MARINE SEABED LANDSCAPE ANALYSES BASED ON HYDROACOUSTIC DATA, UNDERWATER VIDEO RECORDINGS AND BOTTOM SAMPLING IN THE SOUTHERN PART OF THE BARENTS SEA USING GIS DATABASE

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Abstract
We present analyses of marine seabed habitats in the areas of detailed survey in the southern part of the Barents Sea.The actual material was obtained during the 28th cruise of the RV Akademik Nikolay Strakhov (cruise TTR-18, UNESCO-MSU, Geological Institute, RAS, 2011). The hydroacoustic data includes multibeam (MBE) bathymetry and backscatter data (more than 6200 km), side scan sonar data (about 800 km), and subbottom profiling data (the total length is 6500 km). Data on the composition of benthos and benthic communities were obtained by a towed underwater video system (16.5 hours) and by biological and geological sampling (dredge and tube) (57 stations). Based on the results of the geological-geomorphological and biological analysis, a comprehensive geoinformation database is created in the ArcGIS environment. We present geomorphological and biological characteristics of habitats for the areas of interest.

Keywords: *marine seabed landscapes, multibeam echosounder data, side scan sonar data, underwater video recording, bottom sampling, pockmarks, salt diapir, benthic communities*

INTRODUCTION

The shelf of the Arctic seas, and especially the Barents Sea, is the subject of active economic development, exploration and extraction of marine biological and mineral resources. The Barents Sea is of special interest with the development of new gas and oil deposits. Increasing anthropogenic pressure on natural resources of the world ocean requires scientifically sound rational use of marine resources, as well as monitoring and forecasting of the dynamic conditions of marine landscapes. The emergence of new remote methods of marine ecosystems investigation and mapping (Clarke et al, 1996, Fossa, 2005, Schoening et al, 2012) increase the relevance of study of underwater landscapes. A direct visual study of marine ecosystems is accessible only within shallow coastal zone and is limited by depths for human diving. In other cases underwater vehicles are used for visual research. Therefore marine ecosystems and landscape study is costly and time consuming and allow limited areal coverage, which causes a general low level of knowledge. It requires extensive involvement and development of additional remote methods, as well as integrated data analysis. The study area of North–Kildinsky gas deposit is of high interest for ecological studies, as a potential mining area endangered by subsequent reduction of biological and landscape diversity. In addition, this sector of the Barents Sea was "gray zone" (Fig. 1) between Russia and Norway for a long time and was not investigated by modern methods. Solved issue of the disputed economic interests between Russia and Norway resumed interest in the area.

The Barents Sea landscapes are explored mainly on large scale (Zenkevich, 1963, Sorokin, 1987, Kiyko and Pogrebov, 1998, Novikov and Plotitsyn, 2003, Petrov, 2009). Detailed studies and monitoring sites are concentrated mostly in the coastal zone in Murmansk region. Main subjects of marine ecological studies are general biodiversity and bioproductivity of the Barents Sea or studies of specific species. Despite a large number of scientific and applied studies of marine landscapes (Guryanova, 1962, Markov, 1968, Lymarev, 1985, Poyarkov, 1980, Manuilov, 1982, Preobrazhensky and others, 2000, Petrov, 2009), there is still no complete developed methods for their investigation and no clear definition of the concept. Habitat mapping tehniques and seafloor classification methods using remote hydroacustic methods such as MBE and side-scan sonars has been developed in last two decades (Buhl-Mortensen et al, 2015, Dolan et al, 2009). Economically developed countries such as the USA, Norway, Canada and others have federal programs aimed at effective and multipurpose application of time and resource consuming data (Pickrill and Todd, 2003, Buhl-Mortensen et al, 2015).

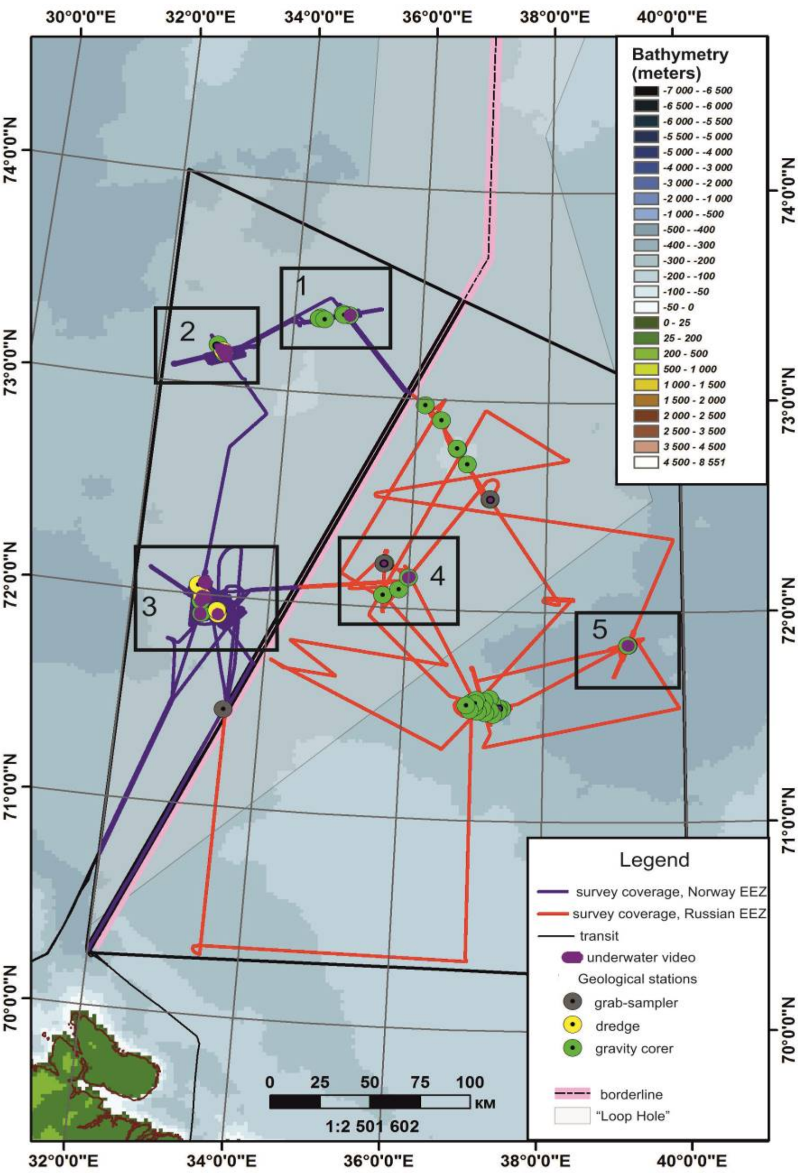

Figure 1. Study area in the southern part of the Barents Sea, the boundaries of licensed areas in the Norwegian and Russian waters, the survey coverage for the TTR-18 cruise (28 cruise of the RV Akademik Nikolai Strakhov) and the position of geological stations (MSU, Geological Institute, RAS, 2011). The figures indicate the study polygons: 1- "Channel", 2- "Northern Diapir", 3-"Southern Diapir", 4- "North–Kildinsky (Fedinsky swell)", 5-"Pockmarks".

Site description

The study area is located on the Eurasian shelf within the southern part of the Central Barents Hight and is a region of subhorizontal shelf plains [Buhl-Mortensen et al, 2015, Smelror et al, 2009]. The bottom sediments are represented by sandy and silty sediments of the Triassic, Jurassic and Cretaceous age accumulated in the conditions of a warm shallow basin [Smelror et al, 2009]. In the Late Cenozoic, the rocks underwent substantial glacial erosion [Buhl-Mortensen et al, 2015]. Within the region, there is a transition from seasonal cryozone to permafrost [Soloviev & Ginsburg, 2004]. The area is located in the active neotectonic zone [Krapivner, 2006, Musatov, 1998]. Complex morphology of the region is characterized by salt tectonics (salt diapirism), imposed by glacial denudation processes, as well as degassing processes expressed in the relief by numerous pockmarks. The salt domes were formed by raising sediments of salt of Permian age. Salt diapirs form gas and oil traps in the tilted sedimentary layers. Seepage of gas through the water column occurs with the formation of specific forms of relief - pockmarks, funnels with diameter from 10 m to more than 1000 m. According to our data, pockmarks have a wide distribution in the Russian as well as in Norwegian sector of the Barents Sea. The animal population of the bottom of the Barents Sea includes, according to various estimates, from 1500 to 2,435 species [Denisenko , 2010], mainly of the foraminifera, sponges, coelenterates, annelids, crustaceans, mollusks, echinoderms and shells [Zenkevich, 1956].

DATA AND METHODS

The main study objective is to characterize marine landscapes, or habitats (Dolan et al, 2009) in the area of detailed survey in the vicinity of North –Kildinsky gas deposit in the southern part of the Barents Sea. We define marine landscape as a homogeneous part of the bottom, characterized by the unity of the geological structure, bottom sediments, conjugated with the geomorphological features of the area, bottom water mass, characteristic composition of the benthic communities (Manuilov, 1982, Preobrazhensky, 1984, Lymarev, 1985, Mitin, 2011). The actual material includes a large amount of hydroacoustic and biological data obtained during the TTR-18 cruise (Training-Through-Research program, UNESCO Intergovernmental Oceanographic Commission, Moscow State University) and 28th cruise onboard RV *Akademik Nikolay Strakhov* (Geological Institute Russian Academy of Sciences, 2011). The data was collected within the program TTR-18 and program of the Presidium of the Russian Academy of Sciences. The hydroacoustic data includes: multibeam echosounder (MBE) data (more than 6200 km); backscatter data from MBE (more than 6,200 km), the side-scan sonar SONIK (about 800 km) and information on the structure of the upper sedimentary cover, obtained by sub-bottom profiler (the total length of the profiles is 6500 km) (Fig.1). Data on the composition of benthos and benthic communities were obtained by the towed underwater video (TUV) unit (16.5 hours), by biological and geological sampling (dredge and tube) (57 stations).

The study includes geological and geomorphological interpretation and analysis of hydroacoustic data. Video and biological sampling data provides information on benthic communities, species composition and abundance as well as for identification of individual elements of underwater habitats. Based on the results of the geological-geomorphological and biological analysis, a comprehensive geoinformation database is created in the ArcGIS environment. Future work includes GIS-based classification of habitats based on correlation between morphological structures, geological composition of seabed and distribution of benthic species and communities abundance (e.g. Dolan et al, 2009).

Multibeam echosounder data acquisition and processing

The MBE data collection, post processing and gridding were performed by the Geological Institute Russian Academy of Sciences during 28th cruise onboard RV *Akademik Nikolay Strakhov.* Data was collected with RESON sonar MBE systems, which included shallow (SeaBat-8111, 100 kHz) and deep water (SeaBat-7150, 12 kHz) multibeam echo sounders, GPS, motion sensors and sound velocity sensors. Data aquisistion and post-processing was carried out in RESON PDS2000 Software. The MBE system was calibrated and motion corrections were applied to the data. Post processing included application of sound velocity corrections and removal of the outliers using filters. The average effective width of the survey line was about 600 m. During the 28th cruise ~ 6,200 km^2 of bathymetric survey was performed. Multibeam data was gridded using Golden Software Surfer with inverse distance to power interpolation (power = 0.5). The resolution of GIN RAS multibeam grids varies depending on the area.

MBE backscatter data (more than 6,200 km) SONIC side scan sonar (about 800 km)

More than 6,200 km of MBE backscatter data as well as about 800 km of SONIC side scan sonar data was collected. The MBE detects the values of the amplitudes received acoustic signal (sonar mode of the MBE) (Sokolov et al, 2017b). From the amplitude data a sonogram of the seabed similar to side scan sonar (SSS) recording is formed (Sokolov et al, 2017b). The processing of the received sonograms is similar to the processing of the SSS data and results in a sonar mosaic. The intensity of the acoustic signal is written directly in the depth record file. The MBE data was exported to XTF and SGY formats, which are industry standards for combined echosounder systems. Data processing includes band filtering and determining the settings of the signal amplification parameters, eliminating of the water column (determination of the first arrivals) and processing of an area-based sonar mosaic. The amplification procedure was used to equalize the amplitudes of the signals, with the AGC parameter setting (Auto Gain Control) with the maximum resolution parameters and the average intensity. Finally, some additional filters were applied to visually improve sonar mosaic: removing the first meters of the central part of the record, dividing the profiles into parts.

Sub-botom profiler data acquisition and processing

Extensive data (*6500 km*) on the upper part of the sedimentary cover (upper 100 m) was acquired with high-speed profilograph EdgeTech 3300 (USA). For further spatial interpretation of the geological structure, and characterization of the spatial distribution of lithological and structural features a method of picking (interpretation with digitization) of acoustic data is used (Sokolov et al, 2014, Sokolov et al, 2017a). Sub-bottom profiler data together with MBE sonar data is analyzed for the following events in the software environment RadExPro (Russia): gas flares, zones with high acoustic reflective properties (outcrops of hard rocks), zones of concentration of gas funnels (pockmarks).

Underwater video recording

Video data were collected with the TUV unit, and resulted in 18 video profiles with 16,5 hours of video footage. Location of the profiles is shown in Figure1. The Towed Underwater Video (TUV) included deepwater box with 3 megapixel digital IP video camera Arecont Vision AV3105AI (sensitivity of 0.2 lux). The optimal distance of the camera to the bottom surface is 1-3 meters, while the surface area of the bottom surface (area of the video frame) is 3-10 m^2. The optimal speed of motion during the video profiling is 0.4-0.6 knots. Processing of video profiles includes georeferenced fixation and identification of species composition, relative abundance, as well as the description of benthic communities in mass forms (Ilyushin, 2014). Each video profile was viewed at least twice. Underwater video data allows to identify the fauna without quantitative assessment, as well as to identidy marine landscape characteristics such as sediment types and associated biodiversity. At this stage of the work, only a qualitative assessment of the composition of the epimacrozoobenthos was carried out. A possible methodology for quantitative or semi-quantitative assessment of the relative abundance of animal species is under development. Based on the results of processing video profiles, distribution of different types and classes of benthic animals have been summarized within the studied polygons.

Biological and geological sampling

Geological sampling provided mass forms of benthos for biological studies. The main objectives for biological sampling included description of the benthic macro-fauna, collection of species for genetic database and search for species which indicate methane sipping. The geological sampling included 47 stations of gravity corer (the upper most 10-15 cm part), 7 stations of geological dredge (the soft sediment) and 3 stations of Van-Vin's grab (Vodopianov, Kolbasova 2012). The location of stations used in this study is shown in Figure 1. The sediment was washed through 0,5 mm sieve with sea water. The collected animals were fixed with neutral 4% formaldehyde and specimens of the most widespread species were fixed with 96% ethanol for further genetic studies (Vodopianov, Kolbasova 2012). The animals were defined with taxonomic keys. Additional biological information was provided by underwater –TV profiles. The processing of biological sampling data includes the study of species composition, relative size, as well as a description of the bottom communities in mass forms of benthos at geological stations. The benthic animals collected during the geological sampling and the benthic animals recorded on the video recordings were disassembled into groups, identified to genera and species. As a result, a table of their occurrence by stations was compiled (Vodopianov, Kolbasova 2012, Kiseleva et al, 2016).

RESULTS

Hydroacoustic survey (ссылки на рисунки) was carried out at five polygons, as well as on transit lines between the polygons. The polygons are shown in Fig. 1. and have the conventional names "Southern Diapir", "Northern Diapir", "Channel", "Pockmarks", and " North–Kildinsky ". The MBE survey revealed detailed morphology of several diapirs of the salt genesis and the section of the underwater channel. In the study area numerous iceberg ploughmarks are observed, as well as pockmarks (up to 100 meters in diameter) in the areas of degassing activity [Chamov et al, 2015b, Kiseleva et al, 2016]. Glacial landforms that were mapped include underwater channel formed by subglacial meltwater beneath the ice sheet [Bjarnadóttir et al 2013, Bjarnadóttir et al 2016, Newton and Huuse, 2017] and numerous iceberg ploughmarks. Ploughmarks were formed by the keels of drifting icebergs during the retreat of the ice sheet. The ploughmarks that were revieled by our survey vary in size, lengths and shapes. Very similar to the iceberg ploughmarks are the traces of trawling. Traces of trawls are determined on video recordings of television profiles and are on average 30-40 cm in depth [Buhl-Mortensen et al, 2015].

The data was compiled in a geoinformation database in the ArcGIS. The database contains a bathymetric model based on MBE data, some results of the interpretation of the sonar data [Chamov et al, 2014, Chamov et al, 2015b, Kiseleva et al, 2016], the results of the geological sampling analysis [Chamov et al, 2015a], and the analysis of biological samples [Vodopianov and Kolbasova, 2012]. An example of the database is shown on Fig. 2.

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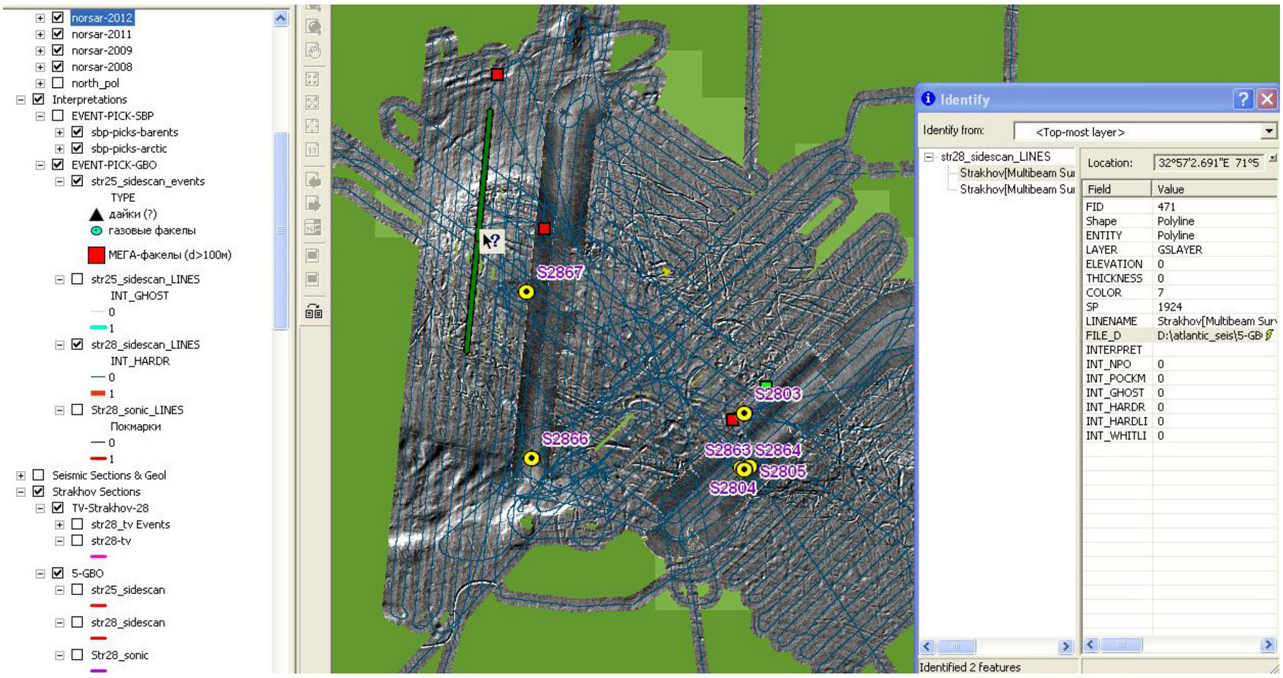

Figure 2. An example of a compiled database in the ArcGIS environment for the polygon "Northern Diapir". Sampling stations, the digital bathymetry model based on MBES data, navigation data and files attached to the survey profiles that can be opened using the Identity Tool are displayed.

In this paper, we present the results of a geological-geomorphological and biological analysis of three study polygons: “Southern Diapir”, “Channel”, and “Pockmarks” (Fig. 1). Southern diaper, or western part of Tyddlybanken (Buhl-Mortensen et al, 2015), is an elevation stretched in the NW direction (175 m long, 125 m wide). The top most elevated surface of the uplift is located at depths of 175 to 220 m, exceeding foot of the slope by 100 m. The top of the diapir is a subhorizontal surface, eroded by wide, deep, linearly oriented iceberg ploughmarks (up to 200 m wide, 10-15 m deep), with individual pockmarks (up to 150 m in diameter). Geological sampling shows that the seabed sediments are represented by muddy sandy gravel (with large amount of unsorted coarse sediments from gravel to bouders) and in some places by gravelly sand. Analysis of the TUV recording showed the presence of the following bottom fauna: community of anemones (*Bolocera tuedia*, *Tealia feline*, *Hormathia sp*.), single sponges, ascidians, starfish (*Urasterias lincki*, *Henricia sp.)*, crustaceans *Bythocaris*, a typical community of fouling on boulders (sponges, actinias, bryozoans). The biological sampling revealed: Polychaeta: *Spiochaetopterus typicus*, Gastropoda *fam.g. sp*., Isopoda *fam.g. sp*.

The slopes of the southern diapir are eroded by irregularly oriented glacial ploughmarks (100 m in width, 5 m deep), with individual concentrations of pockmarks (on average 35 m in diameter). The upper layer of seabed sediments are represented by gravelly sand and clayey silt. In the pockmarks sampling showed the presence of silt with glaci-marine dropstones. Two types of biological communities were observed by TUV: on the lithotypes of clayey silt - the sea anemone complex (*Bolocera tuedia*, *Actinostola sp*., *Tealia feline*, *Hormathia sp*.), on the lithotypes of gravelly sand – ophiuroids complex (*Ophiura sarsi*). On both lithotypes there are representatives of macrozoobenthos: sponges, hydroids (*Tubularia*), gastropods (*Trichotropidae gen.sp*.), starfish (*Urasterias lincki*, *Ctenodiscus crispatus*, *Henricia sp*.), hermit crabs (*Pagurus sp*., *Lithodes*), crustaceans *Bythocaris*; a typical community of fouling on the rocks (sponges, bryozoans, anemones). In the pockmarks on the slope of the diapir is presented the *Tealia feline* complex with Bythocaris, Gastropoda and Porifera, having very high density. Also in the samples from the pockmarks showed presence of: Polychaeta (*Galathowenia oculata*, *Amphicteis ninonae*, *Melinna elisabethae*, *Nephtys pente*, *Owenia fusiformis*, *Chone*, *Spirorbis tridentatus)*, Ophiuroidea *fam. g. sp*, Actiniaria *fam. g. sp*., Bivalvia (*Astarte borealis*), Amphipoda *fam. g. sp*., Holothuroidea (*Psolus phantapus*).

The foot of the diapir is located at 270-300 meters depth, this area is also eroded by glacial ploughmarks, the number of which decreases with increasing depth. This area is characterized by high concentration of small pockmarks (2 m up to 50 m deep). The upper layer of sediments is represented by sandy silt and sandy mud. The biological composition from geological samples: Polychaeta: *Spiochaetopterus typicus*, *Galathowenia oculata*, *Myriochele oculeata*, *Maldanidae g. sp*., *Nephtys sp*., *Galathowenia oculata*; Bivalvia: *fam.g. sp*., *Astarte elliptica*, Gastropoda *fam. g. sp*., Amphipoda *fam. g. sp*, Asteroidea: *Ctenodiscus crispatus*, Ophiuroidea: *Ophiura sarsi*. Analysis of the TUV data showed that the seabed sediments is a subject to significant bioturbation, there are numerous burrows, polychaetes tubes, broken shell, skeletons of corals; single representatives of macrozoobenthos include: sponges, hydroids (*Tubularia*), anemones

(*Tealia feline*, *Hormathia sp*.), Gastropoda, starfish (*Ctenodiscus crispatus*, *Henricia sp.*), crustaceans *Bythocaris*, ascidians *Styelidae*.

The underwater channel cuts throught Thor Iversenbanken with a total length of 50 km (Bjarnadóttir et al, 2016, Newton & Huuse, 2017). The channel is up to 1.5 km wide and 35 meters deep. The average depth of the thalweg is 290-275 m. The channel has meandering valley, overdeepening in some parts. Characterisitic profile across the valley shows channel furcation into two channels, with deposition bars and sedimentary fans. The valley of the channel are complicated by pockmarks, glacial ploughmarks and landslides. In the eastern part of the channel, the outcrops of denser rocks are fixed on the sonar record. The upper layer of sediments is represented by silty clay and sandy silty clay in some parts. From geological sampling various representatives of polychaete worms were found: *Spiochaetopterus typicus*, *Maldane sp*., *Galathowenia oculata,* as well as *Chaetopteridae* tubes and *Maldanidae (cf.)*. Analysis of the TUV showed the following communities on the sides of the channel: anemone *Actinostola sp.*, *Tealia feline*, *Hormatia sp.*, Ophiuroidea: *Ophiocantha bidentata*, *Ophiura sarsi*, with individual representatives of the macrozoobenthos: hydroids *Tubularia*, corals *Gersemia fruticosa*, starfish *Urasterias lincki; Ctenodiscus crispatus*, *Henricia sp*., crustaceans *Bathycaris*; in the channel bottom: boulders and clastic material with a typical community of fouling (ascidia *Styelidae*, anemones, sponge, bryozoans).

Polygon “Pockmarks” is presented by subhorizontal surface (average depths 350 meters) eroded by ploughmarks and numerous isometric pockmarks (on average 150 m in diameter, depth up to 30 m). Sonar record shows that objects with high acoustic reflection are observed within the region. Also sonar data shows sound scattering objects in the water column, spatially coinciding with the pockmarks, which evidence the gas outlets (Chamov, 2015b). Based on the analysis of the TUV, the seabed sediments are represented by loose silty sand. Based on the results of the biological sampling, the following species were identified: Polychaeta *Glypanostomum pallescens*, *Spiochaetopterus typicus*, *Maldane sarsi*, *Nephtys pente*, Mollusca Caudofoveata: *Chrystallophryson sp.*, and Gastropoda *fam. g. sp*. Analysis of the TUV showed the following communities: crustaceans *Bathycaris* with some large macrozoobenthos: corals (*Gersemia fruticosa*), Mollusca Bivalvia, ophiuros (*Ophiocten sericeum*, *Ophiura sarsi*), starfish (*Urasterias lincki; Ctenodiscus crispatus*), holothuria (*Psolus sp*.).

CONCLUSIONS

As a result of the geomorphological analysis of the detailed survey polygons, a complex shape of the relief is observed, due to the processes of salt-dome tectonics, complicated by glacial denudation processes, as well as manifestations of degassing processes expressed in the bottom topography by pockmarks. The macro benthic fauna in the sampling sites varies depending on the seabed topography and sediment type. The typical comnumities present include actiniarians: Hormathia sp., Tealia felina, polychaetes worms, echinoderms (ophiuroids, starfish, sea-urchins and holothurians), Bivalvia and Caudofoveata mollusks, crustaceans: Amphipoda, Isopoda & Decapoda, sipuncula worms, brachiopods and colonial ascidiaceas. The echinoderms, ophiuroids, holothurians and polychaetes (Chaetopteridae, Oweniidae, Maldanidae, Ampharetidae, Nephtys, Lumbrineris and others) were the most commin within the samplings all around the region of the studies. The compiled geoinformation database in the ArcGIS, which include bathymetry, sonar, TUV georeferenced data, biological and geological sampling data, allows future work on nature-type classification. The further studies include GIS-based classification of habitats built on correlation of bathymetric, sonar and geologic variables with species groupings (e.g. Dolan et al, 2009).

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Anastasia Abramova received Sp. degree in Geography: Geomorphology and Paleogeography from Lomonosov Moscow State University, Russsia in 2008. In 2012 she received M.Sc. degree in Marine Geology/Ocean Mapping from the University of New Hampshire, USA. She is working in laboratory of ocean floor geomorphology and tectonics, GIN RAS since 2006. She participated in several expeditions on board RV Akademic Nikolay Strakhov, RV Academic Treshnikov, RV Polarstern and Okeanos Explorer, researching and mapping in the Arctic, Indian and Atlantic Oceans. Currently she is a junior researcher at Geological Institute Russian Academy of Sciences, her research interests include marine geomorphology, geotectonics and geodynamics of mid-oceanic ridges, hydroacoustic methods, quality and accuracy of digital bathymetry models. Besides that she is participating in outreach efforts for popularizing ocean science, such as museum exhibitions and educational activities for children.

Stepan Vodopyanov graduated from Lomonosov Moscow State University in 2008, working with fine anatomy and ultrastructure of polychaetes worms at invertebrates zoology department of biological faculty. He received his PhD in 2014, thesis tilted "Epidermal papillae of polychaetes – structure, development, possible functions". Participated in several scientific expeditions to Barents Sea, Baikal lake, Far East of Russia working with sea and freshwater invertebrates sampling and communities descriptions, including underwater television study in TTR-18 scientific cruise along Barents Sea. Nowadays he is a junior researcher at invertebrates zoology department of biological faculty of Lomonosov MSU, dealing with polychaetes ultrastructure mostly and teaching students during practicum course of invertebrates zoology.

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Sergey Sokolov graduated from Moscow State University, Geological Faculty in 1981, finished post-graduate courses at P.P.Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, in 1985. He received Ph.D. in Geophysics at Research Institute of Geological, Geophysical and Geochemical Information Systems, Russian Ministry of Geology, Moscow in 1990. He worked at P.P.Shirshov Institute of Oceanology RAS, Moscow (engineer), at O.Yu.Schmidt Institute of physics of Earth RAS, Moscow, at University of Houston, USA (research assistant) and at AMOCO Eurasia group. Currentntly he is a leading researcher at Geological Institute RAS, Moscow (since 1986). He participated in numerous geological-geophysical expeditions on board of R/V Akademik Nikolay Strakhov at Central Atlantic, Southern Ocean and Arctic Ocean. Author of ~ 130 publications which deals with geological structure of oceanic crust obtained from geophysical data.