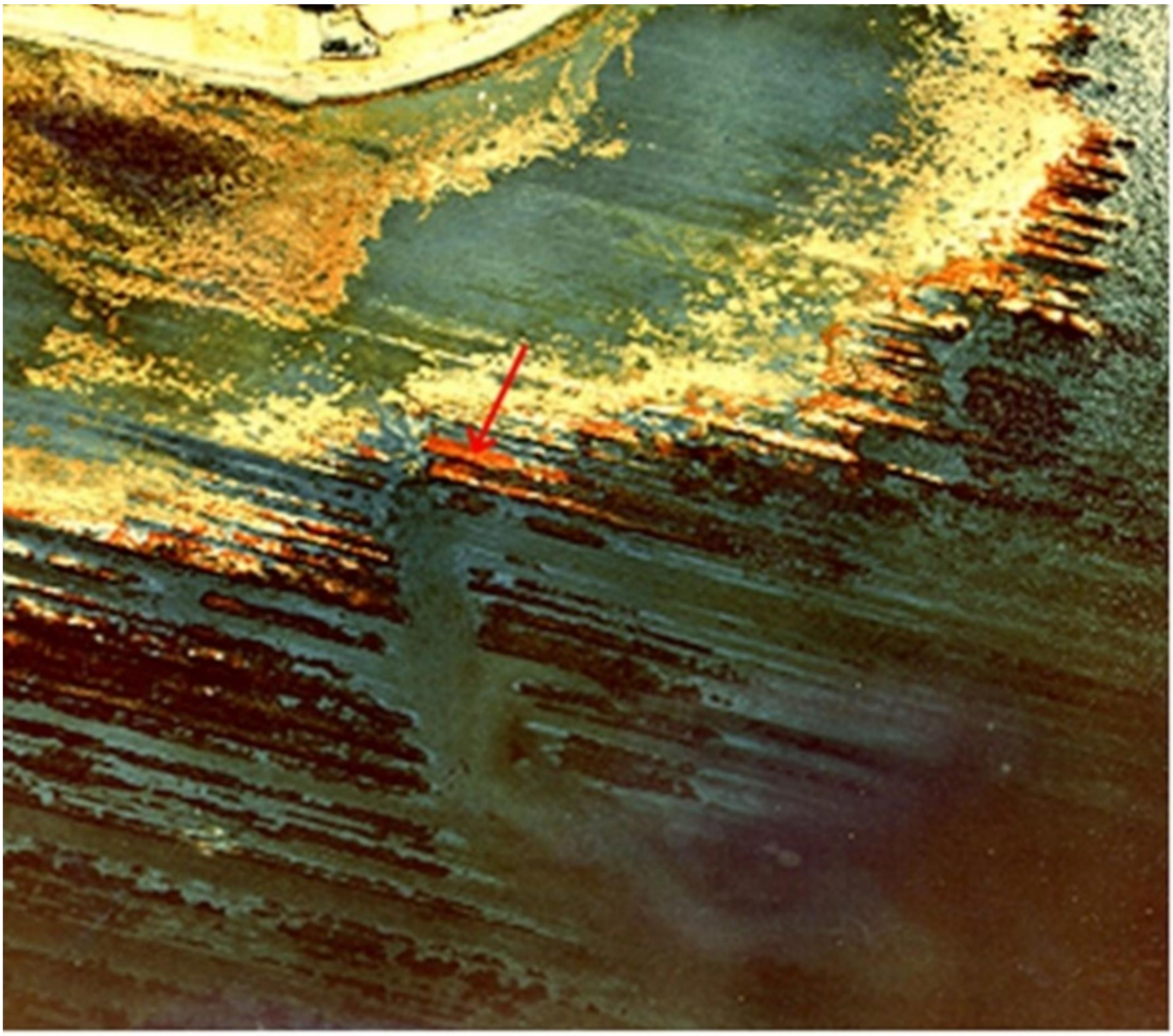

Fig. 9 Image of a high bank to which a low terrace with houses and a road adjoins; then there is a wide littoral zone (foreshore), and an abrasion sculptural-ridge slope adjoins it. A clear image in the form of dark brown stripes was obtained for kelp thickets on ridges. As the depth increases, the water column decreases the colour intensity, and the seabed image becomes monochromatic. Western coast of southern Sakhalin. Multispectral airborne image, scale 1:10,000 (archive of K.M. Petrov).

Satellite survey. In the second half of the 20th century, the era of monitoring the World Ocean from space began (O'Neill, 2011; Tkachenko, 2012; Kutser, 2020). Main advantages of satellite imagery are as follows: large area covered by the survey; high resolution up to 0.3 m; multispectral survey in more than 10 spectral bands; the ability of long-term monitoring. Google Maps, Esri, Bing, etc. are public Internet services with available satellite images (Fig. 10). For example, a fragment of a composite of a satellite image from Google Earth displays a shallow seabed pattern formed by rocky ridges. Imagery of very high-resolution and quality can be ordered in some companies, such as Maxar, Airbus or Planet Labs.

Fig. 10 Image of ridges overgrown with algae and invertebrates, outlining a fragment of an anticline fold on the submarine nearshore slope of Pirallahi Island. Absheron Archipelago (Caspian Sea). Satellite image from Google Earth, based on Airbus Pleiades image composite, 0.5 m resolution.

Survey from unmanned airborne vehicles (UAV). In the 21st century, UAV surveys are being widely developed for the purposes of environmental monitoring of shallow seabed. The flight of the UAV is carried out according to a given programme or is controlled remotely. As a rule, surveys are performed to monitor small water areas at a large scale. Digital cameras provide high resolution multispectral images. The UAVs are equipped with an inertial measurement unit (IMU) and a satellite navigation system (GPS), which makes it possible to determine the position of the camera in flight with a geodetic accuracy of up to 3 cm in plan and height. These data are taken as the basis for coordinating images on the ground. Results of remote monitoring of the seabed area in the Tyrrhenian Sea using the DJI Mavic 2 Pro UAV are shown as a case study (Fig. 11).

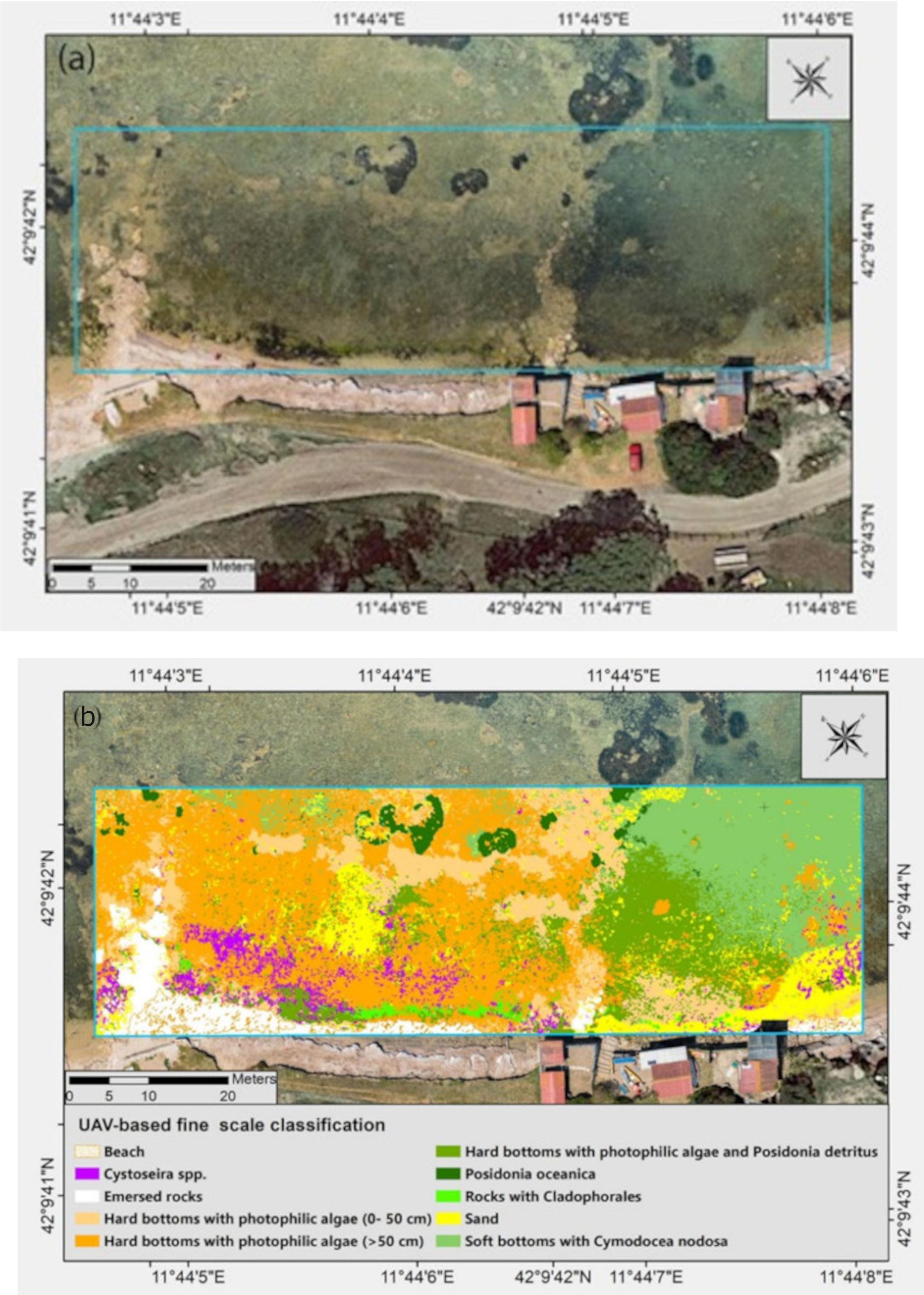

Fig. 11 Application of materials from large-scale airborne survey of the seabed in shallow marine areas obtained from a DJI Mavic 2 Pro unmanned aerial vehicle with a Hasselblad L1D-20c digital camera in the RGB range (Ventura et al., 2023). (a) Mosaic of 1:500 scale airborne images of the shallow seabed of the

Tyrrhenian Sea off the coast of Italy; (b) Map of submarine vegetation and soils, compiled on the basis of ABP interpretation materials. Legend: 1 – bench, 2 – Cystoseira spp., 3 – Surface rocks, 4 – Green filamentous Cladophorales on stony soil, 5 – Light-demanding algae: red (Jania rubens, Corallinales), brown (Padina pavonica, Halopteris scoparia and Dictyota dichotoma) on stony soil at a depth of 0-50 cm, 6 – Light-demanding algae: red (Jania rubens, Corallinales), brown (Padina pavonica, Halopteris scoparia and Dictyota dichotoma) on stony soil at a depth of more than 50 cm, 7 – Light-demanding algae: red (Jania rubens, Corallinales), brown (Padina pavonica, Halopteris scoparia and Dictyota dichotoma) on stony soil at a depth of more than 50 cm, 8 – Light-demanding algae: red (Jania rubens, Corallinales), brown (Padina pavonica, Halopteris scoparia and Dictyota dichotoma) on rocky soil at a depth of more than 50 cm with the participation of leaves and rhizomes of the Posidonia oceanica seagrass, 9 – Posidonia oceanica seagrass on sandy soil, 10 – Sandy soil, 11 – Cymodocea nodosa seagrass on sand-silt soil.

Sonar systems (Sound Navigation and Ranging) are used for surveying the seabed at depths inaccessible to optical methods. The sonar image is obtained by fixing the reflected ultrasonic signal. Modern systems allow mounting individual images into orthogonal layouts of significant areas of the seabed (Fig. 12). These layouts depict an important natural factor – forms of topography and seabed soil types.

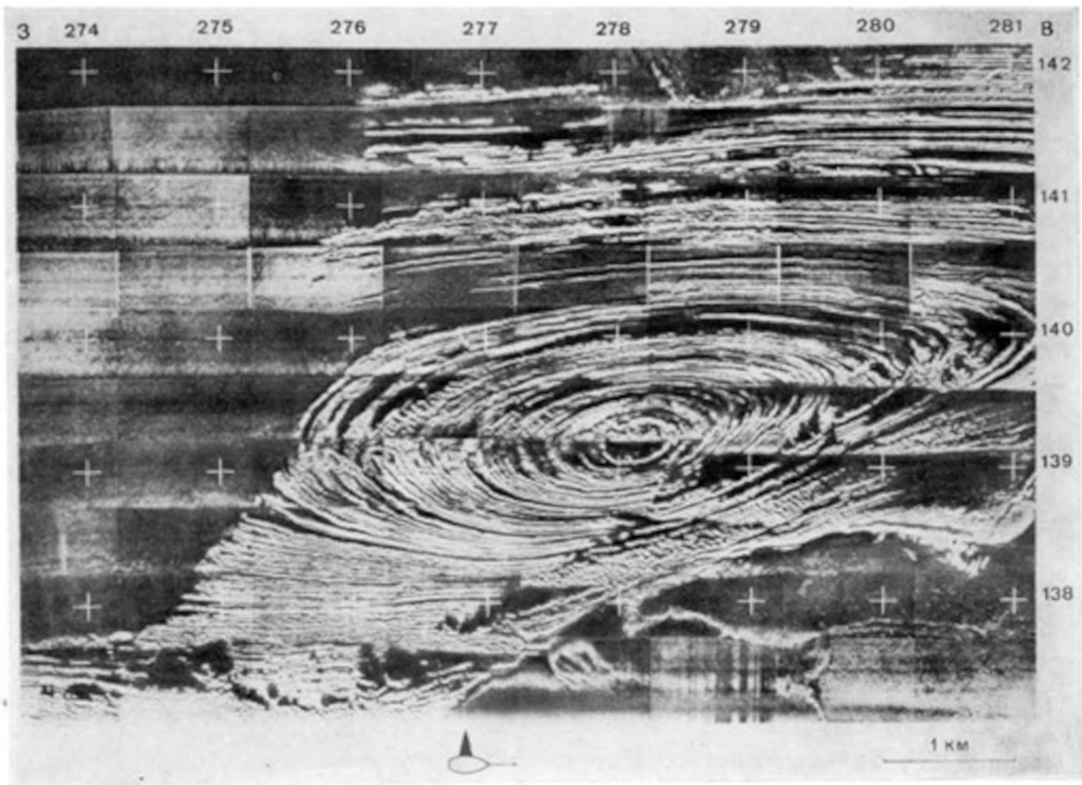

Fig. 12 Sonar image of an anticlinal fold on the seabed of the Bay of Biscay, depth is about 40 m. It is easy to see sculpture-ridge landforms in the place of a sequence of flysch-like interbedded rocks exhumed by abrasion (materials of the French Petroleum Institute).

The intensity of the sound signal reflection varies depending on the soil density: from rocks, the reflection is maximum, from silt, minimum. This allows sonar systems to be adjusted in such a manner that different types of soil receive a specific colour image.

For example, Fig. 13 shows a landscape map of a test area located in the Norwegian sector of the Barents Sea at a depth of more than 200 m. A landscape dominated by stones, gravel and sand (SNC 3,4,5,6) was identified based on the nature of the seabed natural complexes' (SNC) mosaic in the central part of the test area. To the northwest and northeast, it is bordered by deeper water landscapes dominated by SNC 1 and 2 with silt soil.

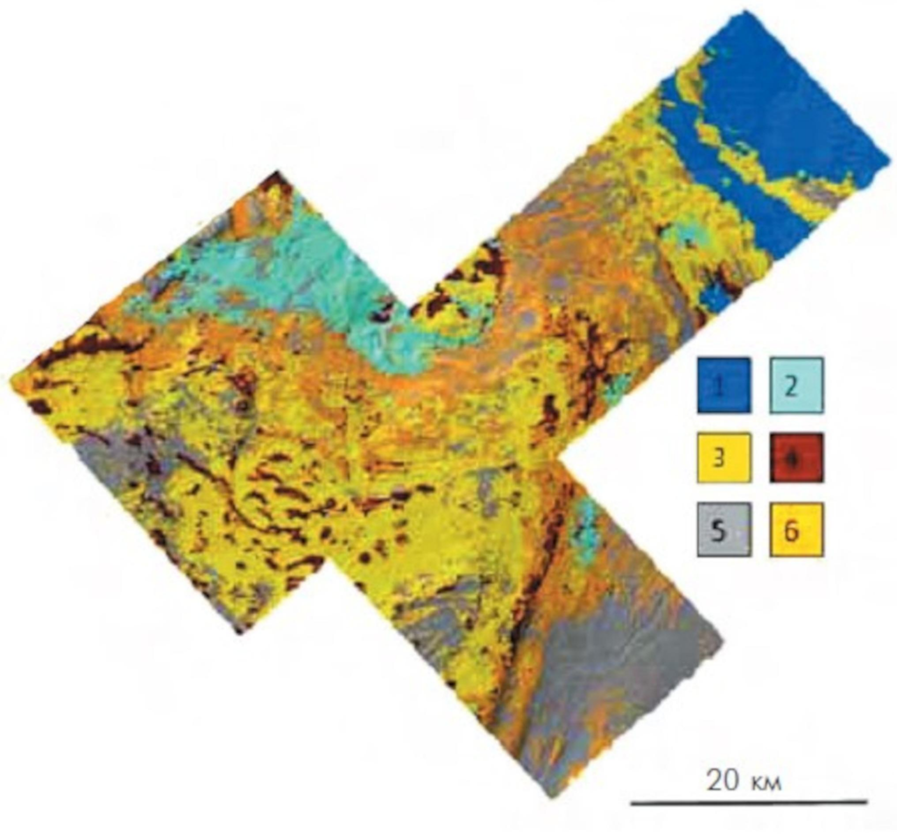

Fig. 13 Seabed natural complexes of the landscape in the Norwegian sector of the Barents Sea shelf, according to MAREANO data (http://www.imr.no/english/activities/mareano) .

Legend: 1 – clay silt, typical fauna: Pelosina/Asbestopluma; 2 – sandy silt, typical fauna: large sponges; 3 – sand, typical fauna: Ceramaster/Stichopus; 4 – sand with gravel, typical fauna: Stylocordyla/Aphrodite; 5 – stones with sand, typical fauna: Phakellia/Axinella; 6 - accumulations of large stones, typical fauna: Polymastia/Porania.

Manned submersible, television and automatic photography are used for interpreting sonar images.

Interpretation of remote sensing images

In orthogonal photographs, the seabed sometimes has a clear and detailed image. However, the unusual angle makes even a large-scale image incomprehensible for its interpretation. Methodological foundations for using remote sensing images were elaborated on the basis of the interpretation of large-scale airborne images of the shallow seabed (Gur'eva, Petrov, Sharkov, 1976). The simplest method of interpretation can be called subject-specific.

The subject-based interpretation method consists in a comparative analysis of image elements on the ABP with objects on the seabed. For example, the ABP of the shallow marine area of the Absheron Archipelago (Caspian Sea) is characterized by a pattern formed by dark spots on a light grey background (see Fig. 2). As a result of submarine studies, it was found that dark spots on the ABP correspond to bedrock layers, which underwent marine erosion and overgrown with red algae, and a light tone corresponds to a field of sand-shell sediments (Fig. 14).

Fig. 14 Submarine landforms controlling the formation of dark and light image details on the ABP (underwater photograph by K.M. Petrov). Description in is given in the text.

For the deep comprehensive interpretation of remote images, a landscape interpretation method is used.

The landscape interpretation method is based on usage of regular relationships between components of nature: through the identification and characterization of objects depicted in images, a conclusion is made, based on logical approach, about the occurrence and properties of objects and phenomena that are not directly displayed in the images, but are associated with the former via natural links. The geometric and spectral features of image details can serve as interpreting features that bear information both about individual components of nature and about the SNC as a whole. Let us consider the landscape interpretation method in more detail using the example of developing interpreting features used for the interpretation of large-scale black-and-white ABP. There is a natural association between certain types and forms of submarine terrain, petrographic features of bedrock, geological structure, soil and groups of seabed biocenoses with the SNC and images of the latter in photographs.

The laboratory stage, submarine studies, and extrapolation of interpreting features are distinguished when developing the interpreting features.

Laboratory stage. Before starting offshore operations, main types of patterns are outlined in the photographs of the studied area and a preliminary contour base of SNCs is created, which receive a characteristic image. The corresponding site on the soil is taken as the key one. The interpreting features developed in it are applied to all images of the same type.

Marine studies. The outlined key areas are successively visited and described during the diving survey using modern navigation tools. The method of describing points and establishing landscape profiles is used in the work. The airborne photograph of the key area is described in detail; during the description, identifying features are developed. To maintain uniformity and a certain order in the observations, it is recommended to describe the key area according to the following programme: profile number, station number, georeferencing, depth fluctuations, and the name of the natural complex. When describing the SNC, following features should be included:

- In places of abrasion-sculptural forms of topography at the place of bedrock outcrop, their petrographic composition, shape, height and strike of ridges are indicated;

- In places of accumulative topography, the forms resulted from wave activities (offshore bars, spits, etc.) are described. A successive change in the granulometric composition of sediments along the profile is recorded.

- Seabed biocenosis (phytocenosis and zoocenosis). When describing phytocenoses (vegetation communities), the projective cover, height, abundance and composition of macrophytes are recorded: green, brown, red algae and seagrass. When describing zoocenoses (animal communities), the composition of nektobenthos, free-ranging and free-lying on the seabed forms of timber beetles, forms that grow over rocky ground (sessile fauna), and forms that burrow into loose soil (infauna) are recorded.

In order to graphically display the association of main components of geographical complexes in space, to tie them to the features of the image in airborne photographs, landscape profiles are arranged. They are based on the bathymetric profile (as a rule, its direction coincides with the normal to the coastline, across isobaths). Symbols show geology, structure, soil, seabed biocenoses. Vertical lines, which divide the profile line into a series of segments, show SNC boundaries. The description is carried out along the measuring line. As an example, Fig. 15 shows the landscape profile of the upper part of the submarine nearshore slope and a fragment of the ABP corresponding to the profile line (Fig. 15).

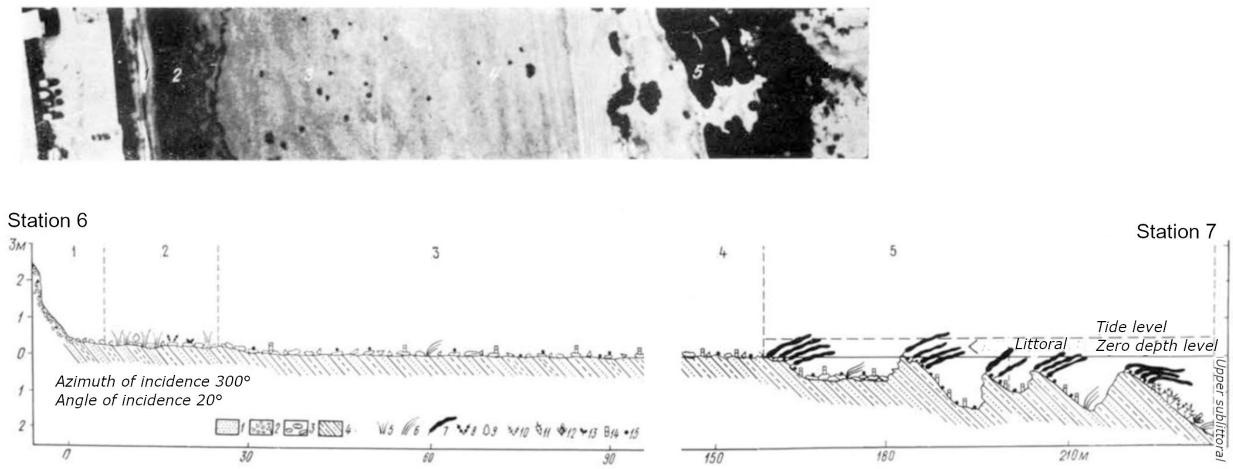

Fig. 15 Interpreting the ABP of the upper part of the submarine nearshore slope (southwestern Sakhalin) by the landscape profile method (Gur'eva, Petrov, Sharkov, 1976).

a - strip of airborne image corresponding to the profile line: 1 – a narrow strip of white and light grey colour, corresponding to the image of the surface and underwater parts of the beach; 2 – small-spotted grainy pattern associated with the image of a complex vegetation cover, where dark details are due to zoster spots, and light details are due to a sparse algae cover on the cobble seabed; 3 – light grey colour corresponding to the flat-smooth cobble seabed with a sparse cover of calcareous algae; the strike of bedrock layers is guessed from slight banding of the pattern; 4 – dark spotty, grainy pattern of the image, due to seagrass thickets (Phyllospadix), occupying large areas in some places; 5 – large spots and bands of intense dark colour – kelp thickets on tops of ridges; ridges and depressions between ridges with a calcareous algae cover – light colour with a slight banding of the pattern due to stratification lines; *b* – landscape profile through the airborne image above. Description points on the ABP (1-5) correspond to the points shown in the upper part of the profile. Soils: 1 – sand, 2 – pebbles and gravel, 3 – boulders, 4 – bedrock; underwater vegetation: 5 – Zostera marina, 6 – Phyllospadix iwatensis, 7 – Laminaria japonica, 8 – Sargassum mijabei, 9 – Ptilota filicina, 10 – Ulva fenestrata, 11 – Tichocarpus crinitus, 12 – Laingia pacifica, 13 –

Corallina pilulifera, 14 – Pachyarthron cretaceum, 15 – calcareous algae.

When interpreting the submarine landscapes of the coastal zone, the bathymetric profile is based on the echogram of the topography. Characteristic airborne photographs are taken as key areas that are surveyed during diving operations. These images are considered as airborne photographic standards, which are attached to the landscape profile (Fig. 16).

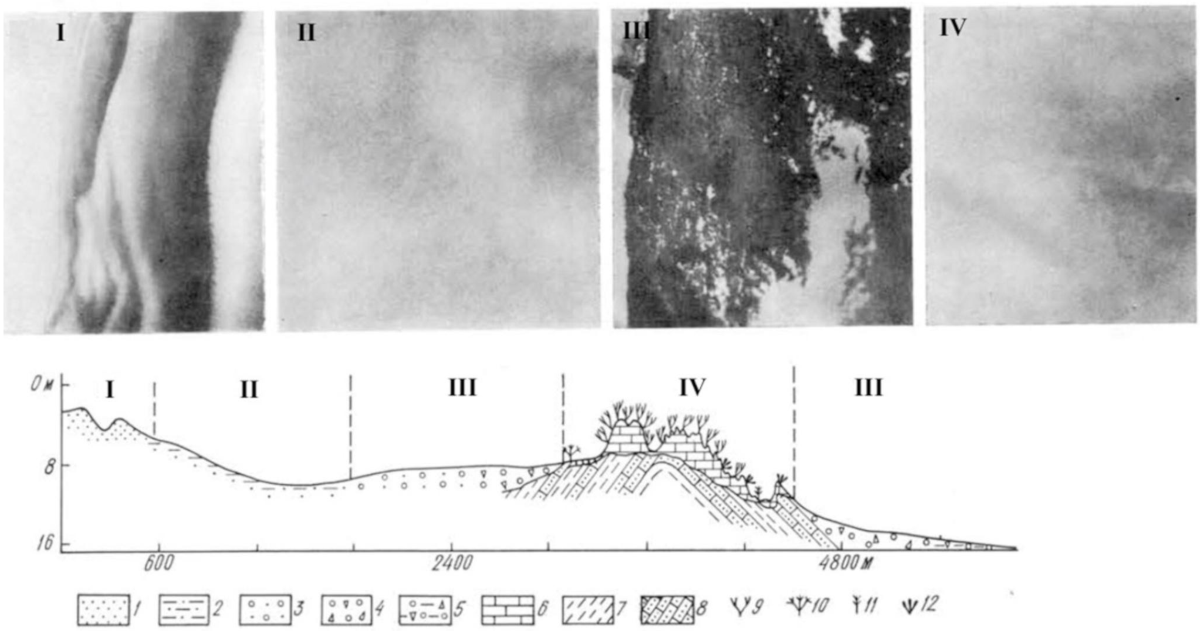

Fig. 16 Fragment of the landscape of the submarine slope of the Anapa Spit, the Black Sea (Gur'eva, Petrov, Sharkov, 1976). a – airborne photographic standards. I – submarine coastal bars; II, IV – shell field; III – bank formed by densely cemented rocks densely overgrown with algae (cystoseira biocenosis). b – landscape profile. *Submarine areas* (vertical dashed lines): a – beach barrier, b – sandy plains, c – shell fields, d – rocks and stones (stony bank), e – silt–shell plains; soils: 1 – sandy, 2 – silty-sandy, 3 - sandy-shelly, 4 – shelly-whole and broken shells, shell sand, 5 – silty-shelly; *bedrock*: 6 – Quaternary lithified shell rocks, 7 – Meotic clays, 8 – Meotic marls; *vegetation*: 9 – Cestoseira barbata, 10 – Nereia filiformis, 11 – Chondria teunissima, 12 – Phyllophora nervosa.

Airborne photographic standardization and extrapolation of interpreting features.

Airborne photographic standardization is faced with the task of presenting the most characteristic images of the SNC revealing the nature of the submarine landscape as a whole. The interpretation of the submarine coastal zone landscape is provided owing to the development of a system of elementary airborne photographic standards. The latter are clippings from airborne photographs that characterize the images of the SNC of key areas. They are systematized in the form of symbols to the airborne image of the entire landscape and used to extrapolate interpreting features to images of the same type.

Intra-landscape extrapolation is carried out by transferring interpreting features from key areas to similar airborne photographs. Inter-landscape extrapolation is implemented through studying analogous landscapes and transferring the established interpreting features to the territories of unvisited landscapes that are of the same type as the studied ones. The areal of inter-landscape extrapolation is associated with boundaries of physical and geographical zoning. The reliability of extrapolation is the higher, the closer the analogous landscapes lie in the classification system and in the zoning grid.

Programme of integrated landscape-bionomic studies of the shallow seabed

The programme of integrated investigations elaborated on the basis of the experience of landscape-bionomic studies in the seas of Russia is given below (Petrov, 2023). Activities, based on the interpretation of remote images, marine and submarine studies, are proposed to be directed to the solution of the following tasks.

1. Reveal the topography features of marine margins related to the latest inherited differentiated evolution of morphostructures:

- morphostructures experiencing inherited uplift, lines of the latest active dislocations, longitudinal- and transvers-type coasts;

- high coasts with an active cliff; on the seabed there are abrasion-sculptural banks and reefs. Biotope of rocks and stones, fouler biocenoses;

- morphostructures experiencing inherited subsidence and related coastal lowlands and the accumulative-type submarine coastal slope. Biotope of sand-silt soil, biocenoses of burrowing groups of hydrobionts (infauna).

2. Assess the ecological role of hydrological conditions:

- temperature regime, salinity, depth of the transition layer;

- sea currents, places of upwelling and downwelling;

- local regime of high and low sea, the intensity of wind waves.

3. Outline boundaries of submarine landscapes and map their internal morphological structure based on morphostructural, hydrological and hydrobiological features:

- describe submarine landforms and dominant facies;

- record their position in the system of vertical seabed units.

4. Determine the place of the landscape in the system of units of geographical zonality, vertical zonation and morphostructural zoning.

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

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