THE BARENTS SEA SYSTEM

CHAPTER 1. GEOLOGICAL STRUCTURE

1.1. Tectonics of the Barents Sea continental edge

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The tectonic situation of the studied region was formed as a result of a long (about 3 billion years) evolution of the Earth's crust. The problem of tectonic zoning of the region is not devoted to many published works and cartographic materials. The position of the borders between the East European and West Arctic platforms remains a debatable issue. More ambiguous, and in some cases, approaches to tectonic zoning of the region are not clear. Nevertheless, the work is based on a unified theoretical basis, reflecting the approach to solving the problems of regional tectonics from the perspective of geodynamic evolution.

Keywords: shelf, riftogenic structures, foundation, platform cover, regional tectonics.

1.2. Features of the glacial formations structure and bottom relief forms related to them according to seismoacoustic profiling data and their role in the decision of discussion issues of the Quaternary sediment cover formation of the Barents Sea

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Hot questions in the modern Quaternary geology of the Arctic seas associated with their glaciation are discussed in this article. The questions of the history of the occurrence of the problem of shelf glaciation or "drift" accumulation of boulder-bearing sediments are considered in detail. The results of seismic-acoustic studies and their interpretation with the aim of seismic stratigraphic and genetic partition of the cover of loose sediments of Quaternary age are considered in detail. Arguments are presented in favour of the continental origin of glaciers (Novaya Zemlya, Ostrovnoy and Scandinavian), which in the late Neopleistocene spread to the shelf of the Barents Sea and occupied its surface to depths of 120–150 m. Further development of glaciation was already due to the expansion of the area of shelves glaciers. The facies zoning of glacial-marine deposits is estimated, which is related to the distance from the front of the glaciers. It is concluded that already at the end of the Late Pleistocene, most of the modern Barents Sea was free from glaciers and from the annual cover of pack ice. Data on the absence of the area distribution of frozen sediment strata within the modern Barents Sea shelf are presented.

Keywords: shelf, glaciation, Neopleistocene, seismoacoustic profiling

CHAPTER 2. PALEOOCEANOLOGY AND BIOSTRATIGRAPHY

2.1. Dynamics of the coastal zone in Holocene on the example of the north-western part of the Kola peninsula

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A lot of work has been devoted to the study of the coastal zone of the southern coast of the Barents Sea. However, they are mainly devoted to the period of deglaciation of the territory and the subsequent marine transgressions. The Holocene

period was less interesting for researchers, because it was believed that the coast was stabilizing by this time and almost no significant changes were taking place. In recent years, interest in the dynamics of the coastal zone of the last millennia is mainly associated with the problem of climate change and the melting of Arctic ice in the modern period. In this regard, the study of new sequences of the coastal zone of the Barents Sea is especially relevant. Recently, new studies of the Holocene history of the coastline of the north-western coast of the Kola Peninsula have appeared, which change some prevailing ideas about the dynamics of the coastline in the Holocene period. The presented review is caused by the need to summarize new results and existing ideas.

Keywords: Holocene, coastal zone, radiocarbon age.

2.2. Palinostratigraphy of glaciomarine and marine sediments of the Barents Sea

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By combining the palynologic, lithologic and published geophysical data a stratigraphic division into three main sedimentary units that represent major stages in the development of post-glacial sedimentary environments in the southeastern and central parts of the Barents Sea has been substantiated. Unit 3 presumably characterizes proglacial environments of the early deglaciation (tentatively older than 15 ka) and is represented by relatively fine-grained, dark grey sediment matrix with numerous coarse terrigenous clasts. The unit contains low in diversity and concentration pollen assemblage, which is dominated by reworked, mostly Mesozoic pollen and sparse dinocysts of a cryophylic species Islandinium var. minutum.

Unit 2 represents later deglacial conditions (estimated *ca* 12–15 ka) and is composed of finely laminated, grey to brownish sandy/silty muds with coarse clasts interpreted as iceberg-rafted debris. It is characterized by a palynozone with a low concentration of plant remains, a significant proportion of reworked pre-Cenozoic microfossils and a high percentage of dwarf *Betula* pollen as well as a predominance of Poaceae and *Artemisia* pollen in the grassy part of the pollen spectra. Club mosses are most common among spores and cysts of *Islandinium* var. *minutum* - among aquatic palynomorphs.

Unit 1, younger than *ca* 12 ka, is mostly composed of soft, olive-grey mud with traces of bioturbations and spots of hydrotroilite at the top, but is replaced by sandy-silty mud and sand with inclusions of pebbles and broken shells within the South-Novozemelskii Trough and the Kanin Plateau, respectively. Three pollen assemblage zones correspond to it. They are marked by a high percentage of birch and pine pollen, an increased share of pollen of spruce and alder, as well as *Sphagnum* mosses and ferns among spores. Constant presence of sparse pollen of broad-leaved plants in combination with peak values of *Operculodinium centrocarpum* and *Spiniferites* sp. testify the enhancement of Atlantic water influence upon the studied regions.

Keywords: lithocomplex, palynomorphs, palynology, stratigraphy.

2.3. Diatoms and aquatic palynomorphs in the Barents Sea sediments: main distribution patterns and use in palaeoceanological studies

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The Chapter deals with the uniqueness of the Barents Sea and adjacent sea areas from the viewpoint of the main groups of phytoplankton (diatom algae and dinoflagellate) development and their reflection in tanatocenoses of bottom sediments. Special attention is paid to the distribution of microfossils in surface waters as an indicator of the modern sea ice and hydrological signal. A distinctive feature of the Barents Sea tanatocenoses is the frequency of re-deposited Paleogene and Cretaceous forms of diatoms and dinocysts. Despite all the difficulties in finding microfossils in bottom sediments, data were obtained on characteristic associations mainly related to the redistribution of relatively warm North Atlantic waters. The issues of microfossils in cores and boreholes located on the Barents Sea shelf and continental slope are considered and the most extensive material on changes in sedimentation conditions in the Pleistocene and Holocene is generalized.

Keywords: diatoms, dinocysts, advection of the North Atlantic waters, shelf, paleoreconstruction.

2.4. Ostracods in the sediments of the Arctic shelf seas of Eurasia (stratigraphy and paleoreconstruction)

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We present data on ostracod assemblage analysis from the Laptev, Kara and White Seas in the Arctic Ocean. We established the relationship between modern ostracod distribution and environmental parameters and applied this knowledge to interpret fossil Quaternary ostracod assemblages. Data on distribution and ecological parameters for different modern Arctic and Boreal species give us an opportunity to interpret even taxonomically poor samples.

Late Pleistocene-Holocene ostracod assemblages from the eastern Arctic shelves and their stratigraphic succession in the studied cores reflect the environmental transition during the gradual deepening of the sites and distance increase from the coastline during the Postglacial sea-level rise. Variations in fossil ostracod assemblages at the continental slope location suggest temporal increases in modified Atlantic water inflow, as well as point to periods of glacier meltwater and freshwater input.

Late Saalian-Eemian assemblages from the White Sea area contain typical Arctic representatives as well as taxa inhabiting boreal and more southern locations and the majority of species present are known to tolerate decreased salinities. Assemblage changes reflect the transition from the initial stage of inundation, with active hydrodynamics, to stable marine conditions with subsequent warming and shallowing of the basin.

Keywords: ostracods, stratigraphy, paleoreconstruction.

2.5. Postglacial paleoceanology of the Barents Sea

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The Chapter presents reconstructions of ice sheet boundaries, surface- and bottom-water environments in the Barents Sea for several postglacial intervals. The evolution of the basin during deglaciation is considered in relation to climate changes in the Northern Hemisphere and variations in the intensity of Atlantic water inflow from the last glacial maximum to the Holocene. Particular attention is paid to changes in the dominant sedimentation processes and to diachronous character of deglaciation. Reconstructions are based on our own (more than 30 deep-sea cores) and published data with the account for the available regional schemes of deglaciation. The early stage of degradation of the Scandinavian-Barents Sea ice sheet was completed by the beginning of the Bølling-Allerød interstadial. This warming was characterized by a significant increase in the Atlantic water penetration in the Barents Sea linked to a re-organization of global thermohaline circulation. The new increases in the Atlantic water inflow into shelf depressions occurred at the end of Younger Dryas and in Preboreal. In the Holocene, glaciomarine sedimentation was replaced by the marine hemipelagic one in the deep troughs and depressions.

Keywords: deglaciation, microfossils, lithostratigraphic units, radiocarbon age, iceberg rafting.

CHAPTER 3. DISPERSED SEDIMENTARY MATTER OF THE NEAR-SURFACE LAYER OF THE ATMOSPHERE

3.1. Atmospheric dispersed sedimentary matter over the Barents Sea

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The concentration and composition of aerosols in the atmosphere over the Barents Sea were studied. Earlier, the contribution of aerosols to the formation of the Arctic environment was underestimated. Our data indicated a noticeable effect of continental aerosol on the atmosphere of the Barents Sea. The relationship of the black carbon concentration and the type of air masses has been established. Its concentration increases hundreds of times in the atmosphere of the sea when continental air is removed. The ionic composition and the content of chemical elements in the insoluble fraction of aerosols of the air over the Barents Sea were studied. The content of most chemical elements (Na, Al, K, Ca, Sc, Fe, Co, Rb, Zr, Cs, Ba, REE, Hf, Ta, Th, U) in the insoluble fraction of aerosols was below the average values for the upper continental crust. The content of Cr, Cu, Zn, As, Se, Br, Ag, Sb, Au, Pb is significantly higher than their average for the upper continental crust, due to the influence of the anthroposphere. Probable sources of anthropogenic pollution of aerosols in the Arctic are discussed.

Keywords: aerosols, insoluble fraction, black carbon, ionic composition, fluxes of matter, Arctic.

3.2. Heavy metals and black carbon in the atmosphere over the Barents Sea: concentrations and fluxes onto the surface

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Estimates of the fluxes of anthropogenic heavy metals (HM) – Pb, Cd, As, Zn, Ni, Cr, Cu – from the atmosphere onto the surface of the Barents Sea are based on previously calculated concentrations of these elements in near-surface atmosphere at three points of the Sea coast (on Kola Peninsula, in Nenets Nature Reserve, on Frantz-Josef Land archipelago). For lead and cadmium, the contributions of their anthropogenic emissions in foreign Europe, as well as of windblowing dust and soil particles have been taking into account (from EMEP reports). About 50% of lead and about 40% of cadmium come from those sources to the whole Sea area. In general, the atmosphere supplies yearly only a fraction of percent of HMs containing in the Barents Sea waters. In spring, during the period of ice melting, the atmospheric contribution to HM concentrations in Sea waters may be 2–10 times higher than average annual values. Also, we studied the spatial variations of black carbon (BC) content in the atmosphere over the Barents Sea based on satellite data (reanalysis MERRA-2).The mean BC fluxes onto the snowed surface, and respective amendments the surface albedo and its radiation forcing were estimated for three regions under investigation.

Keywords: heavy metals, black carbon, aerosols, fluxes.

CHAPTER 4. HYDROLOGY AND HYDROCHEMISTRY

4.1. Review of the Barents Sea hydrological conditions

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Based on more than 50 works published during the period 1946–2019, the chapter gives an overview of current ideas about bottom topography, large-scale circulation, currents and tides, water flows across borders, temperature and salinity distribution, water masses, frontal zones, seasonal and interannual variations in hydrological characteristics, stratification and ice conditions of the Barents Sea. Among the many classifications of water masses of the sea, the review gives preference to the most consistent and reasonable classification proposed by V. Ozhigin and V. Ivshin in 1999.

Keywords: Barents Sea, water masses, water exchange, currents, seasonal changes.

4.2. On climatic changes in the temperature of the Barents Sea and their possible causes

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Analysis of the monthly average temperature data of the Barents Sea at various depths showed its significant increase over the past decades. Against the background of this growth, temperature fluctuations were detected with periods close to the periods of El Nino – Global atmospheric oscillations, North Atlantic fluctuations and changes in the North Atlantic current. Analysis of daily average temperature data of the Barents Sea surface showed an increase in the amplitude, number and duration of extreme temperature phenomena with a positive sign and a decrease in extreme temperature phenomena with a negative sign for the period of satellite observations.

Keywords: climate change, temperature, Barents Sea, El Nino, Global atmospheric oscillation, North Atlantic Oscillation, North Atlantic Current, extreme events.

4.3. Regularities and features of ice conditions of the Barents Sea in the second half of XX – early XXI century

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The warming of the Arctic, especially intensified at the beginning of the XXI century, is accompanied by a significant decrease in the area of ice cover in the Arctic seas. The article shows the quantitative changes in the ice parameters of the Barents Sea, as well as factors affecting the formation of ice cover in recent years. In the twenty-first century the frequency of occurrence of mild winters has increased by 17%, the frequency of severe winters has decreased by 19%. Significantly increased the temperature at the meteorological station Malye Karmakuly, water temperature at transect "Kola Meridian", atmospheric and oceanic heat fluxes, and speed of sea currents on the Western border of the Barents sea. The duration of the ice period decreased by an average of 2–3 weeks, and the rate of reduction of ice cover was 7.2% for 10 years. This is the highest speed compared to other Arctic seas. The article shows that the variability of the ice cover of the Barents Sea and other parameters of the natural environment in the region has the cyclic character. Presumably, the cycle period is close to 84 years, which corresponds to the orbital period of Uranium. The minimum sea ice extent after 1935–1945 is expected in the period 2019–2029.

Keywords: ice cover, ice formation, temperature regime.

4.4. Satellite altimetry of the Barents Sea

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Satellite altimetry data are used for investigation of the sea level variability and sea ice cover retreat in the Barents Sea in 1992–2018. The data from ERS–1/2, ENVISAT, SARAL/AltiKa, and Sentinel-3A/3B satellites were used in this study. An increasing trend of the sea level of about 2.31 mm/yr was observed in this time period, which caused a total increase in the Barents Sea level by about 6 cm. Linear trends of the sea level change varied from 1.84 mm/yr in July to 4.29 mm/yr in September. The average velocity of the ice edge retreat along the tracks in the north-eastern direction is of 10.9 km/yr for the same period. It was found that the ice edge displacement rate tends to increase by 0.30 km/yr per a degree in longitude in the eastward direction. Thus, the ice edge retreat along the "eastern" tracks goes faster than along the "western" ones, which is likely explained by a change in the water dynamics in the Barents Sea.

Keywords: the Barents Sea, satellite altimetry, sea level, sea ice cover, sea ice retreat.

4.5. Organic matter and its transformation rates in different Barents Sea ecosystems

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The article includes proprietary data and data from literature from the last 30 years about the fluctuations in concentration and the elemental and biochemical make-up of the dissolved and particulate organic matter (DOM and POM, respectively) in the different ecosystems of the Barents Sea. The large variability of these values in both surface and deep waters is shown, depending on the intensity of the hydrological and biological processes. DOM concentrations varied from 59 to 664 μM C_{org}, while POM varied from 0.25 to 38.08 μM C_{org}. The reduction of the ice cover affected both the distribution and the qualitative composition of the DOM and the POM. This reduction, as well as the increased flow of Atlantic waters, contributed not only to an increase in the primary production of organic matter, but also to a significant intensification of redox and hydrolytic processes of its transformation, especially in the high-latitude part of the Barents Sea. The DOM of the sea is characterized by high C/P ratios, far exceeding those of Redfeld. At the same time, C/N ratios in the most productive waters are close to those of Redfeld. We highlighted four regions in the sea where concentrations of dissolved carbohydrates increase towards the bottom, which indicates that oil hydrocarbons are supplied here.

Keywords: dissolved and suspended organic matter, elemental and biochemical composition, the activity of redox enzymes and alkaline phosphatases.

CHAPTER 5. HYDRO-OPTICS

5.1. Biooptical characteristics and solar radiation in the surface layer of the Barents Sea

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The data on the calculation of bio-optical parameters in the Barents Sea are presented, for which regional algorithms have been developed. These algorithms were derived on the basis of field measurements made in the region under consideration. The seasonal and interannual variability of bio-optical characteristics was studied and coccolithophore blooms in the Barents Sea were evaluated.

Keywords: bio-optical parameters, remote sensing observations, solar radiation, coccolithophore bloom.

5.2. The vertical structure of the water column according to optical data

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Vertical profiles of the beam attenuation coefficient in different regions of the Barents Sea are analyzed. Data obtained show high space-time variability of seawater optical properties. In particular, the area affected by the river inflow (Pechora Sea) is distinguished. Very high values of the beam attenuation coefficient are observed in areas of coccolithophore blooms. There are a number of features associated with the flow of Atlantic waters into the Barents Sea. A close relationship between the seawater beam attenuation coefficient and total suspended matter concentration is shown. The corresponding regression equation is obtained.

Keywords: light attenuation coefficient, optical properties, coccolithophore, suspended particulate matter.

CHAPTER 6. DISPERSED SEDIMENTARY MATTER OF THE WATER COLUMN

6.1. Concentration and composition of the suspended particulate matter of the Barents Sea

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The results of the study of the distribution and composition of the dispersed sedimentary matter (suspended matter) in the water column of the Barents Sea were presented in the article. The distribution of suspended matter in the sea obeys the laws of circumcontinental (for surface distribution) and vertical zonality. At the same time, the absolute values of the weight and volume concentrations of the suspended matter themselves are low (on average less than 0.5 mg/l and less than 1.0 mm^3/l, respectively). The highest values of all parameters of the suspended matter were found in the Pechora Sea, the most southeastern part of the Barents Sea, where the abrasion of the shores and bottom erosion, and the Pechora River runoff. Surface and bottom peaks are characteristic of the vertical distribution of the suspended matter. An intrusion of the nepheloid layer enriched in the suspended matter into the deep layers can be observed on the continental slope when the depth makes a sharp fall.

Keywords: Barents Sea, suspended matter, chlorophyll «a», surface currents

6.2. Element composition of suspended particulate matter in the Barents Sea

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The elemental composition of suspended particulate matter (SPM) in the Barents Sea was studied based on the materials of the 68th cruise of the RV *Akademik Mstislav Keldysh*, August 2017, using ICP-MS and AAS methods. SPM of the sea surface layer is characterized by significant heterogeneity in the elemental composition, which is due to differences in the course of biogeochemical processes over the water area (for example, high differences in the level of primary production) and different compositions of terrigenous matter from the sources. Biophilic elements significantly enrich the SPM of the surface water layer and fluffy layer relative to the average composition of the earth's crust (the degree of enrichment of the surface SPM is higher than the fluffy layer).

Keywords: suspended particulate matter, microelements, heavy metals, particulate form, fluffy layer.

6.3. Vertical fluxes of settling particles in the Arctic Ocean

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The monthly, seasonal and annual quantity estimates of vertical fluxes of sedimentary matter from the surface layer of the Arctic Ocean, performed out over the years by various researchers, are the basis for direct calculations of incoming chemical components, minerals, and various pollutants to the surface layer of bottom sediments.

Keywords: sedimentary matter, vertical flux, sedimentation, Barents Sea, settling particles.

CHAPTER 7. BIOGEOCHEMICAL PROCESSES, BACTERIA AND FUNGI

7.1. Biogeochemical processes in the Barents Sea

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Biogeochemical processes involving microorganisms play an important role in marine sedimentogenesis. The study of biogeochemical processes in the Barents Sea was carried out from 1997 with interruptions until 2019. Using a complex of geological-geochemical, microbiological, radioisotope and stable isotope methods, it was possible to obtain a quantitative estimate of the total abundance and biomass of microorganisms, rates of biogeochemical processes, methane content and organic matter suspended.

In the course of work in four expeditions, it was found that in the surface (0–10 m) water column south of 74° N the magnitude of the total abundance and the biomass of microorganisms increased by 2019 by about 5 times compared to 1998. To the north, in colder waters, the total abundance and the biomass of organisms were lower than in the southern region of the sea.

The methane concentration in the surface layer of the water column at the border with the atmosphere did not change much for 20 years (1976–1997) and increased noticeably from 1997 to 2017, from 3.3 to 15.8 nM.

The increase in FFM, the biomass of organisms and the concentration of methane in the water column is associated with the melting of glaciers, with the release of organic matter of continental origin released from ice into the water.

The results of the work indicate changes in the ecosystem of the Barents Sea.

Keywords: CO_2-assimilation, sulphate reduction, methane oxidation, methane, bacteria, carbon isotopic composition.

7.2. Fungi of the Barents Sea

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The role of marine mycobiota, which includes marine fungi and fungi-like, is, first of all, in the decomposition of detritus, as well as in the formation of symbiotic relationships with other hydrobionts, and most often it is parasitism or mutualism. The paper presents a generalization of data on the mycobiota of the Barents Sea, as the most studied of the Arctic seas. This allowed the authors to evaluate the role of this little-studied component of the ecosystem, as well as to determine future directions of research of marine mycobiota for the Arctic region as a whole.

Keywords: marine micobiota, the role of fungi, molecular diversity.

CHAPTER 8. BIODIVERSITY

8.1. Phytoplankton of the Barents Sea

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On the basis of the analysis of summer plankton phytocenosis structure, 4 areas representing various stages of a succession cycle are allocated for water areas of the Barents Sea. In the most productive places of the water area the level of phytoplankton growth corresponded to indicators of mesotrophic-eutrophic waters and was maximum in the northern

area. Concentration of phosphates was the main regulator of bloom of coccolithophore *Emiliania huxleyi*, besides water temperature. The presence in the modern plankton phytocenosis structure in the northern part of sea (80° N) of the Atlantic species, along with annual bloom of *E. huxleyi* in the southwest part of the sea, are the indicators of increased «atlantification» of the Arctic Region.

Keywords: phytoplankton, coccolithophore bloom, *Emiliania huxleyi*, atlantification.

8.2. Zooplankton of the Barents Sea

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A review of the published data on the distribution of biomass of zooplankton and its main groups: mesozooplankton, meroplankton, crustacean macrozooplankton and gelatinous macrozooplankton in the Barents Sea are presented. The factors that determine the amplitude and direction of interannual changes in the abundance of zooplankton are considered. The results of studies on the role of zooplankton in biotransformation and vertical flux of organic matter are presented. The data on the possible effect of warming climate on the Barents Sea ecosystem is analyzed.

Keywords: zooplankton biomass, mesozooplankton, meroplankton, macrozooplankton, biotransformation, climate impact.

8.3. Zoobenthos of the Barents Sea

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Based on the analysis of retrospective and recent materials, the species richness of the bottom fauna and the long-term variability of the quantitative characteristics of zoobenthos of the Barents Sea are considered. The role of key taxa in the formation of biomass and trophic structure of zoobenthos is indicated. The negative impact of bottom trawling on benthic fauna is shown and the most vulnerable areas in the basin are identified.

Keywords: bottom fauna, trophic structure, biodiversity.

CHAPTER 9. GEOCHEMISTRY, LITHOLOGY, PETROGRAPHY

9.1. Salt composition and biogenic elements in modern pore waters of the Barents Sea (1997–2019)

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The data (Cl^-, SO_4^{2-}, Ca^{2+}, Alk and biogenic elements) on the salt composition of pore water and the isotopic organic carbon composition of suspended particulate matter, fluffy layer and surface layers (0–30 cm) of bottom sediments in the Barents and Norwegian seas are discussed during the period of the supposed maximum warming in the Arctic region in the 21st century associated with the "atlantification" of the Arctic Ocean.

Keywords: pore water, biogeochemical barrier water–seafloor, fluffy layer, sedimentogenesis, early diagenesis, Arctic.

9.2. Grain-size and mineral composition of the upper layer of sediments of the Barents Sea

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The paper presents data from grain size and mineralogical analyzes of surface bottom sediment samples obtained on several cruises of the R/V *Akademik Mstislav Keldysh* (2016–2018) from different parts of the Barents Sea. Pebble and gravel material is found in surface sediments in the form of impurities scattered throughout the sea. Such a chaotic distribution pattern is apparently associated with ice separation. Coarse material is most common in the Barents Sea off the coast of the Kola Peninsula, off the coast of Novaya Zemlya, Spitsbergen, where it accumulates due to coastal abrasion. In addition, a fraction >1 mm is widespread at depths where fine fractions are stirred and leached. The most common sediments in coastal shallow water are sands. Sands (0.1–1 mm) are widespread in the southern and south-eastern regions of the sea, in the region of the Pechora polygon, the Kaninsky shallow water, the Kola Peninsula, and in the northwest, off the coast of Svalbard. With increasing depth, the sands are replaced by mixed sediments with a low admixture of pelite. Pelitic sediments are prevalent in the central part of the sea. Precipitation with a pelitic fraction (<0.01 mm) of more than 50% occupy about 70% of the Barents Sea. They are widespread in deep-sea hollows and trenches, as well as in the numerous fiords of the North Island of Novaya Zemlya and Franz Josef Land. Surface sediments have a predominantly terrigenous composition; only at the border with the Norwegian Sea the proportion of biogenic material increases. The mineral composition of sediments is dominated by quartz and feldspars, clay minerals are mainly represented by illite, smectite and kaolinite.

Keywords: bottom sediments, grain size, mineral composition, Barents Sea.

9.3. Some geochemical features of the major element composition of the surface bottom sediments of the Barents Sea

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The results of determination of the major element composition of 34 surface bottom sediment samples of the Barents sea are presented in this chapter. The main sources of sedimentary material supply to the sea – river discharge, aeolian input and other – were considered. It was shown that the available own and literature data did not allow obtaining an adequate estimation of entering sedimentary material balance in the sea. The comparison of the compositions of bottom sediments (sands, aleurites, pelites) and of predominated in the sea basin rocks has demonstrated the prevailed terrigenous material input. The interdependences between all major elements in bottom sediments and their grain-size composition were considered in details. It was established that the well-known interrelationships with the politic sediment fraction took place for all elements except Mn – increasing their contents along with growth of pelitic fraction. The exception is SiO_2 and CaO, they demonstrated the highest content in the coarse fractions. The Mn behavior is unusual one. Mn concentration in the sediments of the south-western part of the sea is almost independent on the share of the pelitic fraction that is much unexpected. At the same time the sediments from the north-eastern part of the sea are very enriched by Mn – up to 1.0–1.5%. The probable reasons of such type of this metal distribution in the sediments are discussed. On a base of the results available the fragmental maps of Al, Fe and Mn oxides distribution in the bottom sediments were constructed. The conclusion was made that our new data supported the classical type of the prevailed terrigenous sediment formation in the Barents Sea.

Keywords: major elements, bottom sediments, grain size, geochemistry.

9.4. Geochemical fractions and indicators of sedimentation conditions in the Barents Sea

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Research results of geochemical fractions and distribution pattern of the major and trace elements in the sediment cores of the Barents Sea are presented. In the sediment core AMK- 5193, located in the central part of the sea, Al, Cr and Ni were detected predominantly in the lithogenic form (75–97% of the total content) throughout the core. A large or a noticeable portion (from 65% to 30% from total contents) of Pb, Cd, Cu, Ni, Co, Mn, and As was found to be accumulated due to hydrogenous processes, such as adsorption on amorphous Fe-Mn oxyhydroxides and clay particles. In the uppermost oxidized layer (0–6 cm) of St. AMK-5193, where the most intensive exchange processes between the solid and liquid phases of bottom sediments happen, a significant increase in the proportion of geochemically mobile fraction of most metals was found. In this part of the core, the maximum content of Fe and Mn in the form of authigenic oxy-hydroxides which serve an effective sorbent of most trace elements, including heavy metals, was recorded. At st. 5194, the downcore rythmic covariation of the Si/Al, Ti/Al and Fe/Al ratios reflecting contribution of terrigenous matrix, as well as Al/Ca ratio (indicator of physical and chemical weathering) was revealed. Moreover, the Al/Ca ratio exhibited an asynchronous change with the Si/Al and Fe/Al ratios. Also, the downcore variation in the Ti/Al ratio was opposite to that of Mn/Fe (an indicator of geochemically mobile fraction). Variation of the Ti/Zr ratio, reflecting the range of aerosol transport of clastic material, is weakly expressed in the AMK-5194 core, which supports the proximity of the terrigenous source.

Keywords: heavy metals, bottom sediments, geochemical fractions, sedimentation conditions.

9.5. Rare and trace elements in modern bottom sediments of the Barents Sea. Nd, Pb and Sr isotopic composition

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The article presents a brief lithological description of the modern bottom sediments of the Barents Sea, selected in the 67th voyage of the R/V "Akademik Mstislav Keldysh" at the polygons: 1) "Pechora Sea"; 2) "Western slope of Kaninskoe shoal"; 3) "Central Barents Sea (Shtokman area)"; 4) "Russkaya Gavan' fjord"; 5) "Medvezhinsky Trench"; 6) in the area to the south of Spitsbergen; 7) "Kola meridian"; 8) "Spitsbergen – Franz Josef Land archipelago"; 9) "Cambridge Strait". The distribution of Cr, Ni, Cu, Zn, Cd, and Pb in samples of bottom sediments (pelitic, aleurite-pelitic and sandy-aleuritic-pelitic ooze) is compared with the background concentrations and contents of these elements in the Post-Archean Average Shale (PAAS). The data obtained are consistent with the notion that the distribution of heavy metals and other elements in the bottom sediments is controlled primarily by the global geochemical background. The relationship of the Sc, V, Cr, Ni, Y, Zr, Nb, Mo, Hf, Th, U and rare-earth elements concentrations with content of fine pelite (< 0.001 mm) fraction and organic carbon (C_{org}) is considered. It was found that most of these elements are characterized by a moderate positive correlation with the amount of fine pelite fraction in samples. By the magnitude of the correlation coefficient with the C_{org} content, all elements are attributed into three groups: (1) with moderate positive correlation, (2) weak positive correlation, (3) practically not pronounced correlation. The distribution in the bottom sediments of the Barents Sea of the element-indicators of the source rocks composition (Sc, Th, Co, Cr, La and Sm), as well as of rare earths, make it possible to consider that the majority of bottom sediments is mature in geochemical terms material, the sources of which were rocks of the Kola Peninsula and Spitsbergen (?). The bottom sediments of the Cambridge Strait are represented by geochemically less mature material, which, apparently, entered the sea as a result of erosion of the Franz Josef Land archipelago rocks. The established isotopic characteristics (εNd, $^{207}Pb/^{206}Pb$ and $^{87}Sr/^{86}Sr$) of 17 samples of surface sediments suggest that the main contribution to the formation of bottom deposits of the central regions of the Barents Sea is made by rocks of the mainland part located in the influence zone of the North Cape Current. Archipelagos and islands (Franz Josef Land, Novaya Zemlya, etc.) that frame the Barents Sea supply a relatively small amount of clastic material that is carried by Arctic currents. The values of εNd and $^{87}Sr/^{86}Sr$ in the surface sediments of the central part of the Barents Sea and in the ice-rafted sediments carried by the Transpolar Drift showed a significant difference. This suggests that the contribution of such material to the formation of surface sediments of the Barents Sea is relatively small.

Keywords: Barents Sea, modern bottom sediments, rare and trace elements, granulometric composition, geochemistry, Nd, Pb and Sr isotopic composition.

9.6. Cation-exchange properties of sediments in the Central Depression of the Barents Sea

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The article presents data on the study of cation exchange properties of sediments in the Central depression of the Barents Sea relative to heavy metals. The experiments were carried out both on sediments of natural moisture and on sediments after removal of sludge water. The maximum values of the equilibrium exchange capacity of sediments containing and not containing silt water practically coincide and are (in mg-eqv/g) in Mn, Ni, Zn, Cd – 0.20–0.28; Pb – 0.28–0.40; Cu – 0.36–0.66. According to the obtained values of the exchange capacity of precipitation belong to the class of adsorbents. The influence of sediments size and concentration of metal salt solutions on the exchange capacity of precipitation was studied. It is concluded that, on the one hand, precipitation contributes to the circulation of heavy metal cations in the marine environment, on the other hand, sediments can be considered as cleaners and pollutants of marine waters.

Keywords: bottom sediments, heavy metals, exchange capacity, adsorbents.

9.7. Petrography of bottom rock material

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The Quaternary sediments of the Barents Sea contain a large amount of coarse clastic bottom rock material (BRM), with varying degrees of grain roundedness. Its study is important in determining the type and composition of the earth's crust, with paleogeographic constructions and revealing data on the dynamics of the ice cover. Studies of the Barents Sea BRM began in the 20s of the last century. During this period, were formed basically two hypotheses about the relationship between the distribution of BRM with elements of the sea topography and bedrock exposure. One of them considers BRM a marker suitable for identifying petrographic provinces at the bottom of the Barents Sea [Klenova, 1960]. In this chapter, on the basis of new up-to-date data obtained in 67 and 68 cruises of the RV *Akademik Mstislav Keldysh* in 2016–2017, the grain size, petrochemical and mineral compositions of BRM are estimated, their distribution patterns are given, transportation methods are analyzed and its feasibility is evaluated use in geological mapping. 4,193 samples were processed in Quaternary sediments, among which 86 reference types were identified. It was shown that the diversity of the composition of the Barents Sea BRM depends on glacial and ice-ice spacing. Therefore, the use of BRM for geological mapping of the bottom of the Barents Sea is unsuitable. The petrographic composition of the BRM in different regions of the Barents Sea is subject to significant fluctuations, but in general it is complementary to the set of rocks in the areas of demolition of adjacent land and depends on the extent of exaration and the removal of exaration material by the glacier to sedimentation areas.

Keywords: coarse material, petrographic composition.

CHAPTER 10. GEOECOLOGY AND POLLUTION

10.1. Hydrocarbons in waters and bottom sediments of the Barents Sea

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Hydrocarbons in water, suspended matter and bottom sediments of the Barents Sea were studied based on materials from expeditions to the RV *Akademik Mstislav Keldysh* in 2016–2019. It is shown that at present there is no oil pollution in open areas of the Barents Sea. With the transition from early summer (2019) to autumn (2016), there was a decrease in hydrocarbon concentrations in surface waters, caused by a change in the biochemical composition of organic matter (possibly due to a decrease in the area of ice). With depth, the HC content decreased mainly. An exception was observed

in the area of gutters and deposits, where in the bottom nepheloid layers there was an increase in the concentration of hydrocarbons in suspension and in the surface layer of bottom sediments, and in the thickness of the sediments there was no dependence on their distribution and organic carbon.

Keywords: hydrocarbons, lipids, organic carbon, bottom sediments, pollution, oil, polyaromatic hydrocarbons.

10.2. Content of cesium radionuclides in water and bottom sediments of the Barents Sea

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Based on the results of field research in the cruise 68 of the RV *Akademik Mstislav Keldysh*, the content of anthropogenic ^{137}Cs radionuclides in surface waters and bottom sediments of the Barents Sea was estimated. As a result of a comparative assessment of current levels of radiocesium in other seas, it is concluded that the radioecological situation in the Barents Sea is favorable, despite the presence of a large number of potential sources of radiation pollution. The work was carried out on the topic of the state task of the IBSS "Molismological and biogeochemical foundations of homeostasis of marine ecosystems", No. AAAA-A18-118020890090-2.

Keywords: cesium radionuclides, radioecological monitoring, pollution.

10.3. Evaluation of the modern geoecological state of the fjords of the eastern Barents Sea

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A brief analysis of the history of environmental geological study of the Barents Sea is given. It shows that at the beginning of industrial development the geological environment was characterized by a low level of disturbance and pollution. On example of the Kola Bay, an assessment of the current environmental geological conditions of the fjords in the eastern part of the Barents Sea is given. Seismic-acoustic studies confirm the predominantly tectonic origin of the bay and the hazardous spread of gravitational rocks movement within the coastal slopes. The background geochemical characteristics of recent bottom sediments are quantified. It is shown that geochemical zoning of the bottom of the bay is a consequence of both natural and anthropogenic processes. According to the content of Cu, Zn, As, Cd, Pb, Hg and hexane-soluble petroleum products (PP) in the bottom sediments, the characteristics of various areas were obtained. It is shown that the distribution of PP and several other pollutants in the main components of aquatic and coastal geosystems is a leading element of the environmental monitoring system, quantitative assessment of anthropogenic impact and accumulated environmental damage. Active economic activity within the southern leg of the Kola Bay, as well as the naval bases, significantly affects the distribution of chemical elements. The data concerning distribution of chemical elements forms in bottom sediments are given that suggest a high probability of secondary pollution of the bottom water when the physicochemical conditions of sedimentation processes change. A comparative analysis showed that bottom sediments of the Kola Bay are characterized by the highest concentration of chemical elements in the North-West Region of the Russian Federation.

Keywords: Barents Sea, Kola Bay, geo-ecology, geochemical zoning.