German-Russian Cooperation: Biogeographic and biostratigraphic investigations on selected sediment cores from the Eurasian continental margin and marginal seas to analyze the Late Quaternary climatic variability

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INTRODUCTION: GERMAN-RUSSIAN SCIENTIFIC COOPERATION WITHIN THE PROJECT "BIOGEOGRAPHIC AND BIOSTRATIGRAPHIC INVESTIGATIONS ON SELECTED SEDIMENT CORES FROM THE EURASIAN CONTINENTAL MARGIN AND MARGINAL SEAS TO ANALYZE THE LATE QUATERNARY CLIMATIC VARIABILITY"

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The oceans and shelf seas around northern Eurasia play an important role in world ocean circulation and global climate. Warm Atlantic water flows through the North Atlantic and the Nordic Seas into the Arctic Ocean, cooling on its way north and thereby releasing heat to Western and Northern Europe. In the Nordic Seas, vertical overturning leads to the formation of dense water masses, which flow southward through the Atlantic and can be traced into all major world ocean basins. The "Global Conveyor Belt" leads these deep waters as far as the North Pacific, where upwelling occurs. The Arctic Ocean contributes to this circulation system by the formation of dense brines mainly on the Siberian shelves, where sea ice is formed from low saline surface waters. The brines mix with inflowing saline Atlantic water and partly leave the Arctic Ocean as intermediate waters through the Fram Strait. Another part sinks down the continental shelves and fills the deep basins of the Arctic Ocean.

The reports in this volume deal with various aspects of the micropaleontology, paleoceanography, and sedimentology of the seas around northern Eurasia. They document the major scientific outcome of the German-Russian cooperation project "Biogeographic and biostratigraphic investigations on selected sediment cores from the Eurasian continental margin and marginal seas to analyze the Late Quaternary climatic variability", funded by the German Federal Ministry of Education, Science, Research and Technology (BMBF). The reports deal mainly with the distribution patterns of various microfossil groups on the floor of the shelf seas and open ocean areas along the northern Eurasian continental margin, i.e., from the northern North Atlantic through the Arctic and the Bering Sea to the North Pacific and the Sea of Ochotsk. It had been recognized that during the past decades, Russian scientists had collected a huge amount of data and archive materials which never received the attention of scientists outside the former USSR and Eastern Europe. The reasons were two-fold: Many of the scientific reports were written in Russian language and most of them were practically not available to scientists outside the area.

The cooperation in the frame of the project was established in late 1994 between the GEOMAR Research Center for Marine Geosciences and two major Russian working groups in the field of micropaleontological and paleoclimatic research. The Russian cooperation partners were located at the P. P. Shirshov Institution of Oceanology in Moscow and the All-Russian Research Institute for Geology and Mineral Deposits of the World Ocean (VNIIOkeangeologia) and the Geological Institute of the University in St.

Petersburg. One goal of the project was to establish a data bank for micropaleontological data, which had been obtained by the working groups, but only to a lesser degree had been published in non-Russian language literature and never been archived in data banks. A second goal was to promote collaboration and data exchange among the Russian working groups and the German partner institute. Third, the data should be used for paleoenvironmental and paleoclimatic reconstructions.

The investigated objects include planktic and benthic foraminifers, ostracods, diatoms and radiolarians, as well as grain sizes. The presented results are original data, which may help to reconstruct paleoenvironmental and paleoclimatic changes of the geological past in order to improve our understanding of the global climate system and its possible changes in the future. The reports are arranged according to the investigated regions from west to east (Fig. 1).

Two reports deal with the Late Quaternary history of the North Atlantic. *Barash and Yushina* have investigated the composition of the planktic foraminifer fauna in several sediment cores and applied mathematical models to reconstruct paleohydrological parameters. *Matul and Yushina* analyzed the distribution of radiolarians in surface sediments of a great number of cores and reconstructed the late glacial and Holocene paleoceanography based on one core from the Reikjanes Ridge.

Diatoms in Arctic shelf seas sediments proved to be a reliable indicator for paleonenvironmental conditions. *R. N. Djinoridze, Ivanov, Vanshtein, and E. N. Djinoridze* investigated them in surface sediments and sediment cores from the Barents Sea to reconstruct the Holocene variability in the Atlantic water inflow, sea ice cover and climate. From sediments obtained by four drillings in the Pechora Sea (SE Barents Sea), *Kupriyanova* analyzed the ostracods and could find relationships to transgressive-regressive cycles in the Plio-Pleistocene.

Two studies deal with sediments obtained during the expedition of RV "Professor Logatchev" to the St. Anna Trough (northern Kara Sea) in 1994. *R. N. Djinoridze, Ivanov, E. N. Djinoridze, and Spielhagen* show the reflection of modern ice covers and river run-off in the composition of diatom associations, whereas *Ivanov et al.* report on basic oceanographic and sediment grain size data from the area.

In a diatom study, *Mukhina and Yushina* compare findings in sediment cores from the Kara and Laptev seas. In both areas, freshwater species are dominating in the south, whereas brackish water and marine diatomes become more abundant to the north, demonstrating the possibilities to utilize diatoms as indicators of present and past river-runoff.

In a synoptic study, *Kruglikova* compares radiolarian associations from various seas around northern Eurasia, with emphasis on the North Pacific. From the different biogeographical associations and assemblages, she found that the various basins can have very specific associations, which make it possible to reconstruct the history of inter-basin water mass exchanges.

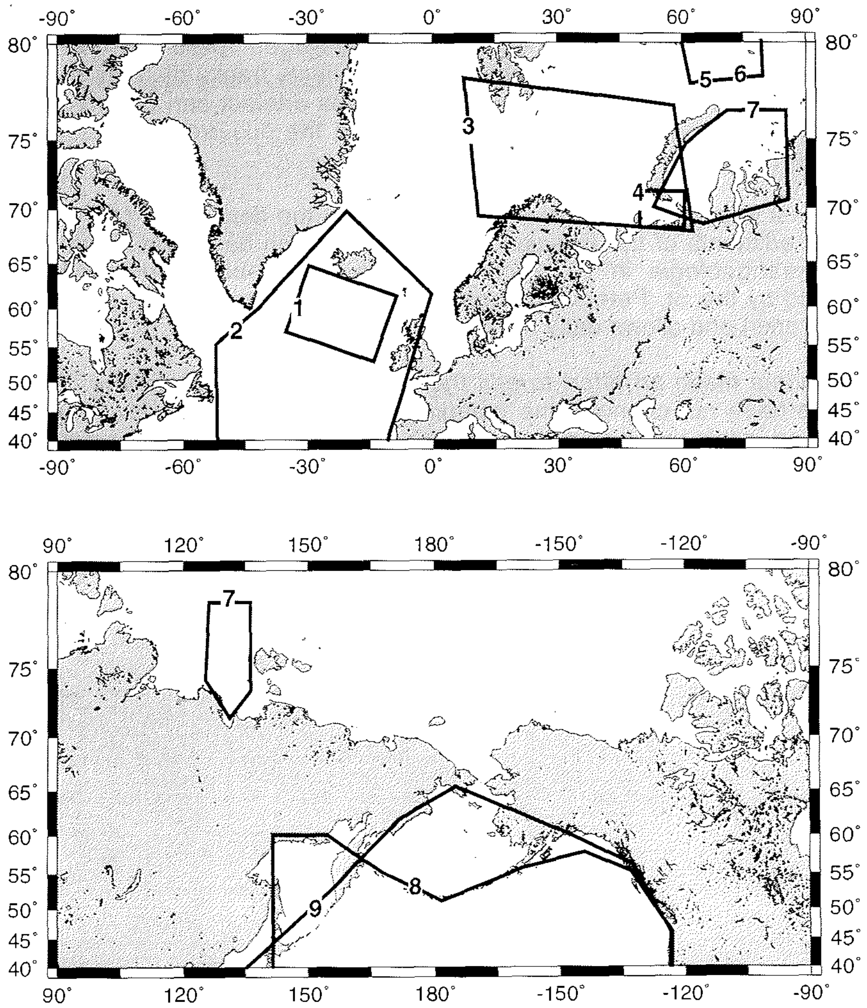

Fig.1: Research areas covered by the individual reports in this volume. 1 Barash and Yushina; 2 Matul and Yushina; 3 Djinoridze, Ivanov, Vanshtein, and Djinoridze; 4 Kupriyanova; 5 Djinoridze, Ivanov, Djinoridze, and Spielhagen; 6 Ivanov et al.; 7 Mukhina and Yushina; 8 Kruglikova; 9 Kazarina and Yushina.

The rich diatom floras in sediments from the Bering Sea allow to study in detail the correlations between species distributions and water mass parameters. *Kazarina and Yushina* have grouped a number of species from surface sediment samples according to the average temperature of the overlying surface waters. Basic assumptions an temperature changes at the Pleistocene-Holocene boundary allowed them to prepare a preliminary isopach map of Holocene deposits in the Bering Sea.

In a final paper on diatoms, Samsonov reports on the different results of diatom preparation using alcohol or hydrogen peroxide. He could demonstrate that partial dissolution strongly affects fragile diatoms during the cleaning with hydrogen peroxide. This possible artefact can be important for paleoenvironmental reconstructions based on the occurrence or abundance of individual species in analyzed samples.

In the last paper, *Ivanov and Novikov* introduce the data bank "Microfossils in bottom ediments of the Russian Arctic shelf", which has been established at VNIIOkeangeologia in St. Petersburg. This data bank holds all results obtained by the St. Petersburg working group within the project (and through other works) and allows easy access to the data.

The editors made an effort to edit the manuscripts by the authors. We hope that we have not changed the meanings of the original papers. The papers contained in this report do not necessarily reflect the opinion of the editors.

RECONSTRUCTIONS OF THE QUATERNARY NORTH ATLANTIC PALEOHYDROLOGICAL VARIABILITY BY MEANS OF PLANKTIC FORAMINIFERA DATA (METHOD OF FACTOR ANALYSIS AND SPLINE INTERPOLATION)

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Introduction

The species composition and the quantitative structure of the living microplankton and microbenthos assemblages correspond to the ecological conditions. After the death of the organisms, their sceletons are accumulated on the ocean floor. Thus, the thanatocoenoses contain information about the paleoceanographical conditions. Statistical relationships between species distribution and oceanographical parameters make it possible to reconstruct the paleoceanographical conditions such as the temperature as a main ecological parameter in the ocean and also the water salinity and density. The reconstructions of these characteristics on a large scale allow to approach spatial-temporal regularities of climatic changes.

The dependence of the microplankton distribution on a climatic zonality was established already in the 19th century (Murray and Renard, 1891, and others). German ocean researchers (Philippi, 1910; Schott, 1935) were the first who supposed that variations in the relations of the planktic foraminifera species in deep sea sediment cores reflect climatic changes. They distinguished "warmwater" and "coldwater" microfossil complexes and introduced the Late Quaternary climatostratigraphic divisions (intervals of the Holocene and the Last Glacial stage). This method in different modifications was unique up to 1960s (e.g., Phleger et. al., 1953; Ericson et.al., 1961), but many paleontologists use it still now for pre-Quaternary and Quaternary times.

Later a number of methods came up of quantitative reconstructions of the Quaternary paleoenvironmental conditions (temperature, water salinity, etc.) based on fossil microfossil assemblages (planktic foraminifers, radiolarians, diatoms, coccoliths, palynological remains, etc.), which are compared with the modern ones reflecting the conditions of their lifetime (Barash, 1964, 1970, 1988; Barash and Blyum, 1975; Imbrie and Kipp, 1971; Kipp, 1976; and many other papers; for a comprehensive list see Pflaumann et al., 1996). On the base of the method of analyses of percentage structures of planktic foraminifera thanatocoenoses proposed by M.Barash, many features of the Late Quaternary paleoceanography were revealed and published since the 1960s (they are collected in monographs by Barash, 1988, and Barash et al., 1989).

Using the method of factor analysis and transfer function (Imbrie and Kipp, 1971), the CLIMAP Project members (1976, 1981, 1984, etc) had created a sea surface temperature (SST) database for the Late Quaternary ocean. Their reconstructions were similar to the reconstructions made by M.Barash and colleagues. The CLIMAP results led to the new concepts of global climatic changes. Also other methods of paleotemperature reconstructions by means of microfossils were elaborated, in particular the Modern Analogue Technique (e.g., Hutson, 1977) and the SIMMAX Technique (Pflaumann et al., 1992, 1996).

Most of these methods were used for reconstructions of the sea surface parameters (mostly SST). However, planktic organisms used for the reconstructions inhabit the whole upper layer of the ocean, which can have a thickness of some hundreds of meters, and not only the ocean surface. In fact, foraminifera inhabit mainly the euphotic zone (upper 80-100 m), and the maximum concentrations usually are found at 10-50 m depth (Be, 1977). Mean habitat depths of planktic foraminifera in the Atlantic Ocean according to oxygen-isotope data are 100-200 m (Nikolaev et al., 1979). The species stratification in the water column is well known: The species are characterized by different habitat depths. Thus, the complex of tests accumulated on the bottom (the "thanatocoenosis") reflects not only surface ecological conditions but also conditions of the whole upper water layer (from 0 to 200-250 m) in which these organisms lived.

In this report an experiment of paleohydrological parameters reconstruction for a series of standard hydrological depths of the upper water layer of the North Atlantic is described. The North Atlantic is the most important region for the understanding of the spatial-temporal regularities of the last dramatic climatic changes connected with the complex processes of the onset and termination of the last glacial stages. Also, it is the best investigated region of the world ocean from the point of view of paleoclimatology and paleoceanography. Hundreds of works in these fields were made here, in particular on the base of the study of microfossils which are contained in the sediments. However, the investigations carried out in the framework of this project on the planktic foraminifera distribution in selected sediment cores from the North Atlantic and the interpretation of data yield new information on paleohydrology and climatic changes in this region.

In this report we present the results of detailed analyses of the planktic foraminifera distribution in samples from two Late Quaternary sediment cores from the Reykjanes Ridge (R/V "Akademik Mstislav Keldysh"): MK-316 (58°44.4'N, 27°17.3'W, 2155 m water depth), MK-325 (58°26.2'N, 31°42.2'W, 1820 m water depth); and from Quaternary sediment cores obtained during the expeditions of R/V "Mikhail Lomonosov": L-348 (63°56.8'N, 30°02.0'W, 2262 m water depth, west of the Iceland), L-198 (55°42.5'N, 18°541'W, 1265 m water depth, southern slope of the Rockall Rise), and L-66 (49°03'N, 20°18'W, 4000 m water depth, western part of the European Basin).

Methods

In this work a method of factor analysis and multidimensional spline interpolation (Yushina, 1989) is used. This method allows to reconstruct paleoceanographical parameters (temperature, salinity and density) for four seasons at several depths.

The paleoreconstruction method consists of several steps: First we diminish the dimension of dataspace using factor analysis, then we create an "influence function" using splines based on Green functions. These "influence functions" show the "distance" between a core datapoint and all datapoints from the surface sediment database. Finally, we can calculate the hydrological characteristics of the ocean water for the ocean of the past. The accuracy of the method is 0.25°C for temperature and 0.05‰ for salinity when the above mentioned data bank of the planktic foraminifera distribution in the surface sediments is used. The accuracy can be raised if new data are added.

For the creation of a micropaleontological database many hundreds of data on the planktic foraminifera distribution in the surface sediment samples from the Atlantic Ocean were revised. There are archive data of quantitative micropaleontological analyses of samples obtained since 1957 during many research expeditions of R/Vs "Mikhail Lomonosov", "Equator", "Georgiy Sedov", "Polus", "Dmitry Mendeleev", "Akademik Kurchatov", "Akademik Mstislav Keldysh" and others. Analyses were carried out in the Laboratory of Paleoecology and Biostratigraphy of the P.P. Shirshov Institute of Oceanology by M.S.Barash and his collaborators. In addition, for some dozens of the samples, the relationship between some planktic foraminifera subspecies was reanalyzed. New samples obtained during expeditions in the last years were analyzed in addition. From this archive (277 samples) the database was created which can be used for paleoceanographical reconstructions by means of the comparison of fossil foraminifera assemblages with the recent ones using different statistical methods.

The hydrological database necessary for revealing of the quantitative relationships between the distribution of the microorganisms and the oceanographic conditions is the computer database of Levitus (1982) which contains the main hydrological parameters of the modern world ocean for four seasons throughout the whole water column. The use of the splines gives the opportunity to order the hydrological information on a regular points system. This establishes the correct base for the paleoceanographical modeling.

Laboratory treatment

For foraminiferal analysis, the laboratory treatment described by Barash et al. (1983) is used. For foraminiferal analyses, the groups of granulometric fractions coarser than 0.1 mm are used. The fractions are thoroughly mixed and divided until the remaining split contains at least 300 tests. All the tests are identified and counted according to the taxonomy of Be (1977). Additionally, all the size fractions greater than 0.1 mm are thoroughly examined under the microscope to discover rare species that might be omitted from the split.

Also the "foraminiferal (= Schott) number" (the number of shells larger than 0.1 mm per 1 g of dry sediment) and the relation of terrigenous and biogenous (foraminiferal tests mainly) components in the granulometric fraction more than 0.1 mm were calculated.

For some cores the paleotemperature reconstructions were made by a method of Barash (a short English description of the method is found in Barash et al., 1983). For a climatostratigraphic division geochemical, oxygen-isotope and lithological data were used. The oxygen-isotope analyses were made on the bulk planktic foraminifera complex (S.D.Nikolaev, V.I.Nikolaev). Besides that, absolute dating was done by the ^{14}C method (V.M.Kuptsov) and by the $^{230}Th/^{231}Pa$ methods (Arslanov et al., 1988).

Results

Core L-66, 298 cm long, was obtained in the western part of the European basin. It consists of an alternation of biogenic coccolith-foraminiferal ooze (0-12, 134-149, 168-255 cm) and terrigenous sandy mud and silt containing gravel and pebbles (12-134, 149-168, 255-298 cm). In the upper part of these layers there is an volcanic ash. Absolute dating was made by the ^{14}C (8420±20 years for 8-12 cm) and the Pa-Th method (146,000±18,000 years for 150-154 cm and 231000±15000 years for 229-234 cm). Based on these datings, mean sedimentation rates for the intervals are 1.19+-0.03 cm/ky, 0.98±0.12 cm/ky and 1.02+-0.07 cm/ky, respectively. In this core 18 analyses of planktic foraminifera complexes were made (Appendix 1) and paleohydrological parameters (paleotemperatures, paleosalinity, paleodensity) were reconstructed. The complex of data allows to make a climatostratigraphic and age correlation of the core in accordance with the oxygen-isotope divisions (Morley and Hays, 1981) (Fig. 1).

The terrigenous layers at 298-255 and 168-149 cm correspond to oxygen isotope stages 8 and 6 (two stages of the penultimate (Riss) glaciation). The biogenic layer at 255-168 cm corresponds to oxygen isotope stage 7 (Riss interstadial). The biogenic layer at 149-134 cm correlates with the oxygen isotope substage 5e (Eemian interglacial). The upper terrigenous layer (134-12 cm) evidently embraces the oxygen isotope substages 5d-5a and the stages 4-2 (the last glacial). The interstadial of the last glacial (stage 3) is reflected in the core only in the relations of the foraminifera species, and in a total increase of their content. Finally, the upper biogenic layer (12-0 cm) corresponds to the oxygen isotope stage 1, i.e. to the Holocene.

Taking into account the age evaluations of the stages boundaries (Morley and Hays, 1981), the sedimentation rates can be calculated. They are 1.6 cm/ky in stage 7, 0.4 cm/ky in stage 6, about 1.2 cm/ky in substage 5e and stage 1, 1 cm/ky during substages 5d-5a, 1.5 cm/ky during the stages 4-2, i.e. the last glaciation as a whole. (Thus, the average sedimentation rate during all the time of accumulation was about 1 cm/ky). These data show sedimentation rates (1.2-1.6 cm/ky), which are normal for foraminiferal-coccolith oozes and variable rates for terrigenous sediments (0.4-1.5 cm/ky). Thus, the increase of the terrigenous accumulation during glacial stadials did not increase the accumulation rates, because simultaneously the biogenic accumulation diminished.

The following planktic foraminifera species were encountered and calculated: *Globoquadrina (Gq.) pachyderma* sin. (Ehrenberg), *Globigerina (G.) quinqueloba* Natland, *G. bulloides* d'Orbigny, *Globigerinita (Gt.) bradyi*

Wiesner, *Gq. pachyderma* dex. (Ehrenberg), *Gt. glutinata* (Egger), *Globorotalia (Gr.) inflata* (d'Orbigny), *Gr. scitula* (Brady), *Goborotalia truncatulinoides* (d'Orbigny), *G. falconensis* Blow, *Gr. hirsuta* (d'Orbigny), *Gt. humilis* (Brady), *Gr. crassaformis* (Galloway et Wissler), *Orbulina (O.) universa* d'Orbigny, *Globigerinoides (Gs.) ruber* (d'Orbigny), *Gs. conglobatus* (Brady), *Gq. dutertrei* (d'Orbigny), *Globigerinella (Gl.) aequilateralis* (Brady).

Only six species and subspecies form 80-100% of the complex (in order from coldest water to the warmest water): *Gq. pachyderma* sin., *G. quinqueloba*, *G. bulloides*, *Gq. pachyderma* dex., *Gt. glutinata*, and *Gr. inflata*. In different samples each of them accounts for at least 10%. The fluctuations of their percentages reflect changes of paleohydrologic conditions: Contents of the cold water subpolar species *Gq. pachyderma* sin. are more than 90% during maxima of the glacial stages (2, 4, 6, 8). During the Holocene and the interglacial stages (1, 5, 7) the contents of all other species increased. During the last interstadial (stage 3) only content of the most coldwater of boreal species *G.quinqueloba* increased (the temperature rise was relatively small).

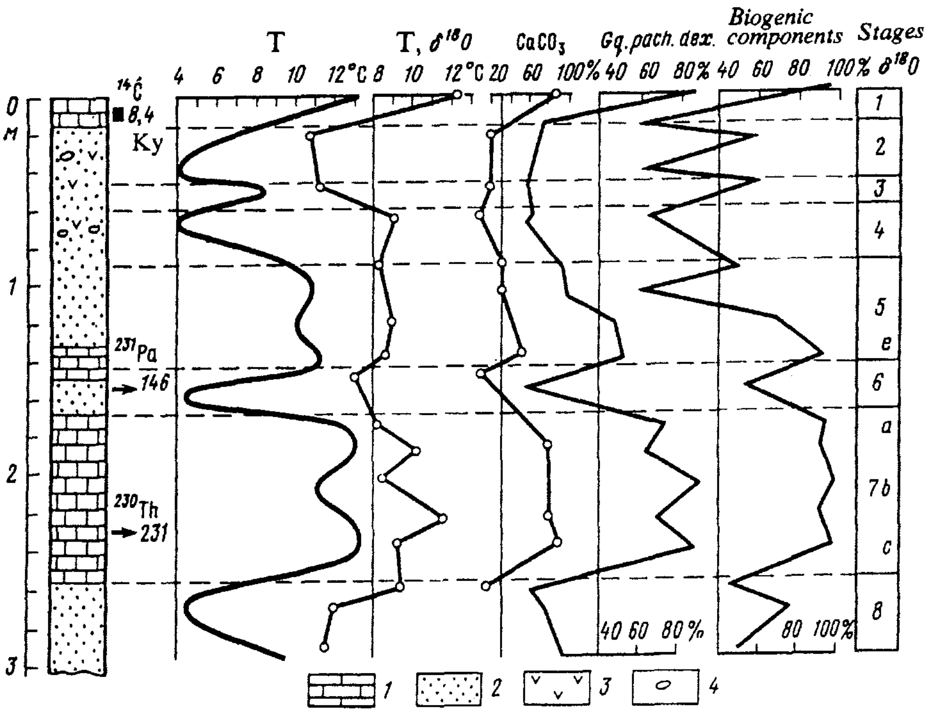

Fig. 1. :Climatostratigraphy of core L-66 (Barash, 1988): Absolute dating results; average annual surface temperatures based on correlation of the climatic groups of foraminifer (T); temperatures calculated from oxygen isotope data; content of Gq. pachyderma dex. (% of planktic foraminifers); contents of biogenic components in the sediment fraction >0.1 mm; correlation with oxygen isotope stages.
Legend: 1 - nannofossil-foraminiferal ooze, 2 - terrigenous sandy mud and silt, 3- volcanic ash, 4 - gravel and pebbles.

Using the method of factor analysis and spline interpolation the paleohydrological reconstructions based on these foraminiferal data were made (Fig. 2). During interglacial intervals, the average annual surface temperatures were 11-14°C, even more in the Holocene and stage 7. Lower temperatures in the time of substage 5e are confirmed by the absence of some tropical species which are present in Holocene and stage 7 sediments: *Gs. ruber, Gs. conglobatus, Gq. dutertrei.*

During the glacial intervals (stages 2-4, 6, and 8) the average annual surface temperatures were 3-6°C, being especially stable and cold (3-4°C) during the last glaciation (stages 4-2, about 75-20 ka).

The winter and summer surface temperature differences, i.e. the amplitude of seasonal temperature changes, were 3-4°C, reaching a maximum (up to 6°C) during the interglacial optimum (substage 5e). Coldest winter temperatures (about 1°C) were reached during the last glaciation (stages 4-2) (Fig. 2).

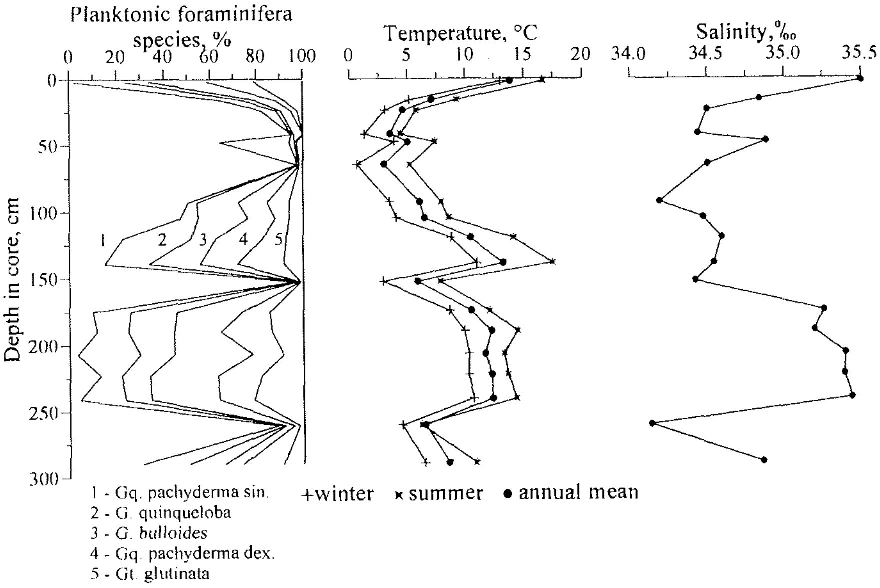

Fig. 2: Correlation of five main foraminifer species and reconstruction of sea surface temperature for winter (W), summer (S) and annual mean, and annual mean salinity for the western part of the European Basin (St. L-66) using factor analysis and spline interpolation.

For the peak climatostratigraphical intervals, 'the average annual paleohydrological parameters (temperature, salinity, density) of the upper 250 m of ocean water were reconstructed (Figs. 3, 4). This was done for the following standard depths of hydrophysical measurements: 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, and 250 m. The reconstructed temperature profiles for the interstadials (e.g., stage 7) and interglacials (e.g., substage 5e) are similar. In the upper 250 m water layer the temperatures lowered by about 4°C (13-

9°C) and 2°C (12-10°C), respectively. The salinity and density profiles are more different. During the interglacial, the salinity was equal (35.4‰) in all upper layers, and the density changed very little. During the Interstadial the salinity was a little lower (34.5‰) and increased from 34.5 to 35.2‰ in the upper 100 m; beneath this depth it was equal. The density lowered from 26.0 to 26.9‰ in the upper 100 m and beneath this depth more slowly to 27.3‰. Probably during the interstadial, the upper homogeneous layer was more stratified than during the interglacial.

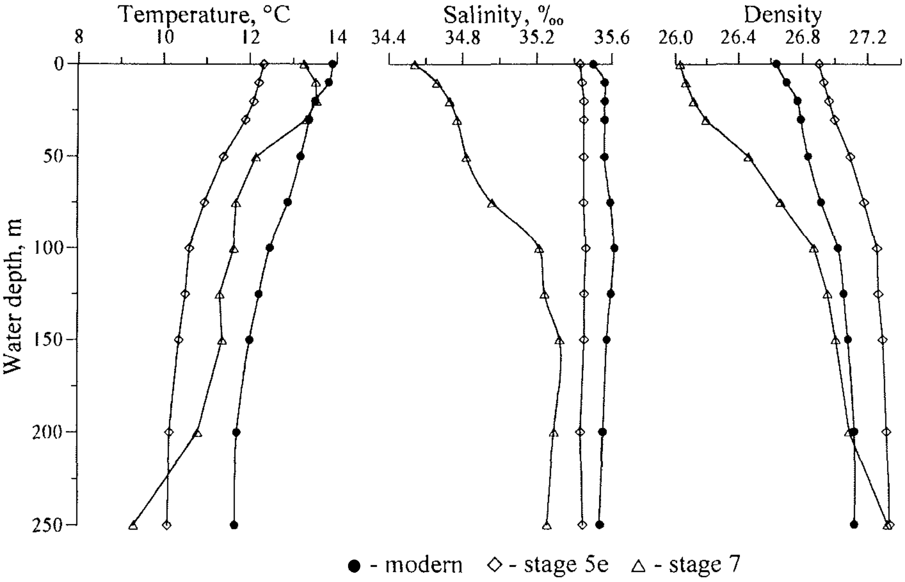

Fig. 3: Core L-66: Reconstruction of average annual paleohydrological parameters (temperature, salinity, density) of upper 250 m of ocean water for warm time intervals: Oxygen isotope substage 5e and stage 7.

During the cold intervals of glacial stadials (stages 2, 6, 8) the average annual temperatures of the upper 250 m water layer were essentially lower: down to 50 m they diminished from 3.5 to 2.5°C in the last glacial maximum, and from 6.0-6.5 to 4.0-4.5°C during other stadials. Beneath 50 m the temperatures were equal (Fig. 4). Salinity profiles were similar to the profile of stage7. All the reconstructed paleohydrological parameters show the noticeable stratification of the upper water layer.

Two cores of the Reykjanes Ridge sediments represent shorter time intervals, but a detailed analysis of the planktic foraminifera tanathocoenoses and ^{14}C dating as well as comparatively high sedimentation rates give the possibility to reveal the frequency and the amplitude of the climatic and paleoceanographic variability in this region. Earlier, these cores (MK-316, and MK-325) were studied by Matul (1994) and the stratigraphic division and some paleoceanographic reconstructions by means of radiolarian data were made.

The layers at 0-37 and 402-456 cm in core MK-316 and core MK-325 are composed of a biogenous nannoforamoniferal ooze with 30-50% $CaCO_3$. The layer at 37-402 cm in core MK-316 is a terrigenous sandy mud and silt containing gravel and pebbles, with lower contents of $CaCO_3$ (15-30%). The foraminiferal analysis was carried out in 73 samples of core MK-316 and 20 samples of core MK-325. Absolute dating was made in 9 samples of the core MK-316 and in 5 samples of the core MK-325 (table 1).

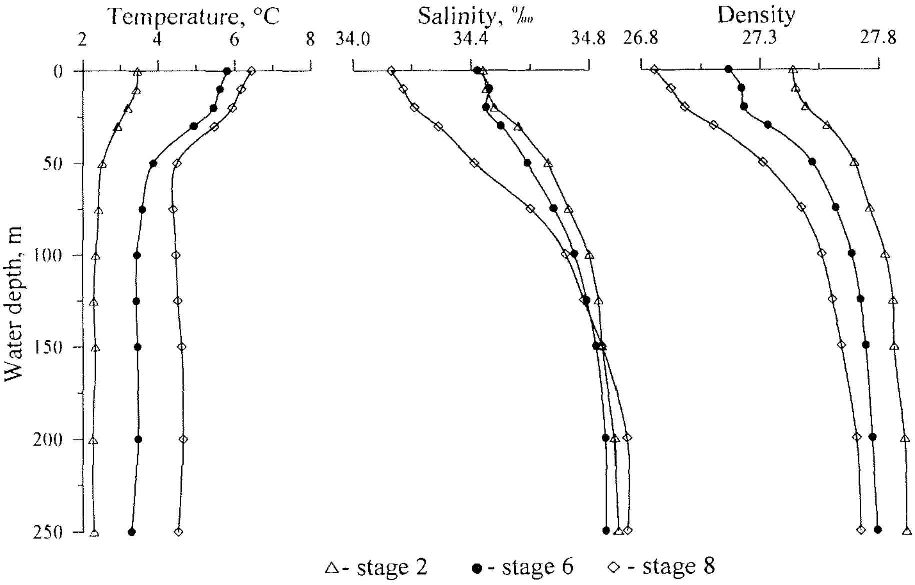

Fig. 4: Core L-66: Reconstruction of average annual paleohydrological parameters (temperature, salinity, density) of upper 250 m of ocean water for cold time intervals: Oxygen isotope stages 2, 6, and 8.

Table 1. ^{14}C dating of the Reykjanes Ridge sediments

Sample (core, cm)	Age (years)	Sample (core, cm)	Age (years)
MK-316 15-20	6340±120	MK-316 300-305	28460±1630
MK-316 30-35	9940±160	MK-325 10-15	2210±160
MK-316 45-50	11750±500	MK-325 50-55	5600±250
MK-316 58-62	12230±350	MK-325 60-74	7460±590
MK-316 85-90	15430±1050	MK-325 80-85	8160±230
MK-316 110-115	22080±820	MK-325 95-100	10320±270
MK-316 195-200	>24620		

Taking into account the accumulation rates of the biogenous ooze and terrigenous sediment of the core MK-316, the rates for the lower part of this core were calculated. The age of the studied section of about 4.5 m is about 46 ka. The mean time resolution per sample in both cores is 300-500 years, but within the interval 32-22 ka it sometimes reaches 150 years.

The foraminiferal complexes here are similar to the above described. Also more than 90% of the foraminiferal complexes consist of the same five species throughout all the cores: *Gq. pachyderma* sin., *G. quinqueloba*, *G. bulloides*, *Gq. pachyderma* dex., and *Gt. glutinata* (Fig. 5, Appendix 2). Sharp fluctuations of the relative species abundances reflect strong paleoceanographic changes during the last climatostratigraphic intervals which are defined by all data. As the species percentages are arranged according to their connection with temperatures, the warm and cold stages are obvious: (1) the interstadial at 41-33 ka, which correlates with the middle part of oxygen-isotopic stage 3, (2) the stadial 33-10 ka, which correlates with late oxygen-isotopic stage 3 and stage 2, and (3) the Holocene 10-0 ka (oxygen isotope stage 1). The warm intervals are marked by increases of the percentages of the warmer water species and the $CaCO_3$ content.

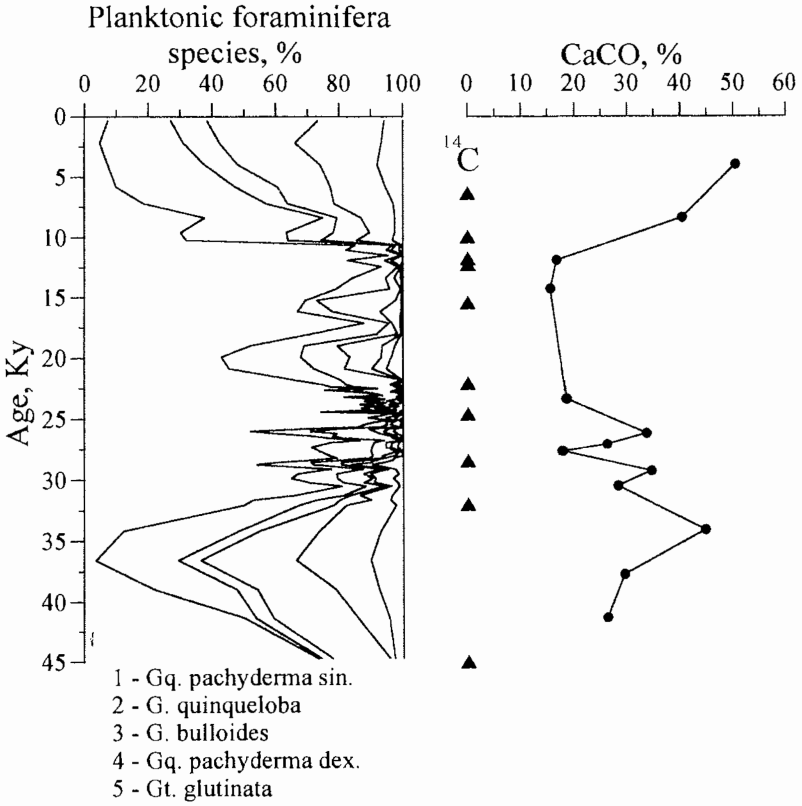

Fig. 5: Core MK-316: Correlation of five main foraminifer species, results of ^{14}C dating and $CaCO_3$ content.

Using the method of factor analysis and multidimensional spline interpolation of the planktic foraminifera data on these two cores, the evaluations of seasonal and average annual paleohydrologic parameters (temperature, salinity, and density) of the surface water were made (Figs. 6-11).

During interstadial time the average annual sea surface temperature was 9.0-12.5°C, with a maximum at 36.5 ka The annual temperatures were reached in the spring time (2-3°C lower), maximum temperatures were mainly summer (2°C higher than the average temperature). The salinity was about 35‰, being highest (35.3‰) around the time of maximum temperatures (36.5 ka). Seasonal salinity fluctuations were very small. The density was stable (about 27); minimal density was reached in summer and autumn, maximal density in spring; the difference was about 0.7.

The stadial time was characterized by two main features: A strong instability of the main hydrological parameters and generally lower temperatures. The average temperature was 6-7°C, fluctuating in the interval 4-9°C. The highest values (8-9°C) are revealed for 28.5, 26.5, 22.5, and 15 ka. The warmings at 28.5 and 22.5 ka were very sharp, and the following cooling more gradual. Minimum temperatures were reached around 25.5 and 17 ka The most unstable conditions were in the interval 26.5-22.5 ka, when the average surface temperatures changed by 2-4°C with a frequency of 300-500 years. Our reconstructions confirm the opinion (McManus et al., 1994) that during the last stadial time the mean position of the boundary between the Arctic and subtropical Atlantic waters (the Polar front) was near and migrated through this area many times.

During the stadial the amplitude of seasonal temperature fluctuations was 2-8°C, being highest in the period of the strongest instability (26.5-22.5 ka). Minimal temperatures were reached mainly in winter, the maximum ones in summer or autumn. The highest summer/autumn temperatures were reached by the Holocene evaluations (up to 11-12°C) but in the same times the winter temperatures were very low (4-5°C).

During the stadial the salinity was unstable too. Usually it was 34-35‰. The seasonal deifferences were small; lower values were reached in autumn and higher ones in spring. But the interval 21-20 ka was different, with very strong seasonal salinity fluctuations (about 2‰), and with minimum summer (33.25‰) and maximum winter (35.2‰) values.

The warm interval at about 17-15 ka was characterized by a high salinity without notable seasonal changes. It was therefore similar to the interstadial and the Holocene.

During the whole stadial time the surface density was unstable, especially in the above mentioned interval of sharp temperature fluctuations (26.5-22.5 ka). The seasonal density changes were higher in this interval and in the end of the stadial (14-11 ka).

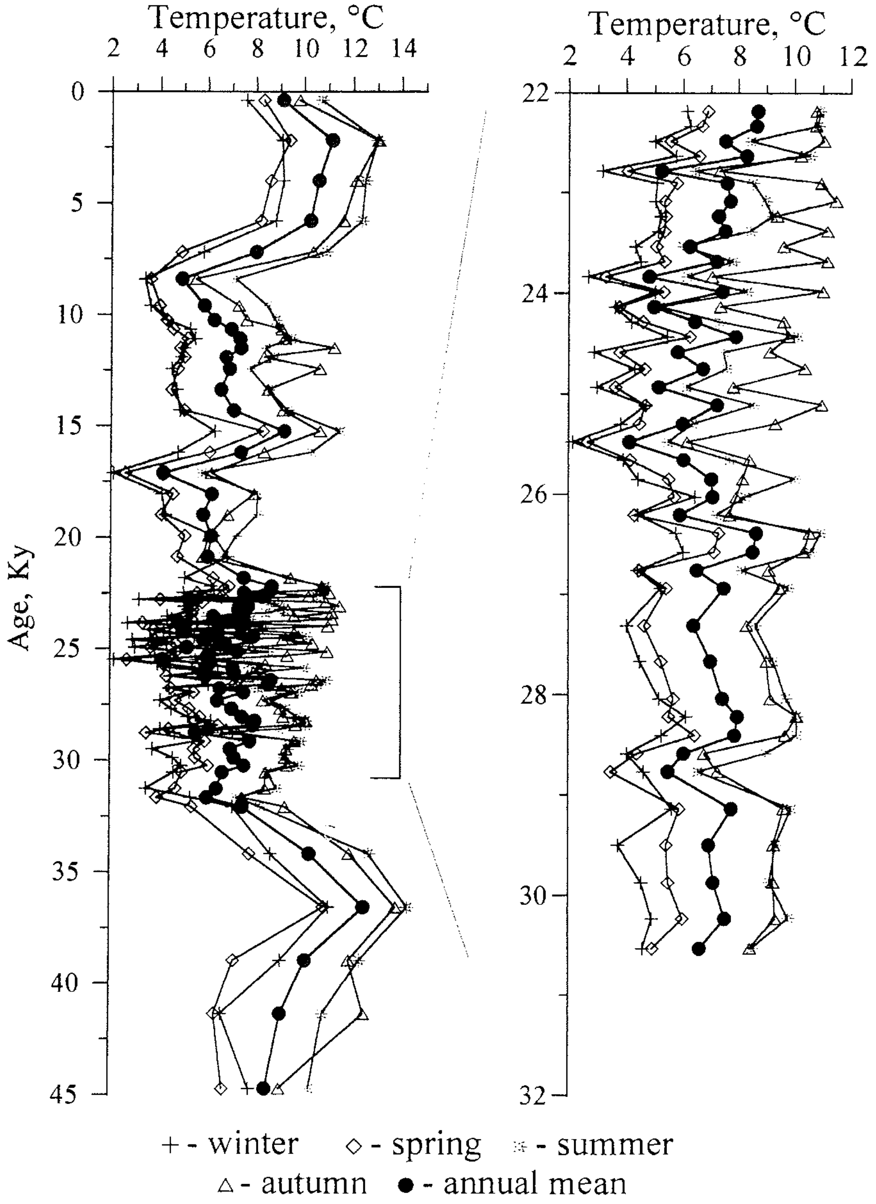

Fig. 6: Core MK-316: Reconstruction of annual and seasonal sea surface temperatures.

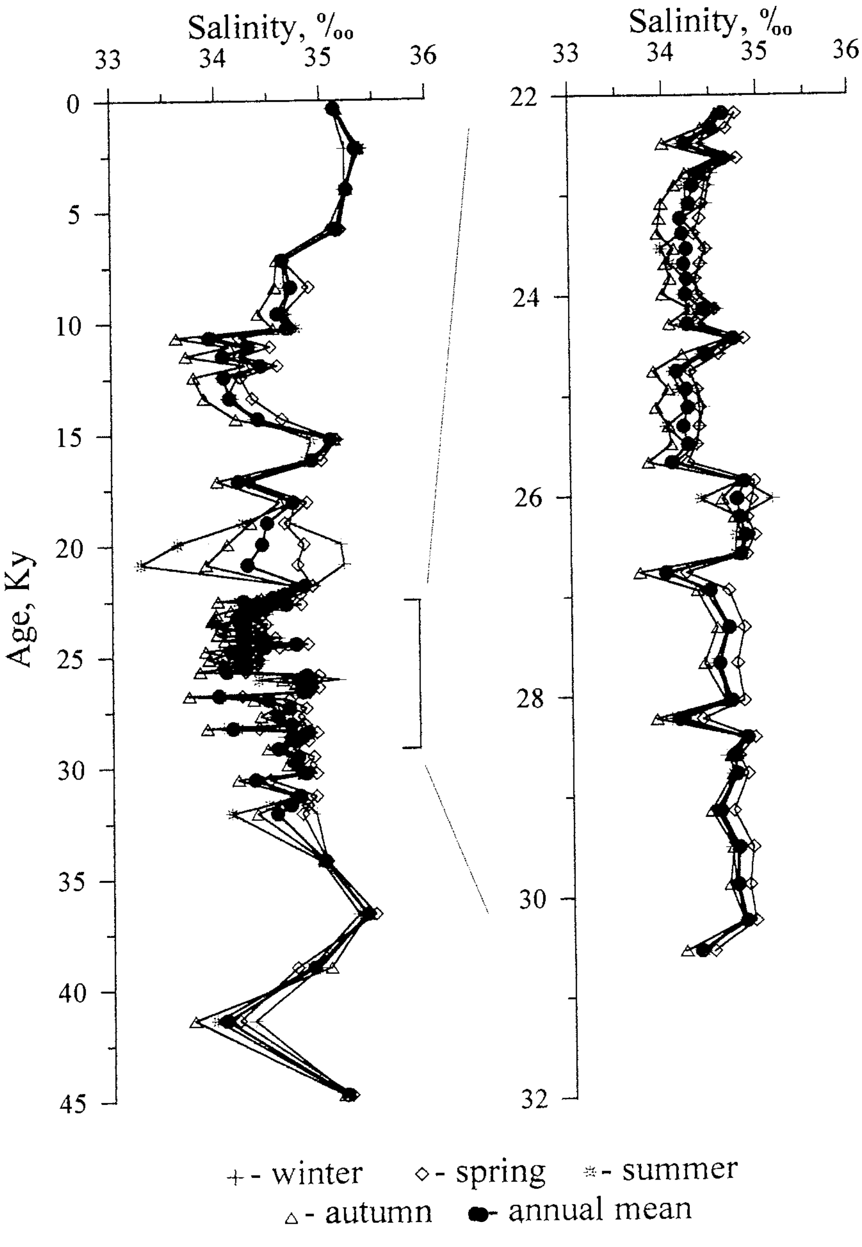

Fig. 7: Core MK-316: Reconstruction of annual and seasonal sea surface salinities.

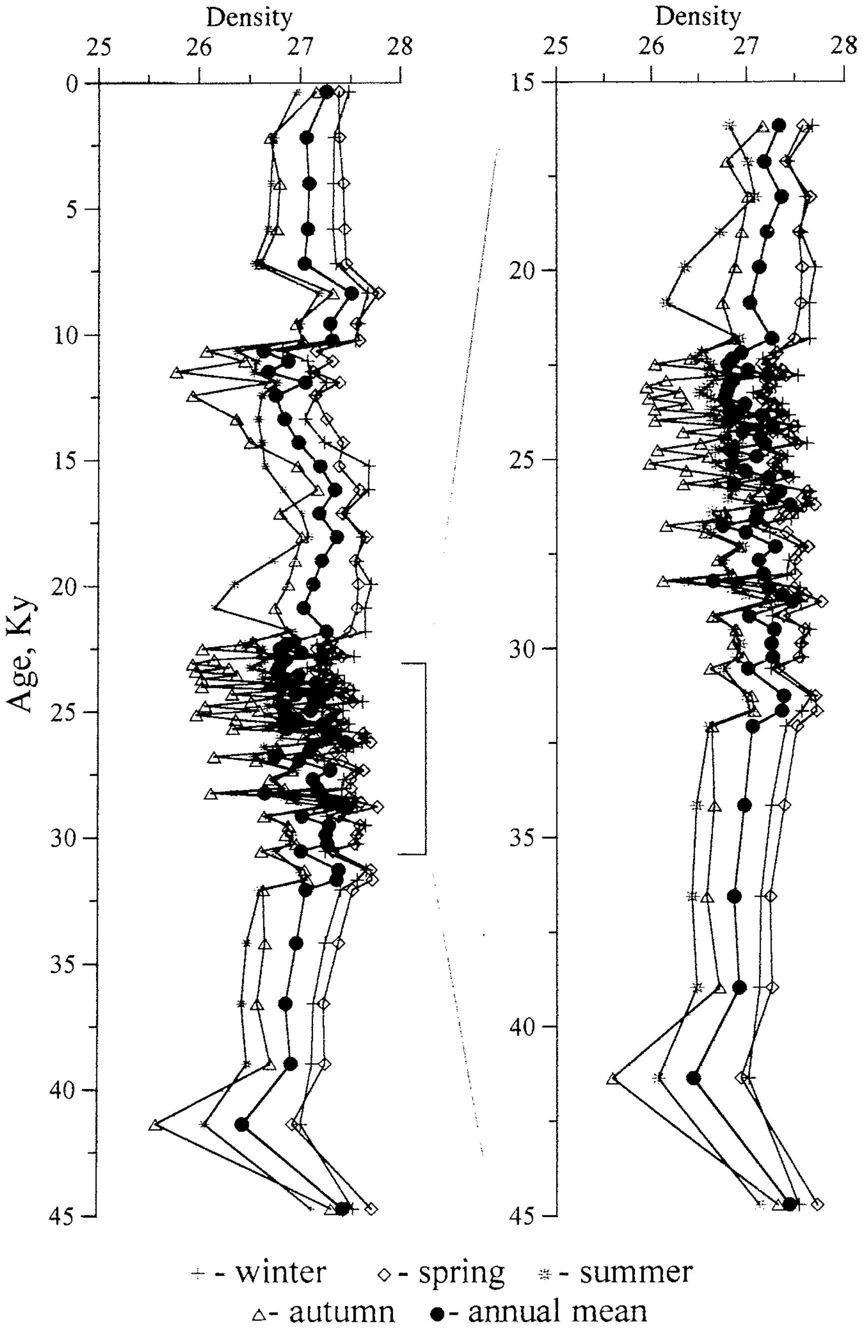

Fig. 8: Core MK-316: Reconstruction of annual and seasonal sea surface densities.

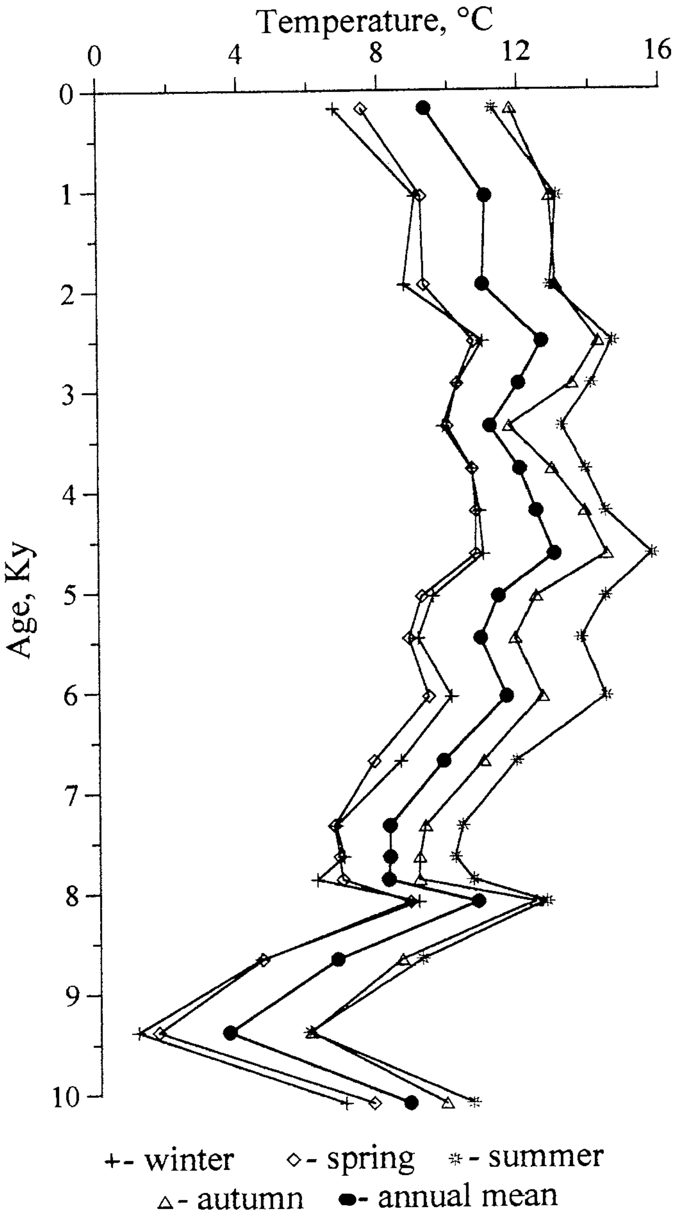

Fig. 9: Core MK-325: Reconstruction of annual and seasonal sea surface temperatures.

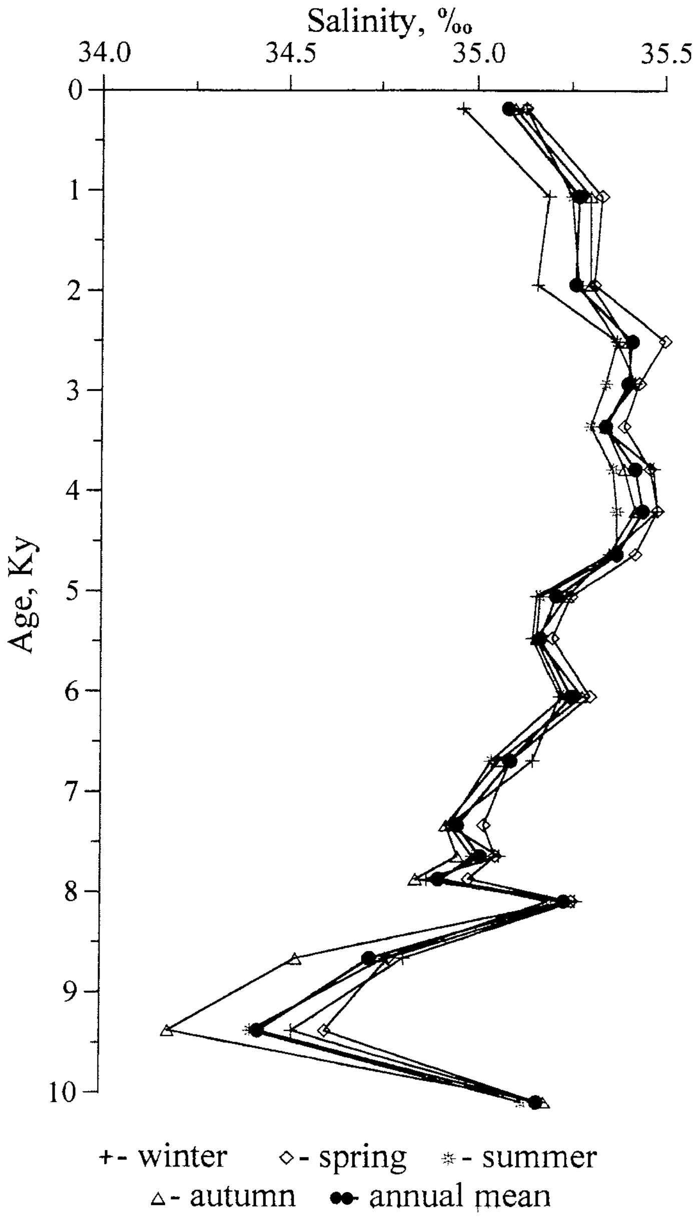

Fig. 10: Core MK-325: Reconstruction of annual and seasonal sea surface salinities.

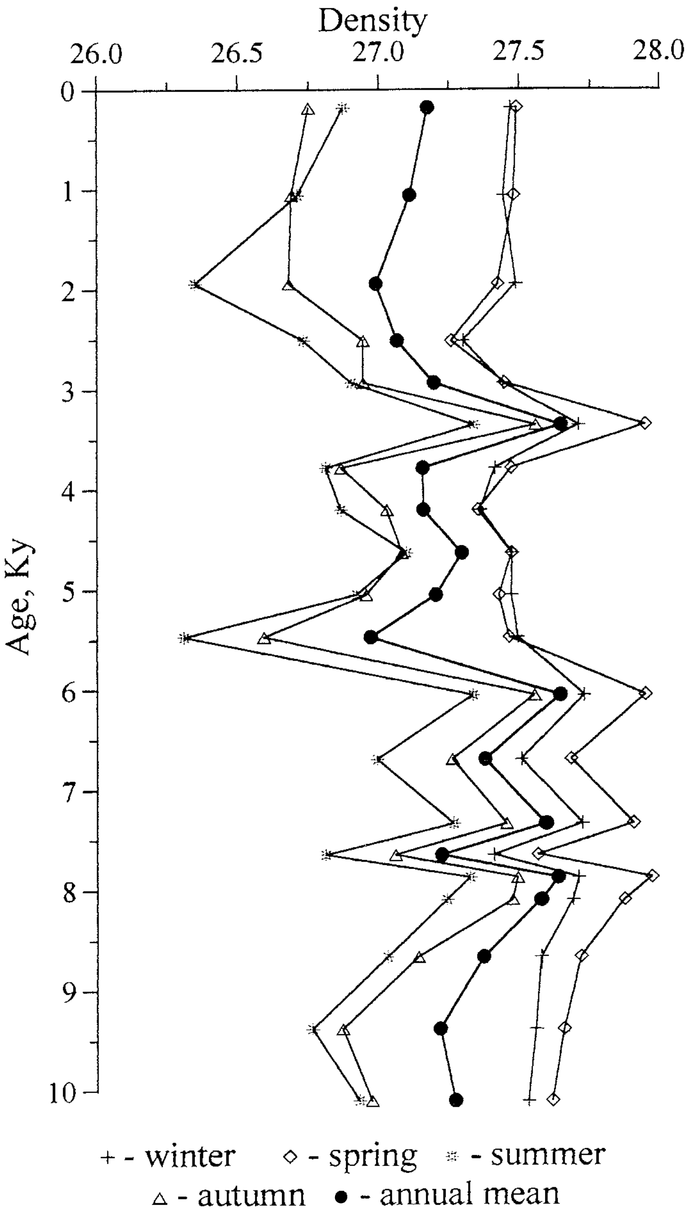

Fig. 11: Core MK-325: Reconstruction of annual and seasonal sea surface densities.

The Holocene paleohydrological reconstructions for this region are revealed in best detail from core MK-325 (Figs. 9-11). Annual average SST fluctuations during the Holocene reached 7-8°C. After an initial Holocene warming up to an annual average of 8.5°C at 10 ka, a cooling down to about 4°C followed with a cooling peak at ca. 9.5 ka (uncorrected ^{14}C ages)). Following this cool event, the Holocene conditions formed. The general warming trend reached a temperature maximum (13.5°C) at 5-4.5 ka and then the average temperature decreased to the recent 9°C. Warm peaks are identified at about 8.1, 6, 4.7, and 2.5 ka, cold peaks at about 9.5, 8-7.3, and 5.5 ka. Seasonal temperatures deviated from the average by about 2°C, thus the yearly amplitudes of SST were about 4°C. Minimum temperatures were reached in winter and/or in spring; maximum temperatures were reached mostly in summer.

The Holocene surface salinity changes in general were in phase with the temperature fluctuations. The same peaks are revealed. The minimum average annual salinity (34.4‰ was reached at 9.5 ka, the maximum (about 35.4‰) during the warm intervals between 5 and 2 ka. Seasonal deviations were very small, with the exceptions of the cold peak at 9.5 ka when they reached 0.2‰ (minimum salinity in autumn, maximum in spring), and the last 2 ky, when the winter salinity was a little lower than the average one.

The Holocene surface density was about 27.0 and changed very little. It reached a minimum in the middle Holocene. Seasonal deviations were 0.4-0.5, the summer/autumn densities showing minimum, and the winter/spring ones maximum values.

The results of the data interpretation of other sediment cores will be discussed more briefly. Core L-198, 558 cm long, was obtained from the southern slope of the Rockall Rise, (water depth 1265 m). It consists of an alternation of nannofossil-foraminiferal ooze (0-57, 167-310, 442-558 cm) and terrigenous sandy mud and silt, containing gravel, pebbles and volcanic ash layers (Fig. 12). The results of ^{14}C datings are as follows:

32-40 cm: 8230 ± 180 yr
77-83 cm: 14670 ± 770 yr
117-125 cm: 29400 ± 750 yr (redeposition)
179-189 cm: 28840 ± 950 yr

$CaCO_3$ analyses were performed on 24 samples, oxygen-isotope analyses (on the bulk planktic foraminifera complex) were performed on 22 samples. Foraminiferal analysis were performed on 25 samples (Appendix 3) and surface winter, summer and average annual temperatures, and salinity were reconstructed by the method of factor analysis and spline interpolation (Fig. 13).

The whole complex of data allows to suppose following climatostratigraphic division: the upper calcareous layer with the warm-water foraminifera complexes and low oxygen isotope values represents the Holocene; the terrigenous layers at 57-167 and 310-422 cm with cold-water complexes and heavy oxygen isotope values were accumulated during the glacial stages of the Last Glaciation (oxygen isotope stages 2 and 4); the calcareous layers at 167-310 and 422-558 cm, which are similar in all characteristics to the uppermost layer, represent the last interstadial and the younger part of the last interglacial (i.e. oxygen isotope stages 3 and substages 5a-c). From this stratigraphic interpretation and the ^{14}C dating, the Holocene accumulation rates were 4.4-5.7 cm/ky. For the underlying horizon (stage 2) the calculated rates are 5.4-7.0 cm/ky and thus somewhat higher.

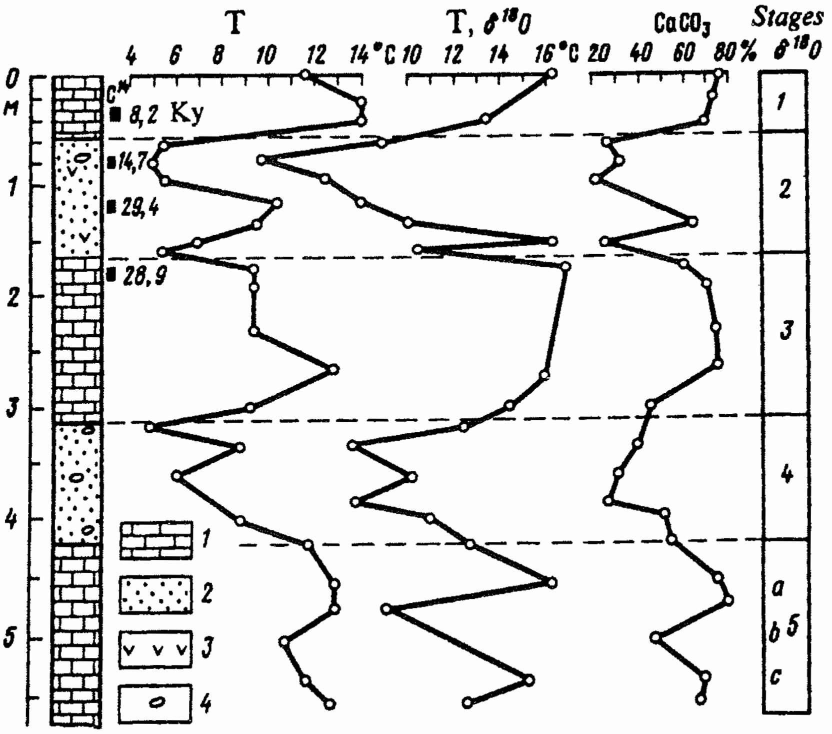

Fig. 12: Climatostratigraphy of core L-198: Lithology; results of ^{14}C dating; $CaCO_3$ content; average annual surface temperatures based on correlation of climatic groups of foraminifers (T) by Barash (1988); temperatures calculated from oxygen isotope data; correlation with oxygen isotope stages.
Legend: 1 - nannofossil-foraminiferal ooze, 2 - terrigenous sandy mud and silt, 3 - volcanic ash, 4 - gravel and pebbles.

From our paleohydrological reconstructions, the average annual surface temperatures were 9-10.5°C during the late interglaciation, 10-14.5°C during the interstadial, and 11-13°C during the Holocene. During peaks of the cold intervals they decreased to 4°C, increasing sometimes to 8°C. Seasonal fluctuations changed from 5°C at cold peaks to 7-8°C at warm peaks. The warmest summer temperature (18°C) was revealed in the interstadial.

The average annual surface salinity at site L-198 changed from 34.25 to 35.4‰, being lower during the cold intervals. The seasonal fluctuations were neglegible with the exception of stage 4 , when the summer salinity was significantly lower.

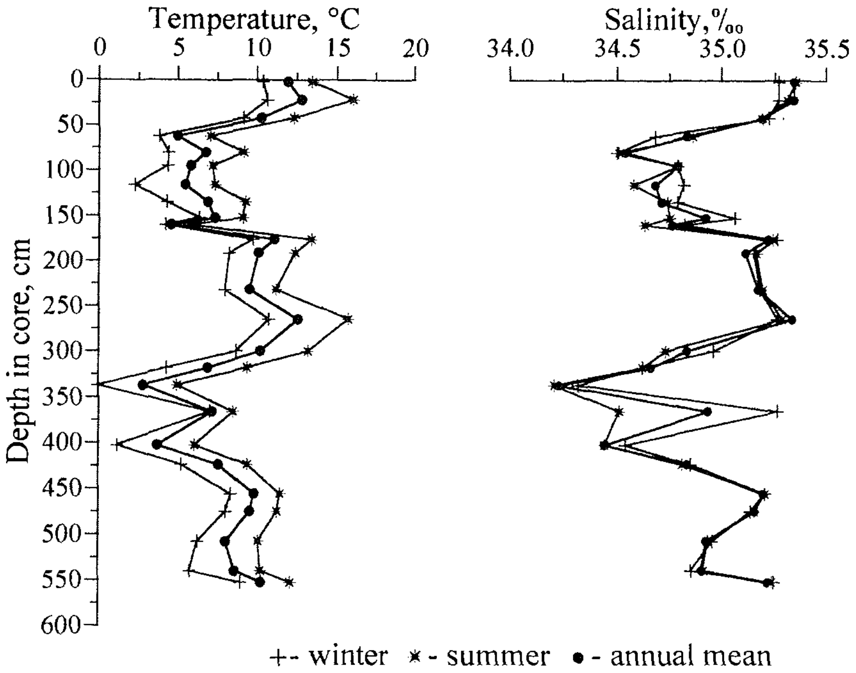

Fig. 13: Core L-198: Reconstruction of sea surface temperatures and salinities for winter, summer and annual mean.

Core L-348, 406 cm long, was obtained westward of Iceland from a water depth of 2262 m. It consists of an alternation of nannofossil-foraminiferal ooze (0-32, 246-256, 312-325 cm) and terrigenous sandy mud and silt (33-246, 256-312, 326-406 cm), containing gravel, pebbles and volcanic ash layers (Fig. 14). The results of ^{14}C dating are as follows:

20-30 cm: 13160 ± 910 yr
80-94 cm: 14960 ± 660 yr

Foraminiferal analysis were performed on 25 samples (Appendix 4) and winter, summer and average annual temperatures were reconstructed by the method of factor analysis and spline interpolation. The whole complex of data including correlation to other cores proves that the upper biogenic layer (0-32 cm) represents the Holocene, and the rest of the sediment was accumulated during the time of the last glaciation. Radiocarbon dating indicates that the accumulation rates in the Holocene were 1.9 cm/ky and in the Upper Pleistocene ca. 30.5 cm/kyr. Thus, in the Holocene they were 16 times lower than at the end of the Pleistocene. This was probably caused by the cessation of the strong accumulation of terrigenous matter from floating ice. Two biogenic layers within the Pleistocene sediment (246-256 and 312-325 cm) correspond to conditions of higher water temperatures and a decrease of the terrigenous sedimentation with interstadial conditions. Possibly the lowermost layer (312-325 cm), when the accumulated foraminiferal complexes and the reconstructed temperatures were similar to the Holocene, corresponds to the last interstadial (oxygen isotope stage 3).

The paleotemperature reconstructions from core L-348 reveal a Holocene optimum when the average annual surface water temperature was about 2°C higher than at present. During interstadial stage 3 it was the same as now (8°C). The coldest average temperatures (3°C) are revealed about 15 ka and just before and after the interstadial. During the rest of the time it fluctuated in the interval 5-7°C. The amplitude of seasononal temperature fluctuations was 2.5-5.5°C, being higher during some warmer intervals of the stadial. The summer paleotemperature during the interstadial (sample from 313 cm) was probably the same (12.5°C) as in the Holocene.

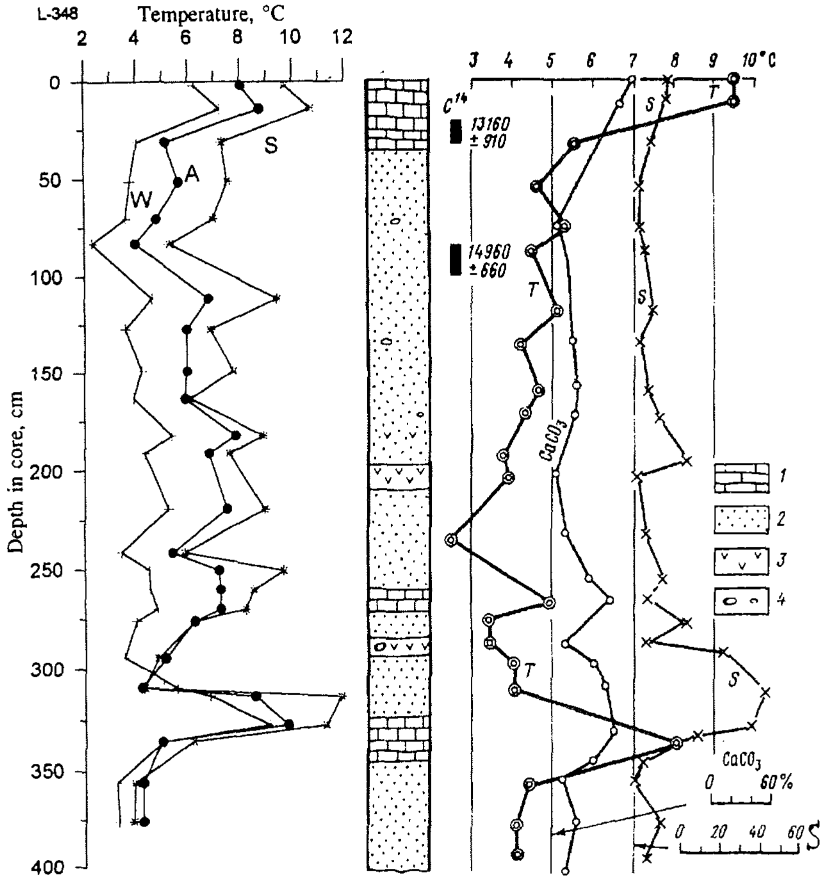

Fig. 14: Selected data from core L-348: Lithology; results of ^{14}C dating; $CaCO_3$ content; average annual surface temperatures based on correlation of the climatic groups of foraminifer (T), Schott number (number of specimens per 1 g of sediment (S); Barash, 1988); and temperature for winter (W), summer (S) and annual mean (A) reconstructed using factor analysis and spline interpolation.

Legend: 1 - nannofossil-foraminiferal ooze, 2 - terrigenous sandy mud and silt, 3 - volcanic ash, 4 - gravel and pebbles.

Main conclusions

The method of factor analysis and multidimensional spline interpolation applied to data on the planktic foraminifera distribution in surface sediments and selected sediment cores of the North Atlantic allowed to reconstruct the paleohydrological parameters (seasonal temperatures and salinity at standard depth down to 250 m) during the main climatostratigraphical intervals of the last 300 ky. The cores were obtained between 49-64°N in regions of the western part of the European Basin, the southern slope of the Rockall Rise, at 59°N on the Reykjanes Ridge, and west of the Iceland.
The longest time interval was studied in the European Basin. Here the average annual surface temperatures were 11-14°C during the interglacial and interstadial intervals (oxygen isotope stages 7, 5, and 3). During glacial intervals (stages 2-4, 6, and 8) the average annual surface temperatures were 3-6°C, being especially stable and cold (3-4°C) during the last glaciation (stages 4-2).

Amplitudes of seasonal temperature changes were 3-4°C, being maximum (up to 6°C) during the interglacial optimum (substage 5e). Lowest winter temperatures (about 1°C) were reached during the last glaciation (stages 4-2).

The reconstructed vertical temperature profiles for the interstadial (stage 7) and the interglacial (substage 5e) are similar. In the upper 250 m water layer the temperatures lowered by about 4°C and 2°C, respectively. The salinity and density profiles are more different. Probably during the interstadial the upper layer was more stratified than during the interglacial.

During the cold intervals in the glacials (stages 2, 6, 8) the average annual temperatures of the upper 250 m water layer were significantly lower than during the warm intervals: down to 50 m they diminished from 3.5 to 2.5°C in the last glacial maximum, and from 6.0-6.5 to 4.0-4.5°C during other stadials.
The detailed study of the Reykjanes cores reveals the great instability of the main hydrological parameters during the stadial. The most unstable conditions were in the interval 26.5-22.5 ka, when the average surface temperatures changed by 2-4°C with a frequency 300-500 years. The average temperature was 6-7°C, fluctuating in the interval 4-9°C. The highest values (8-9°C) were reconstructed for 28.5, 26.5, 22.5, and 15 ka, and minimum temperatures for 25.5 and 17 ka. The amplitudes of seasonal temperature fluctuations were 2-8°C, with maxima in the period of the high instability (26.5-22.5 ka). During the stadial the salinity was unstable too. Usually it was 34-35‰. Seasonal deviations were small.

During the interstadial the average annual sea surface temperature was 9.0-12.5°C, reaching a maximum at ca. 36.5 ka The salinity was about 35‰, being highest (35.3‰) in the time of maximum temperatures. Seasonal salinity fluctuations were very small.

In the Reykjanes area annual average SST fluctuations during the Holocene reached 7-8°C. After the Holocene warming up to an annual average of 8.5°C at 10 ka, a cooling down to about 4°C followed with peak about 9.5 ka (^{14}C age, not reservoir corrected). After this cool event, Holocene conditions formed. The following warming trend reached its maximum (13.5°C) at 5-

4.5 ka and then the average temperature decreased to the modern 9°C. The yearly amplitudes of SST were about 4°C. The Holocene surface salinity records are very similar to the temperature records.

During all analyzed warm intervals of the Late Quaternary the temperature conditions were similar in the investigated regions. Higher values were obtained for different intervals in different cores. In the Rockall and Iceland regions the summer paleotemperatures during the last interstadial were the same as or higher than in the Holocene.

In the northernmost studied region the coldest average temperatures (3°C) were revealed for the time around 15 ka During the rest of the Upper Pleistocene time it fluctuated in the interval 5-7°C. The amplitude of seasonal temperature fluctuations was 2.5-5.5°C.

Acknowledgments

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Appendix 1

Distribution of planktic foraminifera species in core L-66 (%)

No.	Species cm	2	16	24	42	48	65	93	105	120	139	153	175	190
1	Gq. pachyderma sin.	2.4	64.4	82.3	95.1	64.0	97.5	50.2	46.8	22.7	15.0	96.1	10.0	11.7
2	G. quinqueloba	21.5	9.4	6.4	0.0	30.0	0.0	4.0	7.7	28.9	18.7	0.7	15.9	13.3
3	G. bulloides	10.0	5.8	1.8	0.9	2.1	0.0	17.7	21.5	11.0	21.8	0.7	19.5	19.4
4	Gt. bradyi	0.5	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
5	Gq. pachyderma dex.	24.6	8.8	4.3	4.0	0.0	1.0	12.5	11.7	20.1	16.2	1.0	28.5	19.9
6	Gt. glutinata	20.4	3.6	2.9	0.0	1.0	0.0	9.6	6.1	10.1	20.0	0.4	11.6	22.1
7	Gr. inflata	9.4	5.1	0.6	0.0	0.3	1.5	3.6	6.2	5.3	5.3	1.1	8.9	6.0
8	Gr. scitula	7.4	2.2	1.4	0.0	2.4	0.0	1.6	0.0	1.6	2.1	0.0	3.3	5.7
9	Gr. truncatulinoides	1.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	1.3	0.7
10	G. falconensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
11	Gr. hirsuta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.9
12	Gt. humilis	0.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
13	Gr. crassaformis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
14	O. universa	0.1	0.1	0.1	0.0	0.0	0.0	0.4	0.0	0.1	0.1	0.0	0.0	0.1
15	Gs. ruber	0.5	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.7	0.3
16	Gs. conglobatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	Gq. dutertrei	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	Gl. aequilateralis	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

No.	Species cm	207	223	241	261	290
1	Gq. pachyderma sin.	3.3	13.0	4.6	88.9	31.0
2	G. quinqueloba	26.5	8.8	19.2	2.4	20.0
3	G. bulloides	14.6	12.1	10.9	0.8	15.3
4	Gt. bradyi	0.3	0.2	0.0	0.0	0.0
5	Gq. pachyderma dex.	33.8	29.0	29.0	3.7	7.8
6	Gt. glutinata	13.3	18.8	15.0	2.3	17.3
7	Gr. inflata	5.8	13.7	12.3	1.5	5.1
8	Gr. scitula	2.4	2.1	4.1	0.2	2.1
9	Gr. truncatulinoides	0.1	0.9	2.3	0.1	1.4
10	G. falconensis	0.0	0.0	0.0	0.0	0.0
11	Gr. hirsuta	0.1	0.6	1.0	0.1	0.1
12	Gt. humilis	0.0	0.0	0.0	0.0	0.0
13	Gr. crassaformis	0.0	0.0	0.0	0.0	0.0
14	O. universa	0.1	0.1	0.3	0.0	0.1
15	Gs. ruber	0.1	0.6	1.2	0.0	0.1
16	Gs. conglobatus	0.0	0.0	0.1	0.0	0.1
17	Gq. dutertrei	0.0	0.0	0.0	0.0	0.0
18	Gl. aequilateralis	0.0	0.2	0.0	0.0	0.1

Appendix 2

Distribution of planktic foraminifera species in core MK-316 (%)

No.	Species	cm	1	6	11	16	21	26	31	36	41	46	51	56	61
1	Gq. pachyderma sin.		7.4	4.8	7.4	9.9	18.6	37.7	30.2	32.0	85.0	82.2	95.3	82.8	93.2
2	G. quinqueloba		19.7	26.2	30.4	37.4	38.4	37.2	33.2	32.0	11.5	12.6	4.2	11.6	5.1
3	G. bulloides		11.4	11.4	10.4	13.3	6.9	4.6	14.9	10.4	1.2	1.6	0.5	2.0	1.1
4	Gt. bradyi		1.0	0.3	0.4	0.4	0.0	0.2	0.0	0.8	0.2	0.0	0.0	0.0	0.0
5	Gq. pachyderma dex.		34.8	23.8	25.9	16.7	14.6	7.5	11.5	11.2	1.2	2.6	0.0	3.6	0.0
6	Gt.glutinata		21.0	27.2	18.1	17.4	18.6	10.6	7.8	11.2	0.7	1.0	0.0	0.0	0.0
7	Gr. inflata		2.5	3.5	5.9	3.2	1.7	1.1	2.4	1.6	0.2	0.1	0.0	0.1	0.0
8	Gr. scitula		1.5	2.4	1.1	1.1	0.9	1.1	0.1	0.8	0.0	0.0	0.0	0.0	0.6
9	Gr. truncatulinoides-dex.		0.1	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
10	Gr. hirsuta		0.5	0.1	0.1	0.4	0.3	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0
11	Gr. truncatulinoides-sin.		0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	O. universa		0.2	0.4	0.4	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
13	Gs. ruber		0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	Gl. aequilateralis		0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

No.	Species	cm	66	71	76	81	86	91	96	101	106	111	116	121	126
1	Gq. pachyderma sin.		84.3	79.1	69.4	67.0	87.8	70.8	52.0	43.0	45.3	66.0	74.7	77.0	90.0
2	G. quinqueloba		10.3	16.9	3.5	11.0	7.7	21.1	17.0	25.0	26.7	14.5	7.4	7.5	2.0
3	G. bulloides		2.7	3.4	24.8	15.0	1.0	6.4	10.5	15.5	9.7	19.0	13.9	13.0	6.8
4	Gt. bradyi		0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.3	0.0	0.0
5	Gq. pachyderma dex.		2.0	0.6	1.7	6.5	2.5	1.2	14.0	10.0	8.5	0.0	1.0	1.0	0.4
6	Gt.glutinata		0.7	0.0	0.0	0.0	1.0	0.0	4.0	3.0	4.6	0.0	1.7	1.0	0.4
7	Gr. inflata		0.1	0.1	0.1	0.5	0.0	0.0	2.0	3.0	4.4	0.0	0.0	0.0	0.0
8	Gr. scitula		0.0	0.1	0.6	0.0	0.0	0.1	0.5	0.5	0.4	0.5	1.0	0.5	0.4
9	Gr. truncatulinoides-dex.		0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
10	Gr. hirsuta		0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0
11	Gr. truncatulinoides-sin.		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
12	O. universa		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	Gs. ruber		0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	Gl. aequilateralis		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

No.	Species	cm	131	136	140	146	151	156	161	166	171	176	181	186	191
1	Gq. pachyderma sin.		75.4	84.5	89.2	93.6	81.5	91.4	88.0	92.9	86.6	91.4	87.0	90.2	74.2
2	G. quinqueloba		9.3	3.0	1.3	0.1	6.6	2.9	1.0	1.6	5.3	3.0	4.0	4.5	10.6
3	G. bulloides		12.8	8.5	8.2	5.3	9.8	3.8	6.0	3.1	3.8	3.6	2.0	1.8	7.4
4	Gt. bradyi		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	Gq. pachyderma dex.		2.0	2.5	0.9	0.7	1.1	0.1	4.0	2.0	1.9	0.5	4.0	1.3	2.6
6	Gt.glutinata		0.5	1.5	0.4	0.4	0.0	1.4	1.0	0.4	2.4	1.5	3.0	2.2	4.2
7	Gr. inflata		0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
8	Gr. scitula		0.1	0.0	0.0	0.0	0.5	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.5
9	Gr. truncatulinoides-dex.		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	Gr. hirsuta		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
11	Gr. truncatulinoides-sin.		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	O. universa		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	Gs. ruber		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	Gl. aequilateralis		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

No.	Species	cm	196	201	206	211	216	221	226	231	236	241	246	251	256
1	Gq. pachyderma sin.		95.8	93.0	89.1	95.5	90.5	88.0	85.9	66.0	52.0	61.2	71.0	76.3	86.6
2	G. quinqueloba		0.4	5.0	5.5	1.3	4.1	7.0	7.2	12.7	19.0	18.0	7.0	4.7	7.4
3	G. bulloides		1.7	1.0	2.7	1.3	2.0	1.0	5.3	10.7	20.0	13.7	18.0	15.7	5.5
4	Gt. bradyi		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.4	0.0
5	Gq. pachyderma dex.		1.3	1.0	2.7	0.6	3.4	3.0	0.8	6.0	3.0	2.4	1.5	1.7	0.0
6	Gt.glutinata		0.4	0.1	0.0	1.3	0.0	1.0	0.8	2.0	3.0	2.7	2.0	0.8	0.5
7	Gr. inflata		0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	Gr. scitula		0.4	0.1	0.0	0.0	0.0	0.0	0.0	1.3	3.0	2.0	0.5	0.4	0.0
9	Gr. truncatulinoides-dex.		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	Gr. hirsuta		0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
11	Gr. truncatulinoides-sin.		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	O. universa		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	Gs. ruber		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	Gl. aequilateralis		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

No.	Species	cm	261	271	281	291	296	301	306	311	341	351	359	379	390
1	Gq. pachyderma sin.		77.3	71.3	74.0	77.2	79.4	70.0	59.5	54.0	65.0	70.6	81.0	66.0	52.9
2	G. quinqueloba		13.7	19.0	16.0	13.4	10.1	9.5	11.6	18.0	14.5	10.9	7.5	15.5	20.1
3	G. bulloides		3.5	4.3	8.0	3.1	3.7	8.5	9.5	9.0	11.0	6.3	6.0	2.0	7.4
4	Gt. bradyi		0.0	0.0	0.0	0.0	0.4	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.3
5	Gq. pachyderma dex.		2.0	1.6	1.0	3.6	0.9	3.0	9.1	3.0	1.0	3.4	2.0	3.0	9.9
6	Gt.glutinata		2.0	2.2	0.5	2.7	3.2	5.5	4.1	6.5	5.5	7.1	2.5	10.0	5.9
7	Gr. inflata		0.0	0.1	0.0	0.1	1.4	1.5	2.9	1.5	0.1	0.1	0.1	2.0	1.9
8	Gr. scitula		1.5	1.6	0.5	0.1	0.9	2.0	3.3	7.0	3.0	1.7	1.0	1.5	1.6
9	Gr. truncatulinoides-dex.		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
10	Gr. hirsuta		0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
11	Gr. truncatulinoides-sin.		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
12	O. universa		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	Gs. ruber		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	Gl. aequilateralis		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

No.	Species	cm	401	411	421	431	441	455
1	Gq. pachyderma sin.		50.0	12.4	3.5	22.3	50.3	73.5
2	G. quinqueloba		17.5	36.2	26.0	25.5	3.6	1.0
3	G. bulloides		11.0	6.6	7.0	6.5	5.5	3.5
4	Gt. bradyi		0.0	0.8	1.0	3.2	0.0	0.0
5	Gq. pachyderma dex.		4.0	18.7	30.0	24.8	26.7	18.0
6	Gt.glutinata		15.5	19.4	23.5	13.5	9.7	1.5
7	Gr. inflata		0.5	3.5	3.5	3.2	3.0	2.5
8	Gr. scitula		1.5	0.8	2.5	0.5	1.2	0.1
9	Gr. truncatulinoides-dex.		0.1	0.6	2.0	0.5	0.0	0.0
10	Gr. hirsuta		0.1	0.1	0.1	0.0	0.1	0.0
11	Gr. truncatulinoides-sin.		0.1	1.0	0.5	0.0	0.0	0.0
12	O. universa		0.1	0.1	0.5	0.1	0.1	0.1
13	Gs. ruber		0.0	0.0	0.0	0.0	0.0	0.0
14	Gl. aequilateralis		0.0	0.0	0.0	0.0	0.0	0.0

Appendix 3

Distribution of planktic foraminifera species in core MK-325 (%)

No.	Species cm	1	6	11	16	21	26	31	36	41	46	51	56	61
1	Gq. pachyderma sin.	4.5	5.5	5.4	3.4	5.8	4.7	3.4	4.5	1.9	2.5	4.0	3.8	9.5
2	G. quinqueloba	25.5	21.6	23.9	30.6	21.0	17.8	24.9	23.5	23.2	43.8	41.3	39.0	35.5
3	G. bulloides	12.0	7.9	6.7	13.6	13.0	15.0	13.6	13.1	28.0	12.3	18.0	15.3	13.4
4	Gt. bradyi	2.0	1.2	0.1	1.4	1.1	0.5	0.0	0.4	0.5	0.5	0.0	0.0	0.0
5	Gq. pachyderma dex.	26.5	27.6	25.7	31.1	31.2	37.1	37.1	33.2	23.2	19.2	18.0	18.6	26.4
6	Gt. glutinata	25.5	33.1	33.8	18.0	24.6	22.5	18.6	22.1	18.8	18.7	16.0	19.9	12.6
7	Gr. inflata	0.5	1.6	1.8	0.5	1.8	0.9	1.9	0.4	1.0	1.0	2.7	2.1	2.2
8	Gr. scitula	3.5	1.5	2.7	1.4	1.5	1.5	0.5	2.4	1.4	2.0	0.1	1.3	0.4
9	Gr. crassaformis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.1	0.1	0.1	0.1
10	Gr. hirsuta	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1
11	O. universa	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.4	1.0	0.1	0.1	0.1	0.1

No.	Species cm	66	71	76	81	86	91	96
1	Gq. *pachyderma sin.*	5.1	8.7	3.4	7.7	16.1	23.9	70.3
2	G. quinqueloba	47.0	38.4	54.3	25.6	39.4	49.4	6.4
3	G. bulloides	10.1	15.8	11.1	16.1	19.7	6.8	10.7
4	Gt. bradyi	0.0	0.0	0.4	0.0	0.0	0.6	0.0
5	Gq. pachyderma dex.	24.4	27.9	21.8	29.8	13.3	8.5	7.5
6	Gt. glutinata	10.6	5.5	4.8	15.4	5.5	9.6	2.6
7	Gr. inflata	1.4	1.6	1.7	3.6	5.0	0.6	1.9
8	Gr. scitula	0.1	1.1	0.4	1.8	0.5	0.0	0.0
9	Gr. crassaformis	1.4	0.5	2.1	0.1	0.5	0.6	0.6
10	Gr. hirsuta	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	O. universa	0.1	0.5	0.0	0.0	0.0	0.1	0.1

Appendix 4

Distribution of planktic foraminiferal species in core L-198 (%)

No.	Species	cm	2	22	42	62	80	95	116	135	152	160	176	191	232
1	Gq. pachyderma sin.		1.6	1.6	4.8	64.5	77.1	63.4	24.0	14.3	43.3	58.2	7.0	8.7	6.3
2	G. quinqueloba		30.6	29.8	26.9	20.9	17.9	21.0	20.7	41.2	31.8	25.4	43.3	43.2	54.1
3	G. bulloides		8.2	19.5	17.9	3.4	1.3	9.5	41.5	23.3	10.6	3.9	12.6	16.5	9.4
4	Gt. bradyi		1.0	0.0	0.0	0.1	0.0	0.0	0.0	0.5	0.0	0.0	1.1	0.1	0.5
5	Gq. pachyderma dex.		25.2	14.2	20.6	5.6	2.4	1.9	4.5	5.9	3.3	4.4	12.9	8.6	12.8
6	Gt. glutinata		22.9	16.3	11.6	2.2	0.3	2.7	4.3	8.9	8.9	2.9	11.8	15.3	9.9
7	Gr. inflata		4.4	5.1	8.0	1.7	0.3	0.8	1.8	0.1	0.2	2.9	4.7	1.0	3.8
8	Gr. scitula		6.0	13.5	7.6	1.7	0.7	0.7	3.0	5.9	1.9	2.3	6.6	6.1	2.9
9	Gr. truncatulinoides dex.		0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	Gr. hirsuta		0.0	0.1	1.7	0.1	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1
11	Gr. truncatulinoides sin.		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
12	Gt. humilis		0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	Gr. crassaformis		0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	O. universa		0.1	0.1	0.7	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1
15	Gs. ruber		0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
16	Gs. conglobatus		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
17	Gq. dutertrei		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
18	Gl. aequilateralis		0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.0	0.0

No.	Species	cm	265	300	318	337	366	403	424	456	475	508	540	553
1	Gq. pachyderma sin.		1.8	13.1	73.5	28.3	48.3	22.1	10.0	6.7	5.4	12.0	3.5	6.3
2	G. quinqueloba		36.8	33.0	15.6	42.8	33.3	43.1	56.0	48.1	50.4	41.0	62.5	46.6
3	G. bulloides		6.9	8.2	3.9	14.1	5.9	11.7	5.4	4.9	2.3	6.8	5.6	9.2
4	Gt. bradyi		0.5	0.0	0.0	1.2	0.4	0.3	0.0	0.4	0.4	0.0	0.3	0.6
5	Gq. pachyderma dex.		19.0	22.2	3.1	4.6	5.4	9.5	8.9	11.4	16.0	10.7	5.6	13.3
6	Gt. glutinata		19.5	11.4	2.3	6.5	4.8	3.6	6.7	11.2	9.7	12.9	7.6	8.4
7	Gr. inflata		7.0	4.9	0.8	1.4	0.4	2.9	2.5	7.7	7.0	7.2	5.6	7.2
8	Gr. scitula		7.0	6.9	0.8	0.9	1.5	6.8	10.3	9.2	8.4	8.6	8.5	7.2
9	Gr. truncatulinoides dex.		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	Gr. hirsuta		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1
11	Gr. truncatulinoides sin.		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	Gt. humilis		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	Gr. crassaformis		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	O. universa		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
15	Gs. ruber		0.2	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0
16	Gs. conglobatus		0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	Gq. dutertrei		0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.8	0.3	0.0
18	Gl. aequilateralis		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0

Appendix 5

Distribution of planktic foraminifera species in core L-348 (%)

No.	Species cm	2	14	31	51	70	83	111	127	149	163	182	191	219
1	Gq. pachyderma sin.	6.9	6.8	62.2	86.4	67.5	87.0	74.9	90.5	83.7	88.2	94.0	92.8	98.1
2	G. quinqueloba	45.6	46.8	18.4	10.9	31.0	8.4	16.2	5.2	10.7	2.8	2.4	5.2	1.9
3	G. bulloides	20.7	9.8	7.8	0.0	0.6	0.1	1.1	2.5	1.0	4.7	3.6	2.0	0.0
4	Gt. bradyi	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	Gq. pachyderma dex.	20.0	21.6	6.9	2.4	0.0	4.6	7.4	1.8	4.4	3.7	0.0	0.0	0.0
6	Gt. glutinata	4.8	12.6	3.8	0.3	0.9	0.0	0.4	0.0	0.2	0.4	0.0	0.0	0.0
7	Gr. inflata	0.2	0.5	0.9	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
8	Gr. scitula	1.8	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
9	Gr. truncatulinoides	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	Gr. hirsuta	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	Gr. crassaformis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	O. universa	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
13	Gq. dutertrei	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

No.	Species cm	241	250	260	270	276	294	309	313	327	335	356	376
1	Gq. pachyderma sin.	88.8	72.4	95.0	94.5	90.3	90.2	49.2	27.3	37.4	85.1	89.4	89.0
2	G. quinqueloba	4.4	14.0	1.1	4.1	3.1	4.1	23.7	35.1	16.4	0.0	4.9	4.7
3	G. bulloides	2.7	8.2	2.7	0.4	2.6	0.5	7.9	5.9	8.4	0.1	0.1	0.0
4	Gt. bradyi	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.2	0.3	0.0	0.0	0.0
5	Gq. pachyderma dex.	3.7	3.0	1.0	1.0	3.8	5.0	12.3	20.6	30.6	11.6	5.7	5.6
6	Gt. glutinata	0.0	1.0	0.2	0.0	0.1	0.2	4.3	10.2	6.3	3.3	0.1	0.7
7	Gr. inflata	0.2	0.2	0.0	0.0	0.1	0.1	0.7	0.2	0.3	0.0	0.1	0.0
8	Gr. scitula	0.2	1.2	0.1	0.1	0.2	0.0	0.3	0.5	0.3	0.0	0.0	0.0
9	Gr. truncatulinoides	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
10	Gr. hirsuta	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0
11	Gr. crassaformis	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
12	O. universa	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0
13	Gq. dutertrei	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0

RADIOLARIANS IN NORTH ATLANTIC SEDIMENTS

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Introduction

Radiolarian studies of the North Atlantic (NA) bottom sediments are relatively few compared to other World Ocean regions due to the relatively low fossilized silica content and species diversity. Nigrini (1967) and Goll and Bjørklund (1971) have discussed non-quantitative data on the occurence of a number of typical radiolarian species in the temperate and subtropical NA. Petrushevskaya (1969), Petrushevskaya and Bjørklund (1974), Bernal-Ramirez and Molina-Cruz (1994), Schröder-Ritzrau (1995) have analyzed the radiolarian distribution in the sea surface sediments with emphasis on the Norwegian-Greenland Sea features. There are some publications concerning oceanographic conditions associated with the distribution of the radiolarian species *Cycladophora davisiana* and its use for the Quaternary stratigraphy (Morley and Hays, 1979, 1983; Bjørklund and Ciesielski, 1994; Ciesielski and Bjørklund, 1995).

Matul (1989, 1990) has studied the quantitative distribution of 33 radiolarian species and has used these data to propose a paleotemperature technique according to the method of paleoclimatic reconstructions of Barash (1988). This technique allows to calculate paleotemperatures on curves "percentage versus sea surface temperature" of modern radiolarian climatic assemblages from the bottom surface sediments. It has been used for a Late Pleistocene/Holocene paleoceanographic study of NA sediment cores (Matul, 1994a,b). Obtained results were in principal aggreement with available paleoclimatic records.

Materials and methods

Samples and species composition

The current study has two radiolarian data sources: (1) Basic data on the distribution of 33 well-defined and abundant (percentage >1% at least in a few samples) species from 55 surface sediment samples (Matul, 1989), and (2) new data from high-latitude areas (23 samples), which make up a total of 78 sediment samples and 35 species (Figs. 1 and 2). Content of all other species has been added in data files as the content of the "36th species". Sediment samples consisted of the uppermost 1-2 cm of gravity cores and grabs. Previously obtained data were revised to check species definitions, to correct quantitative calculations,and to specify samples and results which are suitable for further statistical analyses.

Sample preparation

All samples have been prepared by the standard procedure with disaggregation in the sodium polyphosphate and hydrogen peroxyde solution. For the microscope analysis the sediment fraction coarser than 0.046 mm was used. As a rule, 200-500 radiolarian specimens per one slide have been counted.

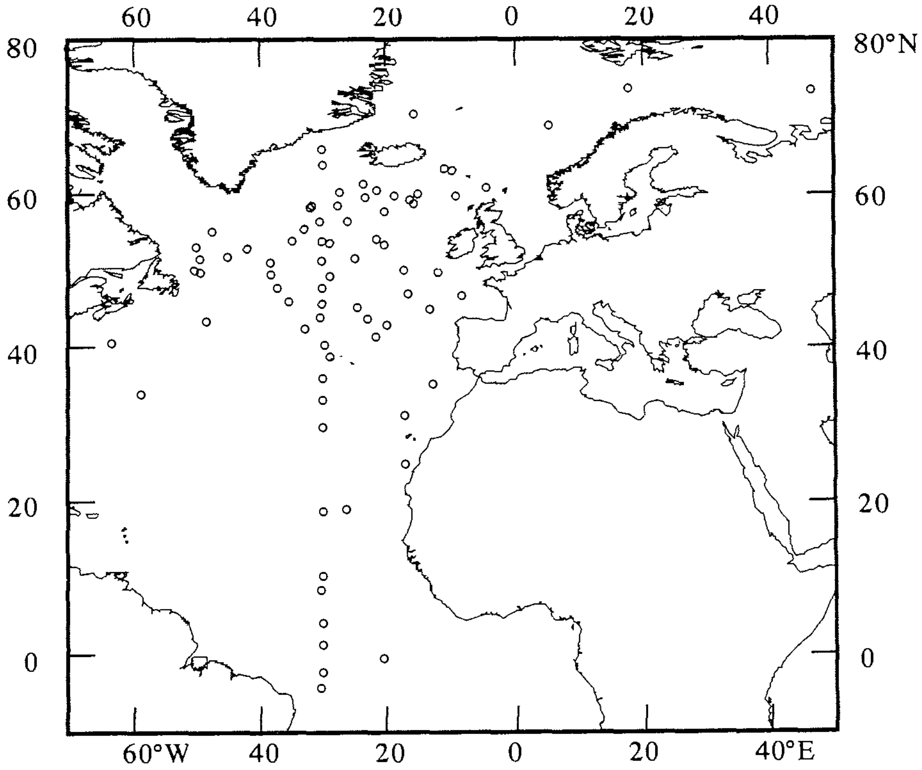

Fig. 1: Location of samples studied by radiolarian analysis.

Cluster analysis

To specify some groups of species and stations (radiolarian assemblages) we have used a Brei-Kertis matrix and the strategy of union based on the increment of the sum of coordinates' squares. The Brei-Kertis matrix requires a standardization of data and initially was created to use percentages as initial data. The strategy of groups union based on the increment of the sum of coordinates' squares supposes that the distance between groups is defined as the increment of the sum of squares of distances from the corresponding centers of the groups.

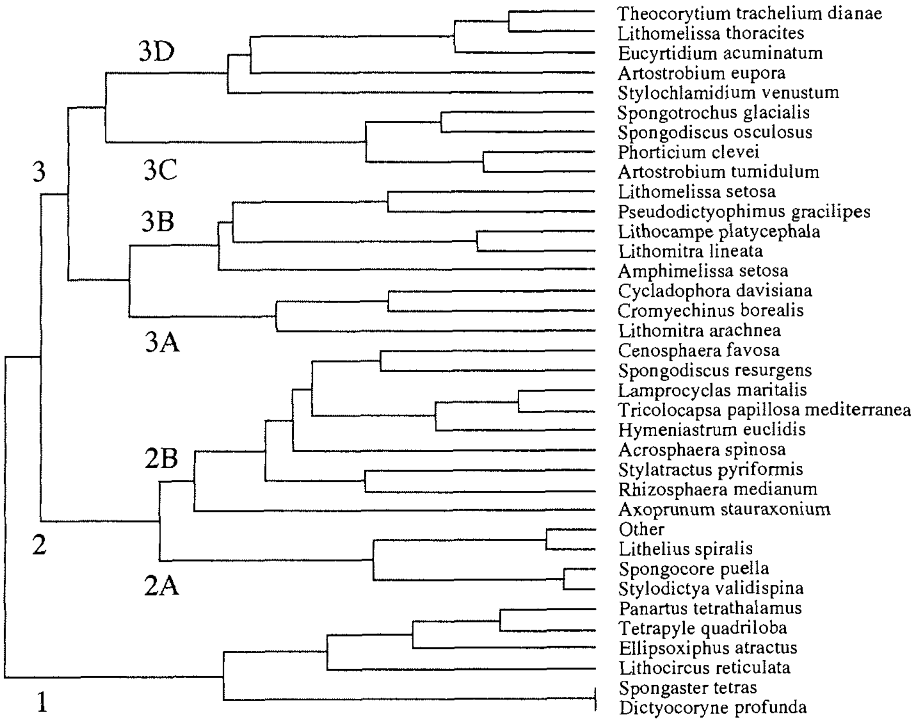

Fig. 2: Groups of species based on cluster analysis.

Reconstruction of paleohydrological parameters

To obtain paleoceanographic information from radiolarian data, a new method of the interpretation of micropaleontological proxies, proposed by Yushina on base of factor analysis and multidimensional spline interpolation (Yushina, 1995a, b, et al.) has been used.

Modern hydrology data

The distribution of modern hydrological parameters at the studied stations - seasonal temperature and salinity at different water depths - was taken from Levitus (1982).

Results and discussion

Cluster analysis of radiolarian distribution in the surface sediments

We have used groups of species and single species as objects (see Fig. 2):
Group 1 Species typical for the tropical-equatorial Atlantic with an annual sea surface temperature (SST) >24°C; they do not occur at SST <13-14°.

Group 2 Species widely distributed in sediments underlying the North Atlantic (NA) current and the northern part of the subtropical anticyclonic gyre. Species of subgroup 2A were found in almost all the samples, with a maximum content in the central temperate and northern subtropical NA with a SST of 8-18°. Species of subgroup 2B are concentrated mostly in sediments of the eastern temperate and subtropical NA with a SST of 12-24°.

Group 3 - species with more or less compact areas of maximum concentration which are located within the temperate and northern subtropical NA. Species of subgroup 3A have the greatest content in the northwestern NA with a SST of 4-10°, without a close relation with surface water circulation. However, the area of the *L. arachnea* maximum concentration follows the North Polar Front. Species of subgroup 3B are most abundant in the northeastern NA underlying the northern part of the NA current with a SST <8-10°. Subgroup 3C includes species concentrated in the central temperate and northern subtropical NA, in the main area of the NA current with a SST of 9-16°; they do not occur with a SST >21-22°. Subgroup 3D contains species dominating in sediments of the Labrador Sea with SST <10°.

We made the same analysis using stations as objects. Stations were grouped by their radiolarian assemblages (Figs. 3 and 4):

As shown in Fig. 3, the content of species subgroup 2A is a background for all the assemblages. Other species groups are the main information source to divide assemblages.

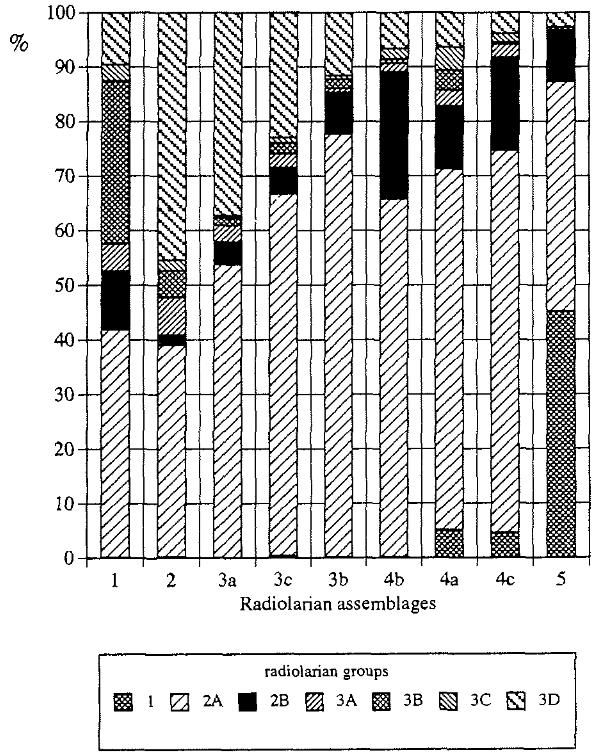

Fig. 3: Cluster radiolarian assemblages defined by species groups ratio.

Assemblages 1 from sediments of the southern Norwegian Sea are the most complicate ones. They reflect the modern oceanographic situation in the Norwegian Sea: The contact of warm NA water and cold polar/subpolar water of the Norwegian-Greenland Seas.

Assemblages 2 are distributed in the area of subpolar waters of the Labrador Sea.

Assemblages 3 are found in sediments underlying the region of distribution, transformation of NA current, its contact and interaction with subpolar waters of the Labrador Sea.

Assemblages 4 are found in sediments from the area of the subtropical anticyclonic water gyre.

Assemblages 5 are characterized by the strong dominance of species group 1 and the distribution in the region of the Atlantic tropical and equatorial currents.

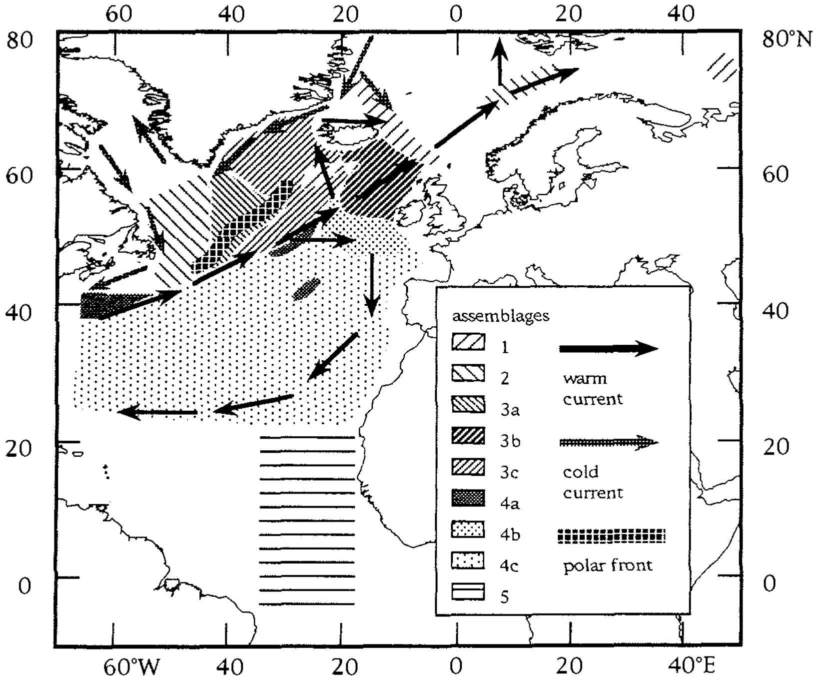

Fig. 4: Radiolarian assemblages in the North Atlantic surface sediments based on cluster analysis.

Paleoceanographic changes in the northwestern North Atlantic during the last deglaciation based on radiolarian data

Paleoceanographic information for the Late Glacial/Holocene in the northwestern NA (seasonal paleotemperatures and paleosalinities at different water depths) was obtained on base of factor analysis and spline interpolation of radiolarian data as proposed by Yushina (1989, 1995, and others).

As an example, we will consider paleohydrological parameters reconstructed for core MK-340 from the Reykjanes Ridge, 58°30.6'N, 31°31.2'W (Fig. 5 and 6). Earlier mean annual sea surface temperature estimates (Matul, 1994b) have been made by paleotemperature techniques mentioned in the introduction chapter.
A number of ^{14}C-data and high sedimentation rates provide a high-resolution study of core MK-340 (Table 1).

Table 1. Absolute age data on the core MK-340.

Core samples, cm	^{14}C-data, years (Kuptzov et al., 1990)	Reservoir correction, years (Bard et al., 1994)	Corrected age, years	Calendar age (calculation according to Bard et al., 1990)
10-15	2130±270	-450	1680	1809
25-30	3440±180	-450	2990	3220
125-130	7730±260	-450	7280	7840
280-285	8600±510	-450	8150	8776
375-380	13110±460	-750	12360	14360

Radiocarbon ages were corrected by -400÷500 (-450) years (yr) for the Holocene interval, and by -700÷800 (-750) yr for the near-Younger Dryas (YD) interval (Bard et al, 1994). Calibration to calendar years occurred according to Bard et al. (1990). Further in the text, we will use calendar ages.

Paleotemperature records for all four seasons and for different water depths (from 0 to 200 m) were obtained for two large intervals: Interval A (14,300-10,050 yr B.P.) with low temperatures, and interval B (9,850-200 yr B.P.) with high temperatures. The temperature shift between these intervals is about 7°C (see Fig. 5). These temperature intervals in principle coincide with the ones previously revealed by Matul (1994b, Fig. 7). The paleotemperature records are in good aggreement with the oxygen-isotope record from Greenland ice core GISP2 (Grootes et al., 1993) and other paleoceanographic records from the North Atlantic (e.g., Bond et al., 1993; Sikes and Keigwin, 1996), in particular regarding the timing of of the Younger Dryas cooling event (paleotemperature minimum at 12,800-12,100 yr B.P. in core MK-340).

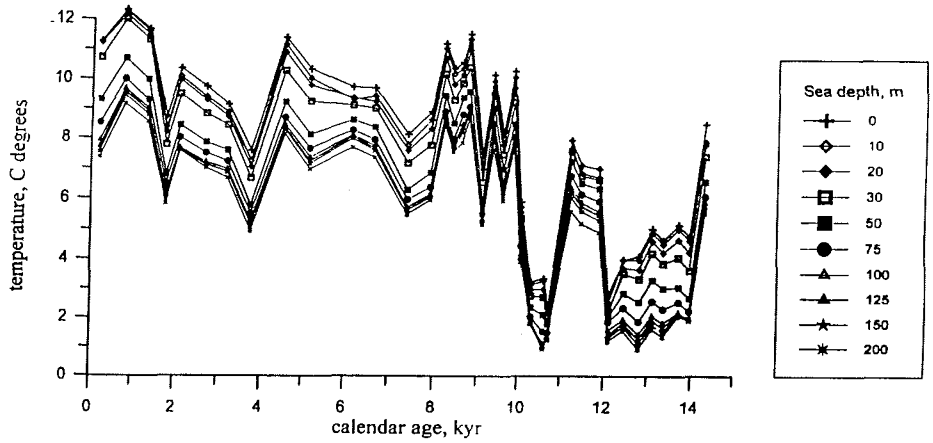

Fig. 5: Core MK-340, summer temperature fluctuations.

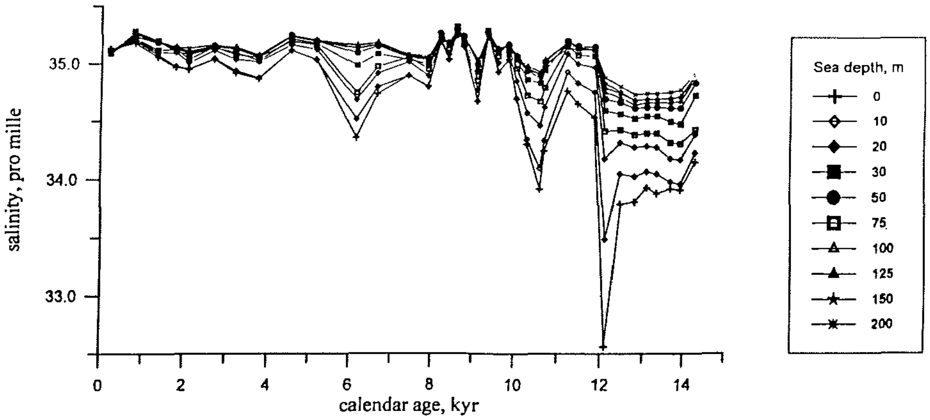

Fig. 6: Core MK-340, summer salinity fluctuations.

There is one discrepancy to the other available paleoclimatic data. Within interval A (10,700-10,050 yr B.P.), the reconstructed paleotemperature has a significant minimum not observed in published records (see Fig. 5). We will comment on this fact by discussing data on the chronology of the last deglaciation presented by Broecker et al. (1988). Generally, these authors supposed that changes in the direction of the meltwater outflow in the NA from proglacial Lake Agassiz could control climate changes in NA: Meltwater drainage via the Missisipi increased the NA heat conveyor, and drainage via Hudson and Saint-Lawrence valleys caused its reduction and a NA cooling (Younger Dryas cooling event). The Younger Dryas cooling event stopped when the Hudson and St.Lawrence valleys were blocked by ice.

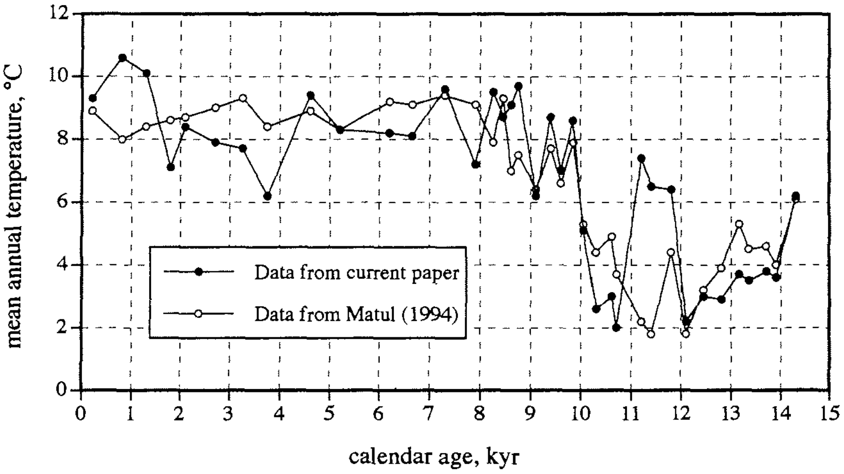

Fig. 7: Core MK-340, mean annual sea surface temperature fluctuations.

Broecker et al. (1988) could not give a good explanation for the fact that there was no evidence for a second (YD-style) cooling after the final return of the meltwater drainage system to the Hudson and St. Lawrence valley at the beginning of the Holocene. Possibly, our data on the paleotemperature minimum at 10,700-10,050 yr B.P. may contribute to the search for such an event. As it can be expected during the Younger Dryas, the NA sea surface temperature drop was followed by a salinity decrease (Bond et al., 1993). If we consider the paleosalinity at site MK-340 as an indicator of the meltwater input into the northwestern NA (see Fig. 6), we find a meltwater maximum during the interval 10,700-10,050 yr B.P. similar to the one during the Younger Dryas. Moreover, from the radiolarian assemblages, these intervals contain information about a "Labrador Sea-style" basin, in which water circulation depended on water masses originating from northeastern North America. At least for the interval 13.7-12.45 kyr B.P., such a scanario may be supported by speculations of Keigwin et al.(1991) about the source of meltwater discharge and about the sea surface circulation in the northwestern NA at 10.5 ^{14}C kyr B.P. (12.5 cal kyr B.P.).

Based on own and published data concerning the radiolarian distribution in the surface sediments of NA and Greenland-Iceland-Norwegian Seas (GIN) (Petrushevskaya, 1969; Petrushevskaya and Bjørklund, 1974; Matul, 1989; Bernal-Ramirez and Molina-Cruz, 1994) (Table 2), we attempted to define some radiolarian groups as possible indicators of water masses which are sources for North Atlantic Deep Water (NADW) formation. Evidence for the possible use of radiolarians for this purpose came from the interpretation of the radiolarian data from core MK-340: In the sediment samples of the last deglaciation interval, the peak concentration of species typical for the GIN and the Labrador Sea were alternating (Matul, 1994b).

Table 2. Content of radiolarian species in the surface sediments of the North Atlantic and Greenland-Iceland-Norwegian Seas.

Radiolarian species	Data by Matul (1989)	Data by Petrushevskaya (1969), Petrushevskaya and Bjørklund (1974), Bernal-Ramirez and Molina-Cruz (1994)
Amphimelissa setosa	Single specimens southward from Newfoundland; max. 1.4-2.6% at several sites in southern Labrador Sea (LS)	1-2% (max. 32% in several sites) in Greenland-Iceland-Norwegian Seas (GIN)
Artobotrys borealis	Does not occur south of Iceland; 1.7% in one sample from southern LS	1-2% in GIN
Artostrobium tumidulum	Max. 31% in LS	Max. 16% in Denmark Strait (DS); does not occur in GIN
Cromyechinus borealis	Max. 3-4% in central NA	1-2% in LS;2-4% in DS; up to 16-32% in GIN
Cycladophora davisiana	Max. 2% in central NA	1-2% over entire NA; max. 5% in several sites of GIN and LS
Lithomitra arachnea	Max. 4-6% in southern LS	Not found in DS and GIN
Lithomitra lineata	Max. 1.5% in central and eastern NA	Max. 4-8% (max. 16-32% in several samples) in GIN
Phorticium clevei	Max. 30% in central LS	Max. 16-32% in DS and GIN
Pseudodictyophimus gracilipes	Max. 4-7% in central NA	1-2% in LS and DS; 8-16% in GIN
Spongodiscus osculosus	Max. 16-19% in DS and southern LS	Has been found in GIN (non-quantitative data are available)
Spongodiscus resurgens	Max. 11-16% in eastern NA	Has been found in southern GIN (non-quantitative data are available)
Spongotrochus glacialis	Max. 2-3% in southern LS and central NA	1-2% in DS; 2-4% in GIN

It is supposed that

1. The distribution of *Artostrobium tumidulum* and *Lithomitra arachnea* correlates with the part of Labrador sea water which is not connected with NADW formation.
2. The distribution of *Cycladophora davisiana*, *Cromyechinus borealis*, and *Pseudodictyophimus gracilipes* indicates in a large measure the main area of NADW formation (Norwegian-Greenland basin).
3. The distribution of *Phorticium clevei, Spongodiscus osculosus*, and *Spongotrochus glacialis* reflects conditions of the main area of NADW formation as well as its possible region south of Greenland. Furthermore, these species can be brought in from the north in the Labrador Sea by Return North Atlantic Water (? some part of NADW).
4. *Amphimelissa setosa* correlates with the arctic and subarctic surface water and has the highest concentration in sediments of the main area of NADW formation.

From the paleoceanographical study of core MK-340, we suppose that the Reykjanes Ridge area was one of the active regions of NADW formation during the interval 12.45-8.6 kyr B.P. Within the interval 14.3-12.45 kyr B.P., the oceanographic situation was similar to the modern one; the corresponding radiolarian assemblages indicate NADW presence. These results give no evidence for a long-term (within a few centuries) considerable reduction or breakdown of NADW formation during the interval 14.3-8.6 kyr B.P.

Conclucions

1. As defined by cluster analysis, radiolarian assemblages of the surface sediments of the North Atlantic reflect the main oceanographic features: The distribution of major water masses, their transformation and interaction.
2. A high-resolution paleoceanographic study of the last deglaciation in the northwestern North Atlantic on the base of radiolarian data correlates in detail to available ice core and marine paleoclimatic records.
3. It is supposed that a) radiolarian data may reflect water cooling and freshening as the result of a final meltwater discharge in the northwestern North Atlantic via the Hudson and St. Lauwrence valley at the beginning of the Holocene and b) during14.3-8.6 kyr B.P., radiolarian data do not confirm a considerable long-term (within a few centuries) reduction or breakdown of North Atlantic Deep Water formation.

Acknowledgments

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DIATOM PALEOGEOGRAPHY OF THE HOLOCENE IN THE BARENTS SEA

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Introduction

This work is the generalized result of several years of diatom investigations on bottom sediments of the Barents Sea. In previous publications (Djinoridze 1978, 1986, 1988; Polyakova 1992, 1994) main attention was paid to questions of the taxonomic composition of diatoms and their distribution in the sequence of bottom sediments. Advances in diatom systematics, the appearence of new data on their ecology, and the use of new methods in micropaleontological investigations made it necessary to re-examine these data (Sancetta 1981, Grebennikova 1989).

A detailed statistical adaptation of materials using ecological and biogeographical diatoms characteristics allowed to establish relations between the thanatocoenoses composition in sediments and the hydrological properties of the water masses: their temperature, salinity, and currents. On the basis of the actualism method an attempt of biostratigraphical analysis of the sediment sequence and the reconstuction of paleogegraphical conditions of sedimentation during the last 1000 years on the Barents Sea shelf is undertaken.

Materials and methods

Sediment cores of were obtained by M.A. Spiridonov, A.E. Ribalko, and Yu. A. Pavlidis during cruises of RVs "Tunets" (1963), "Valerian Albanov" (1981, 1983, 1986); "Ivan Kireev" (1979, 1987); "Professor Shtokman" (1984); "Geolog Fersman" (1992); "Professor Logachev" (1994; Ivanov et al., 1995). 600 tests have been studied by our diatom analysis method. A location map of stations is shown in Fig. 1. The information about station localities, sediment lithology, taxonomic composition, diatom number, ecological and biogeographical distribution of diatoms was entered into a computer data bank. The technical treatment of tests and preparation of constant slides were done according to a standard method (Glejzer et al., 1974. The diatoms of the USSR, Fossil and recent.- Nauka Publishing House, Leningrad, 402 p.). The method by Jakovshikova (Kvasov and Jakovshikova, 1971) was used for calculation of the amount of diatoms per 1 g of dry sediment. The results of the diatom analyses are given in diagrams. The number of main species was calculated in % of 200-700 frustules. The coefficient of reworking by Johnson (1972) was calculated for all stations, as reworked species are found in all sediments. The basic diatom stratigraphy of Jouse (1962) was used in this work. The principles of the paleotemperature reconstruction method of the water enviroment proposed by Grebennikova (Grebennikova and Pletnev, 1988; Grebennikova, 1989) for planktic diatoms were used to reconstruct paleohydrological conditions. Earlier similar models of quantitive reconstructions were worked out by Kanaya and Koizumi (1966) and Sancetta (1981).

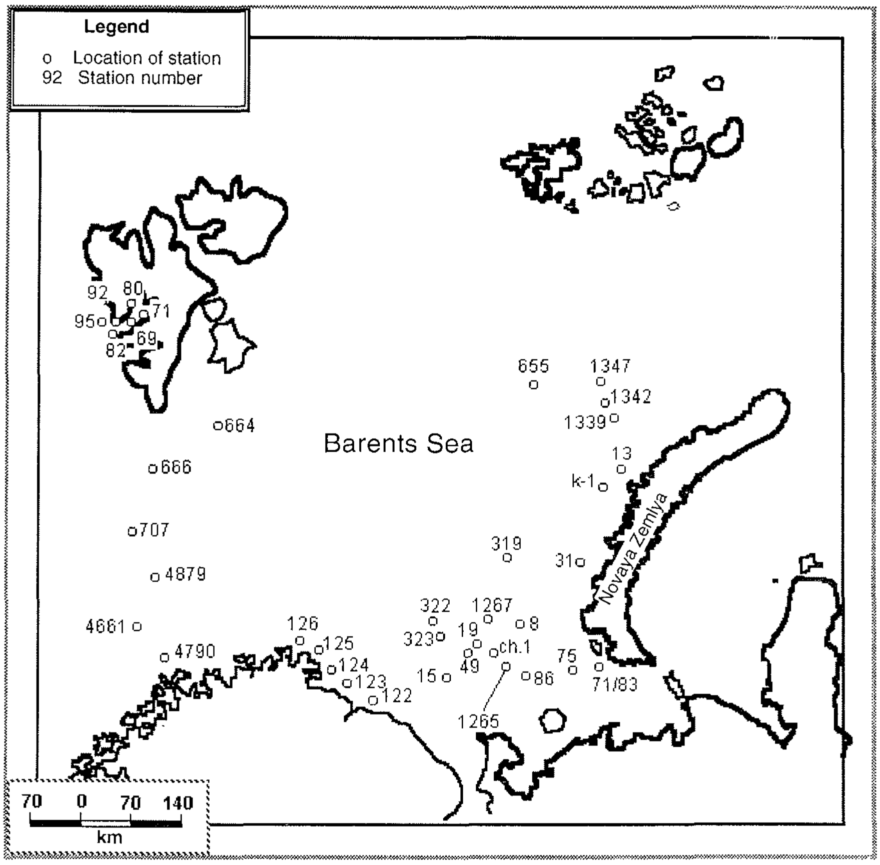

Fig. 1: Map of studied station locations in the Barents Sea.

Thanatocoenoses of the surface layer of the Barents Sea bottom sediments

The Barents Sea is situated in a transformation zone of different water masses (Arctic, Atlantic, Barents Sea waters), each of which is characterized by a certain number of species (according to Anonymous, 1986). In spite of high phytoplankton productivity (Rouhijanen, 1960), the number of diatoms in surface sediments appears to be low. In samples of 11 stations representative diatom assemblages were found, constituting up to thousand of frustules per 1 g of dry sediment (st. 4790, 126, k-1, 13, 86, 71, 80, 82, 92, 95, 69). In total 80 species and varietes of recent diatoms were found in the Barents Sea sediments. About 50 species of them are planktic (22 panthalassic and 28 neritic). The rest belongs to benthic species, 13 of which are frehwater types.

Besides the recent species, 22 extinct Cretaceous and Paleogene species were found in the surface sediments.

In the studied surface sediments, 2 types of diatom complexes were established, depending on the biogeographical composition. One of them is found in sediments of the ice-free southern and south-western areas (70-72°N) and the other in regions of seasonal ice cover (76-79°N). Thanatocoenoses from the southern sea regions correspond to a subarctic type, according to the scale of Grebennikova (1989). These thanatocoenoses are established in areas of water masses with an average annual surface temperature from 4° to 10°C (Fig. 7).

In surface sediments of the south-western Barents Sea with depths of 1000-1300 m (stns. 4790, 4879, 4661), where summer surface water temperatures fluctuate from 8° to 10°, and winter temperatures from 6° to 8°, the biographical thanatocoenosis structure corresponds to a subarctic subtype 1a (4-8°C): Northboreal species constitute about 50%, arctoboreal 25%, southboreal up to 26%, and subtropical up to 5%. Panthalassic species adapted to Atlantic water masses prevail: *Coscinodiscus radiatus* (15-20%), C. *marginatus* (20%), *C. curvatulus* (3%), *C. asteromphalus* (2%), *C. oculus-iridis* (1-2%), *Actinocyclus ehrenbergii* (9%), *Actinopthychus undulatus* (2%), *Planktoniella sol* (1-5%), and *Thalassiosira oestrupii* (1-3%). Neritic cold-water species are not abundant or have a low abundance (about 8%): *Thalassiosira gravida*, *Th. antarctica*, and *Th. anguste-linneata.* In some of these deep-sea stations accumulations of frustules of the sublittoral species *Paralia sulcata* (over 30%) and sponge spicules were found. *Paralia sulcata* and sponges dwell on sandy shoal waters (25-100 m) with a strong mixing of the bottom water layers. Their presence in deep-sea regions can be explained by downslope transport of sediments from Scandinavian coasts.

Atlantic waters cool and become fresher on their way eastward. Near the Kola peninsula (st. 126, water depth 410 m), summer temperatures of the surface water do not exceed 8°C, and winter temperatures are ca. 6-4°C. In the sediments, southboreal warm-water species are present (19%): *Coscinodiscus radiatus, C. asteromphalus*, and *Actinocyclus ehrenbergii.* The number of arctoboreal and bipolar species increases (29%): *Thalassiosira gravida, Odontella aurita*, and *Synedra kamtschatica var. finmarchica.* Northboreal and widespread species dominate (over 50%): Paralia sulcata and *Grammatophora angulosa.* The thanatocoenosis corresponds to the subarctic subtype 1a.

In sediments of the southeastern Barents Sea (st. 75, 86) on shoal water, littoral diatoms prevail (98-100%): *Paralia sulcata, Navicula distans*, and *Rhaphoneis surirella.* The representatives of neritic plankton are few (2%): *Thalssiosira gravida, Th. angulata*, and *Odontella aurita.* Single southboreal species occur. Brackishwater species are present as a result of water freshening:*Thalassiosira bramaputrae var septentrionalis, Cyclotella striata*, and *Thalassiosira baltica.* The temperatures of surface waters reach 4-6°C in summer and in winter they have values from 0° to -1°C.

Diatom assemblages reflecting the low temperature regime of the Arctic and Barents Sea waters are wide spread in sediments of northern regions of th

Barents Sea (75-79°N). Maximum summer temperatures reach 2-4°C here, and winter temperatures fluctuate from 0° to -1° in the West and from -1° to -1.8° in the East.

Arctoboreal and bipolar neritic species prevail (75-97%) on the surface of the Isfjorden and in the adjacent waters (stns. 69, 71, 80, 82, 92, 95, Figs.2-6): *Thalassiosira gravida* and *Th. antarctica* (over 60%), *Th. nordenskioldii* (2%), *Th. kryophila* (1-2%), *Bacterosira fragilis* (3-10%), *Porosira glacialis* (up to 23%), *Rhizosolenia hebetata f. hiemalis* (1%), *Chaetoceros furcellatus* (2-3%), *Fragilariopsis oceanica* (5-6%), and *Odontella aurita* (2-6%). The number of southboreal species does not exceed 5%: *Coscinodiscus asteromphalus* (1%), *C. radiatus* (2%), *Actinocyclus ehrenbergii* (0.3%), and *Rhizosolenia styliformis* (0.5%). Northboreal and widespread species constitute 2-30%.

In sediments near Admiralteistvo peninsula (Novaya Zemlya, stns. k-1, 13), arctoboreal and bipolar species also prevail, constituting 85-98% in total. In addition to the named species, in the thanatocoenosis composition following species occur: *Thalassiosira bioculata* (14%), *Thalassiosira angulata* (7%), *Th. hyalina* (1.4%), *Chaetoceros compressus* (1.4%), and *Ch. subsecundus* (1%). Single atlantic species are present (about 1%).

A thanatocoenosis in which planktic arctoboreal and bipolar species are prevailing is distinguished by us as a new type of thanatocoenosis: The "arctic" type. As demonstrated above, this type of thanatocoenosis characterizes the sediments of ice-covered regions, where arctic water masses are present, with surface water temperatures of 1-4°C in summer and -1.8-0°C in winter.

The percentages of the ecological diatom groups in sediments of the deep sea regions shows a dominance of marine stenohaline species (88-100%). The distilling effect of the continental flow is revealed in the thanatocoenoses of the littoral regions (st. 83, Besimanaya Bay), where marine species constitute about 60%. Brackishwater and euryhaline species (*Diploneis smithii, Amphora commutata, A. coffaeformis, Pinnularia quadratareae var. baltica*) are present in significant amount of frustules (39%); freshwater species constitute less than 1%.

Findings of Paleogene species in recent sediments allowed to calculate the coefficient of reworking (K, the relation of the number of reworked species to the total number of species found in test). K is especially high (0.25-1) in sediments near Franz Josef Land (st. 142, 144, 145, 159), in the central Barents Sea (st. 319, 322, 71-83, well 1), along the Kola peninsula coast (st. 122, 123,125) and in the continental slope region (st. 4790). Reworked diatoms are almost absent in surface sediments near Svalbard.

Diatoms in the sedimentary sequence of the Barents Sea

Analysis of the sedimentary sequences from 33 sites showed that in the central and NE parts of the Barents Sea the environmental conditions were unfavourable for diatom accumulation both during the Holocene and at present. Representative diatom complexes are found in sediments from the north-western and southern parts of the sea (Figs. 2-8).

In total 150 diatom species and verietes were indentified in the bottom deposits of the Barents Sea, all of them living in contemporary seas. Among them there are 131 marine species and 19 freshwater ones. 53 species belong to the order *Centrophyceae* and 97 species and varietes belong to order *Pennatophyceae*. Besides that 28 species reworked from Cretaceous and Paleogene deposits were identified.

In sediments of the Isfjorden and adjacent waters, 4 diatom complexes are established (st. 69, 71, 80, 82, 92, 95). Investigations of pollen, spores and foraminifera carried in sections of cores 92 and 71 allowed to correlate the intervals of diatom complexes with periods of climatic-stratigraphical scale by Blitt-Sernander.

Complex IV is found in sediments of preboreal-boreal periods only in a section of core 92 (Fig. 2), obtained from a water depth of 97 m. Arctoboreal and bipolar species constitute over 80%: *Thalassiosira gravida, Th. antarctica, Thalassiothrix longissima*. The number of frustules of the southboreal species *Coscinodiscus radiatus* does not exeed 2%. This complex belongs to the arctic type of thanatocoenosis (A), based on its biogeographical composition. The temperature of surface waters during the early Holocene must have been close to the modern one and did not exceed 4°C.

Complex III characterizes the sediments of Atlantic period; the total number of diatoms exceeds by 2-10 times the contents in the surface layer. Most characteristic the complex III is found in sediments of core 92 (Fig. 2). It includes a lot of northboreal sublittoral species (40%). Southboreal species constitute 6-7% and the number of arctoboreal ones decreases to 50-55%. The biogeographical diatom composition allows to distinguish the subactic subtype 1a here with average annual temperatures 4-6°C according to the scale of Grebennikova (1989).

The sediments of Atlantic period at the deeper water stations (144-419 m) contain thanatocoenoses with larger contents of arctoboreal species. At site 71 (Fig. 3) in some samples arctoboreal species constitute 65-70%, southboreal ones constitute 5-6%, and northboreal ones constitute 25-305, which allows to identify a thanatocoenosis of the subarctic subtype 1a here. In other samples the contents of arctoboreal species exceeds 85% and the diatom composition corresponds to the arctic thanatocoenosis. Complex III has a similar structure in sections of sites 95 and 82 (Figs. 4, 5). In Atlantic time, when the influence of warm water masses became stronger, the activation of circulation processes leading to an increase of the productivity of the ice-neritic flora took place. In the shoal water zone (site 92), the hydrological maximum of the Atlantic period is more distinctly reflected in the thanatocoenoses composition. The average annual temperature was about 2-3°C above the modern one at that time.

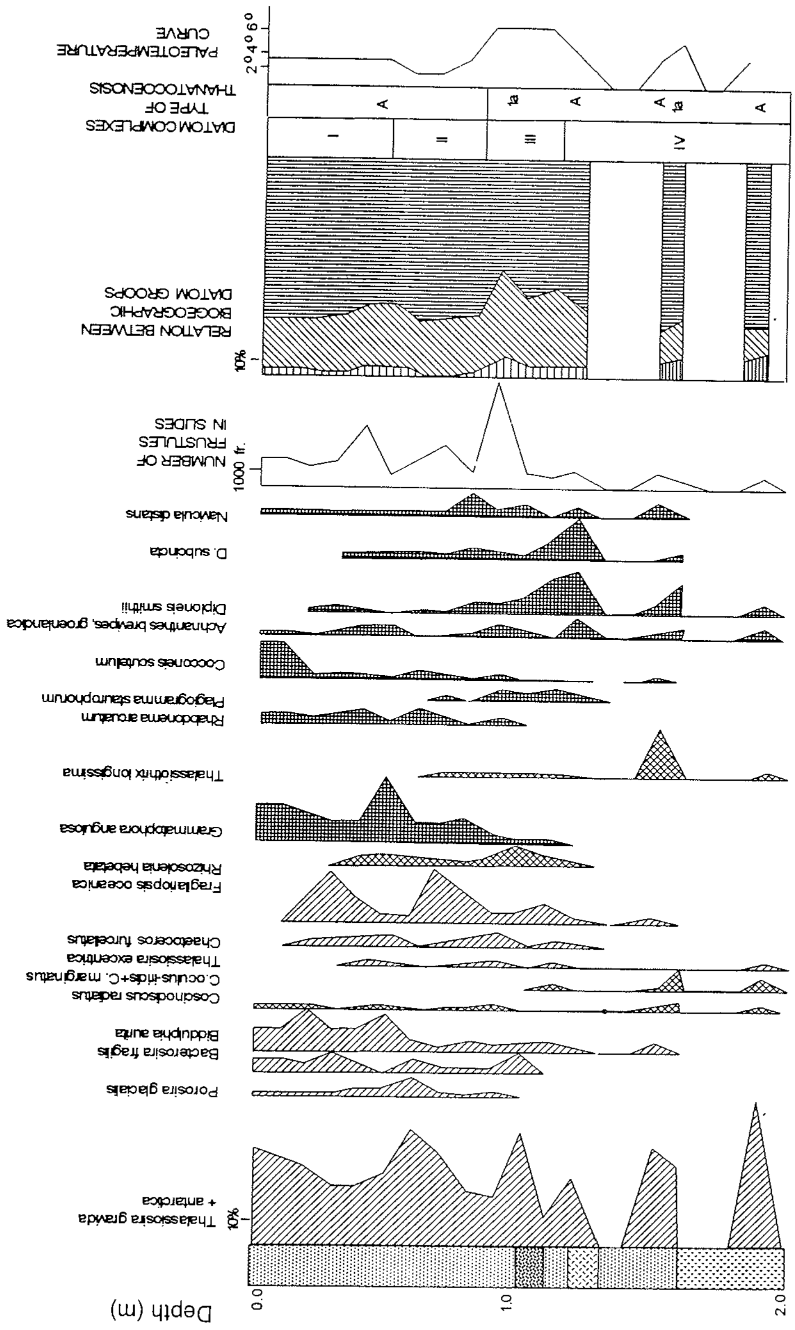

Fig.2a: Diatom diagram of site 92

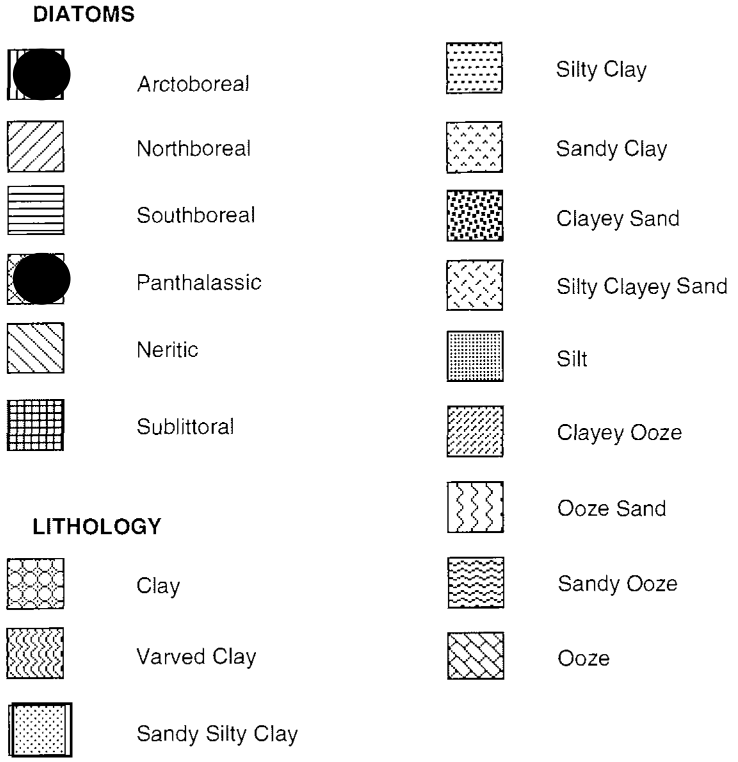

Fig. 2b: Legend to Figs. 2a, 3-8.
(taken from T.A. Grebennikova (1989))

Diatom complex II is found in sediments of the subboreal period (stns. 71, 92, 95, 82). It is characterized by an abrupt decrease in the species variety, the almost complete disapperance of warm water species and the predominance of arctoboreal and bipolar species (over 80%): *Thalassiosira gravida, Th. antarctica, Chaetoceros furcellatus, Odontella aurita*, and *Grammatophora angulosa* (Figs.3-6).

In the composition of complex I (stns. 71, 92, 95, 80, 82) cold water species prevail and the total number of diatoms decreases. The biogeographicalal structure of the complexes I and II corresponds to an arctic type of thanatocoenosis (Fig. 3-6). The average annual temperature must have been less than 4°C in the Postatlantic period.

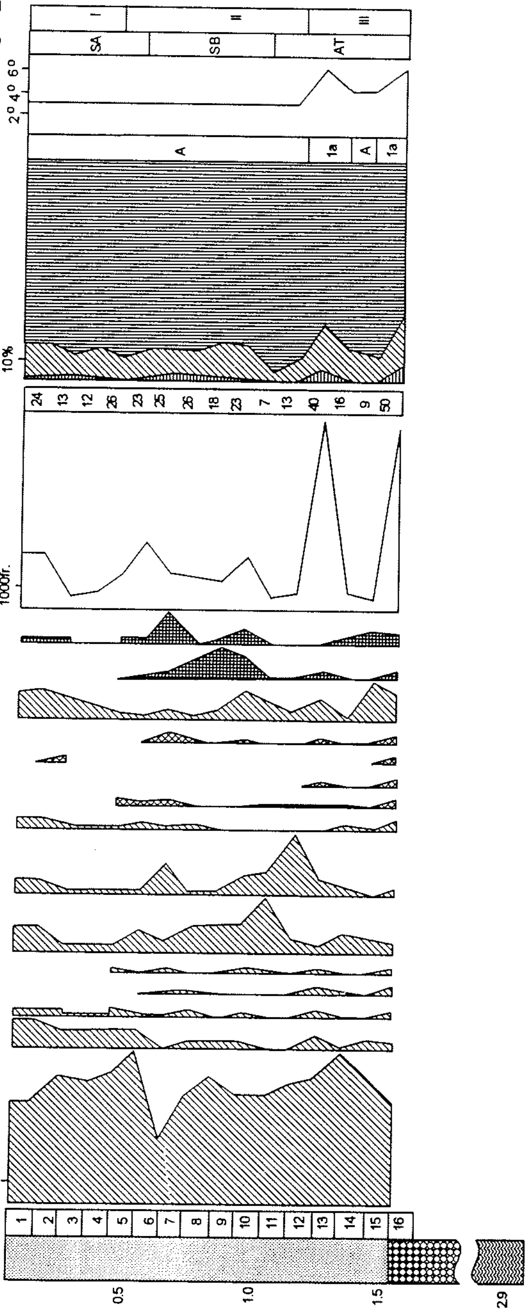

Fig. 3: Diatom diagram of site 71. For legend see Fig. 2b.

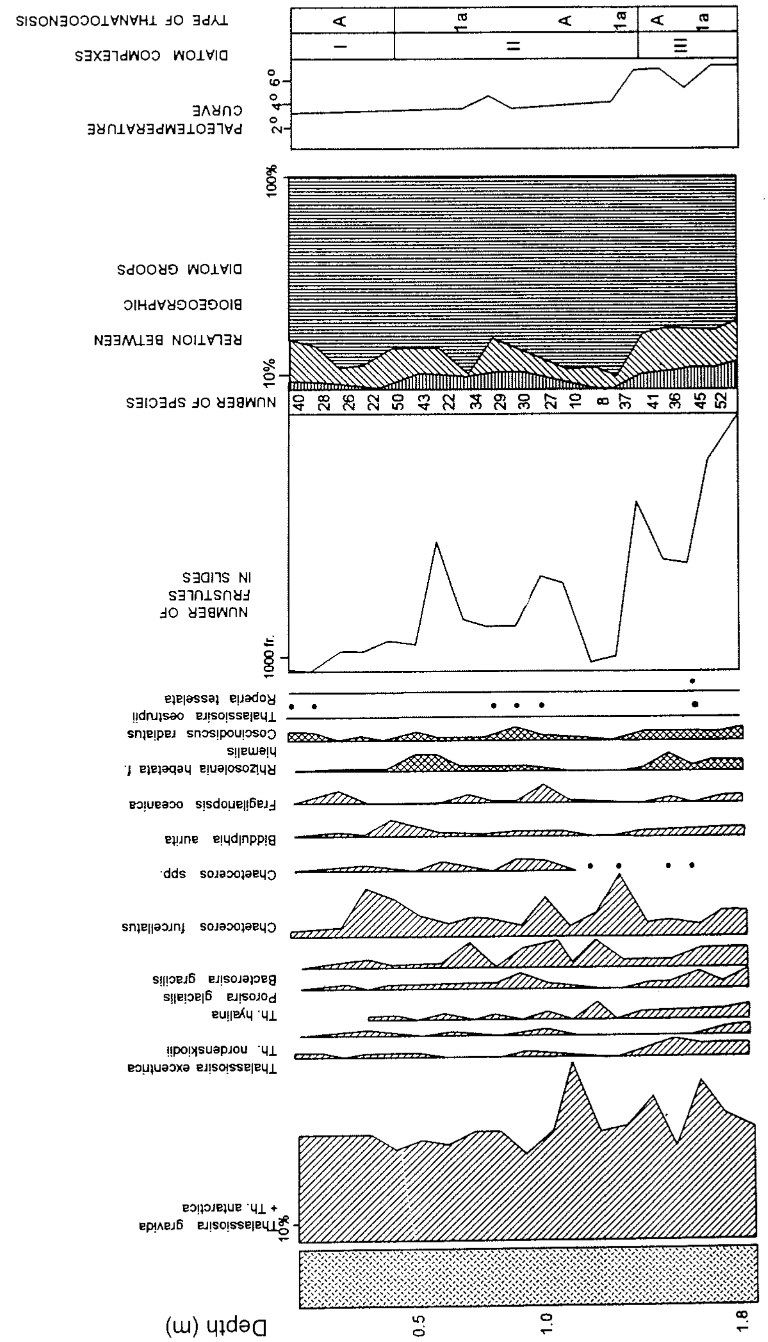

Fig. 4: Diatom diagram of site 95. For legend see Fig. 2b.

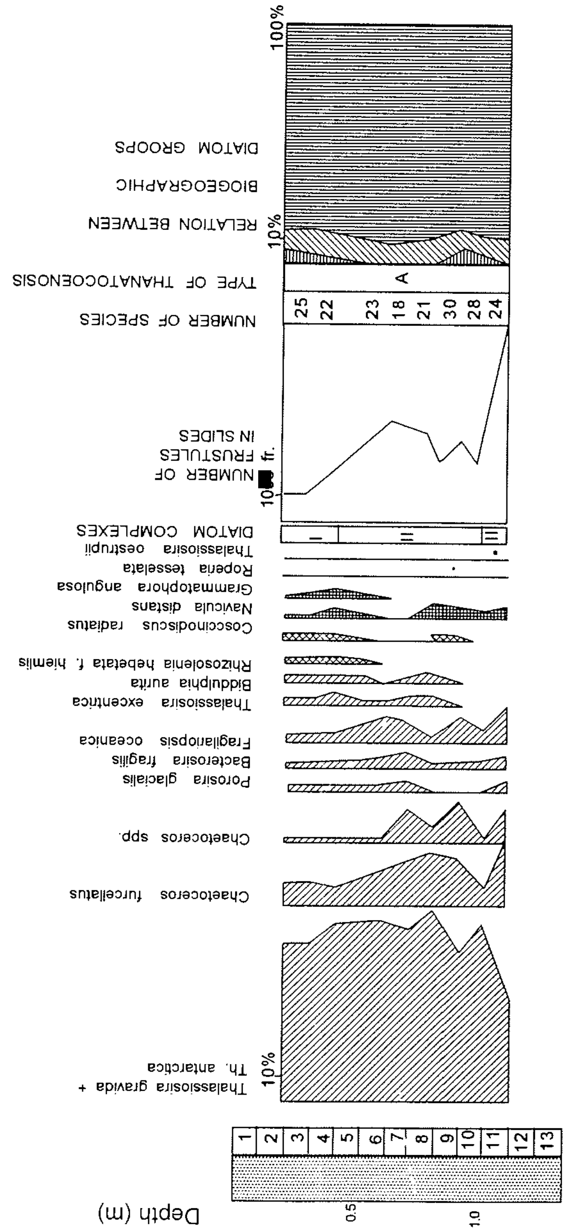

Fig. 5: Diatom diagram of site 82. For legend see Fig. 2b.

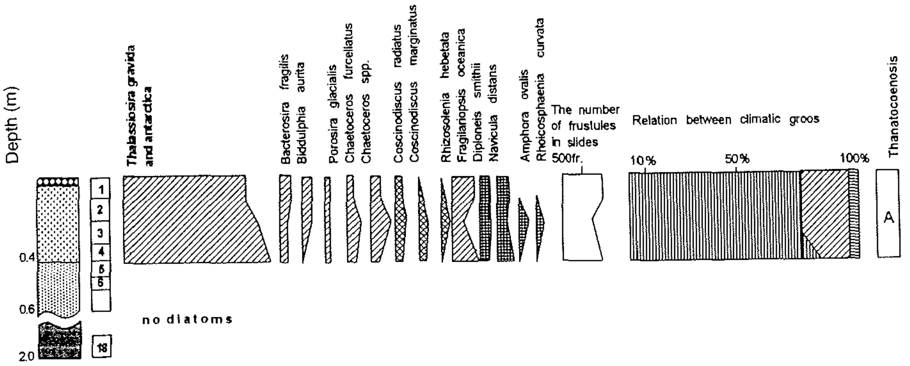

Fig. 6: Diatom diagram of site 80. For legend see Fig. 2b.

In the diagrams (Figs. 2-5), besides the absolute maximum number of diatoms which corresponds to complex III, other minor maxima and minima are recorded. The intervals between two minima or maxima of the curve usually are about 20-40 cm. The variability reflects the rythmic reduction and increase of the phytoplankton productivity and is correlated to the intensity of the Atlantic water inflow, which is influencing also the sea ice regime.

Three complexes are distinguished in sedimentary sections of the deep southwestern Barents Sea. Unfortunately, no other micropaleontological data from these sediments are available yet. Thus, the complexes were established according to changes of the number of frustules in the sediments and their biogeographical composition. The concentration of diatom frustules by 2.5 times exceeds their contents in the surface thanatocoenoses in sediments where complex III was found (Figs. 7, 8). In the composition of the complex (stns. 4879, 4661, 122), panthalassic North Atlantic species play an important role (up to 70%), among wich southboreal species constitute 15-40%: *Coscinodiscus radiatus, C. perforatus, Actinocyclus divisus*, and *Actinoptychus undulatus*. Subtropical species constitute 2%: *Planktoniella sol* and *Thalassiosira oestrupii*.. The number of arctoboreal species does not exceed 15-35%. The half-benthic species *Paralia sulcata* is constantly present (over 30%). The biogeographical diatom composition in sediments with complex III corresponds to a subarctic type of thanatocoenosis; in one sample it corresponds to subtype 1b, in others to subtype 1a-b. This suggests that the average annual temperature during deposition was about 2-3° above the modern one.

Comparison of our results of the deep sea sediments from the southwestern Barents Sea with data of Polyakova (1992) appears to be possible due to the presence of North Atlantic panthalassic species which allows to trace common features of the Holocene diatom complex composition (called "ecozones" by Polyakova). The planktic diatom composition of the ecozone III in sediments from the Kolguev shoal includes the same North Atlantic species which are found in complex III in cores 4879, 4661, 122: *Coscinodiscus radiatus, C. perforatus*, and *Actinocyclus divisus*.

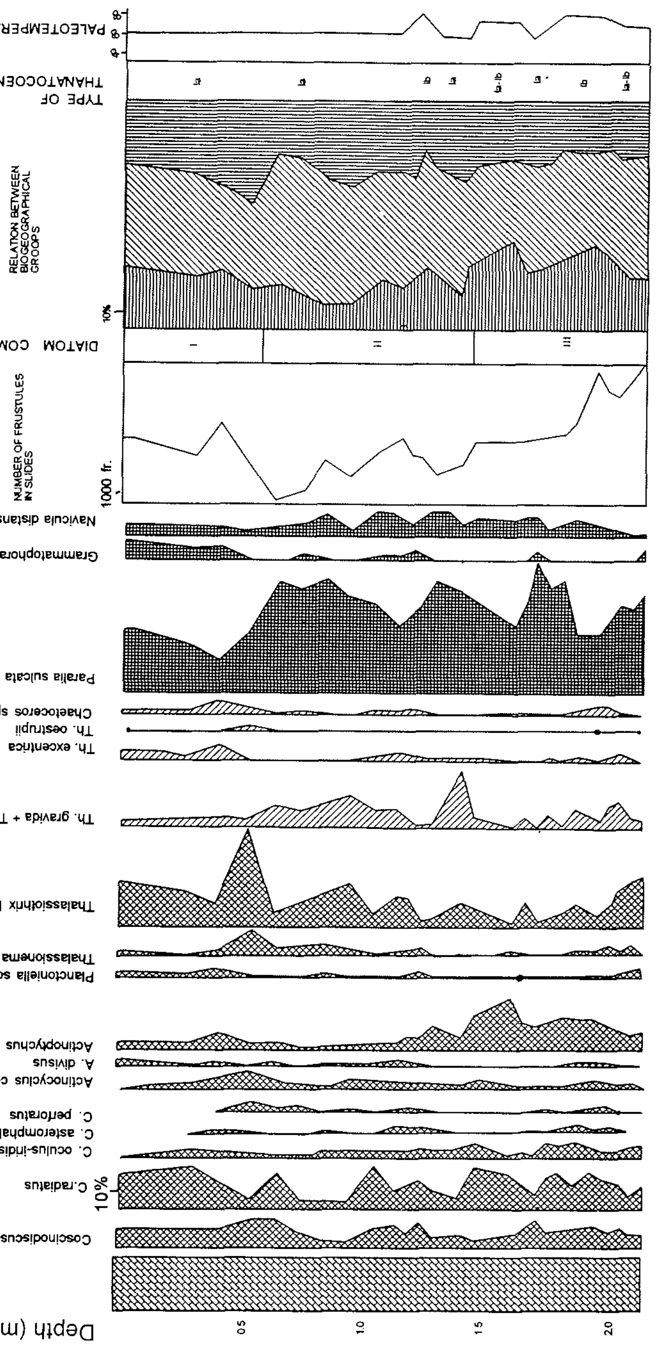

Fig. 7: Diatom diagram of site 4879. For legend see Fig. 2b.

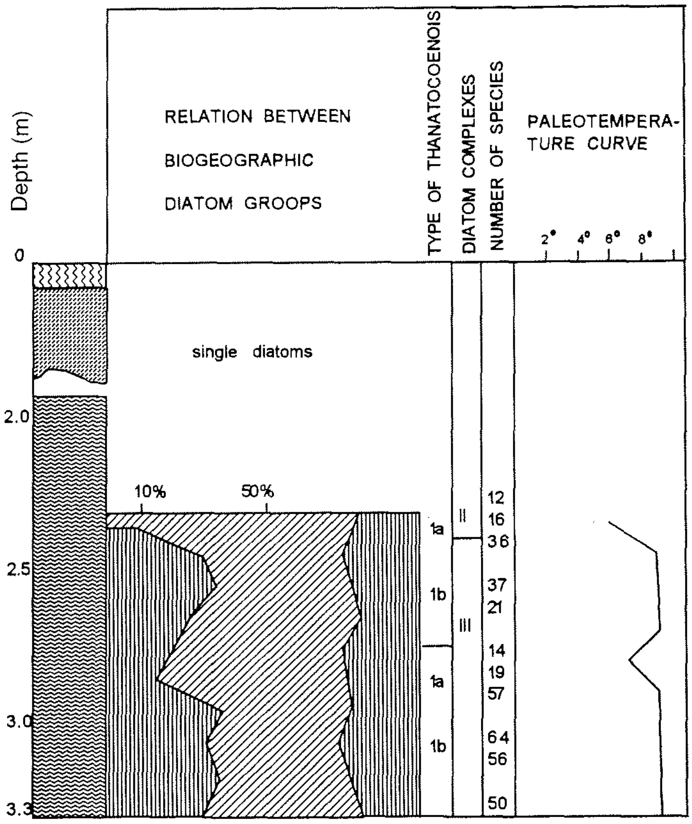

Fig. 8: Diatom diagram of site 122. For legend see Fig. 2b.

Complex II is characterized by a significant reduction in the concentration of frustules, the decrease of of warm-water species (10-20%) and the increasing abundance of arctoboreal and bipolar species (*Thalssiosira gravida, Th. antarctica*).
In sediments characterised by complex I the total number of diatoms increases, compared with complex II. A significant amount of species inherent to the divergence zones appears, mainly *Thalassionema nitzschioides* and *Thalassiothrix longissima*. The role of the North Atlantic panthalassic diatoms grows. The biogeographical structure of the complexes I and II is correlating to subtype 1a of the subarctic thanatocoenosis, with average annual surface water temperatures of 4-8°C.

By statistic computer adaptation changes of the reworking coefficient (K) can be traced in the sedimentary sequence. In sediments where diatom complexes are poor and recent species are few, the indices of K fluctuate from 0.5 to 0.9 (stns. 122, 123, 125). In absence of recent diatoms K is equal to 1. In sediments with complexes II and III, K has values from 0 to 0.01. At the boundary between the complexes K increases up to 0.02-0.04 and in diatom composition of diatoms characterizing the divergence zones are noted.

Discussion

During our analysis of >600 samples, new data on diatoms distribution in sediments of the Barents sea were obtained. The results extend and basically confirm literature data (Polyakova,1991,1992,1994). In sediments of the northwestern and southwestern Barents Sea the representative diatom complexes are found. During the Holocene and in subrecent time the environmental conditions in the central and northeastern parts were unfavourable for diatom accumulation, possibly because of a silica deficit in the waters.

The distribution of planktic diatoms in the sediments corresponds strictly to their modern biotopes (Polyakova, 1994). Sublittoral species dominate in shoal waters; among them there is the half-benthic species *Paralia sulcata*. The accumulation of frustules of this species in a continental slope region is probably the result of sediment transport by currents.

From our analyses of surface sediments, specific thanatocoenoses corresponding to regions of the expansion of different water masses could be established. The Arctic thanatocoenosis corresponds to Arctic and Barents Sea water masses with an average annual surface water temperature <4°C. The Subarctic thanatocoensis with the two subtypes 1a and 1b is distinguished in the southern Barents Sea where with a strong influence of North Atlantic water masses and average annual surface water temperatures of 4-10°C.

According to changes of ecological diatom composition the stratigraphical division was applied. Four assemblages corresponding to the Early, Middle and Late Holocene are distinguished. The marker horizon containing the complex III to the Holocene climatic optimum. The changes of the diatom complexes reflect the variable expansion of water masses during the Holocene: Strong inflow of North Atlantic waters into the northern regions during warming phases and the advancement of Arctic water masses southward in the Barents Sea during cold periods.

It is difficult to give an absolute chronology of the environmental changes based on the variability of the diatom complexes, because no radiocarbon datings are available yet from our samples. Radiocarbon datings reported by Polyak et al.(1995) for Holocene deposits of the southern part of the Barents Sea were obtained from sections where diatoms were not studied by us.

Conclusions

The onset of the Holocene transgression in the southern Barents Sea coincided with the end of the second stage of deglaciation (Polyak et al, 1995) and a global sea level rise at about 9.5 ka (Fairbanks, 1989). In the southern regions, in the Early Holocene marine conditions existed, witnesse by a high relative abundance of planktic northboreal diatoms. In the northwestern regions, an ice-covered marine regime was established. In the warm season ice-free areas were forming, where a neritic kryophil diatom flora lived. The influence of the North Cape Current was restricted. Later the representatives of oceanic and panthalassic North Atlantic diatoms appeared. The permanently ice covered area gradually shifted northward. The deglaciation process was complex, as reflected in alternating layers of strongly variable diatom abundances. The decreasing power of the North Cape Current caused a transitional increase of sea ice and a decrease of the phytoplankton productivity. The average annual temperatures of the surface waters were close to the modern ones in the northern and southern Barents Sea.

Sea level rise and global warming in the middle Holocene are reflected in the composition of the diatom associations. Southboreal panthalassic species appeared everywhere in the Barents Sea and their ranges advanced northward to 78°N. The appearance of sublittoral brackishwater species from kryopelagic and kryointersticial classes in sediments of the northern deeper water regions witnesses ice melting and a salinity decrease. Comparison of the diatom composition with surface thanatoecoenoses shows that the average annual surface water temperature was about 2-3° above the modern one. The hydrological optimum of the Middle Holocene in the Barents Sea took place 3.7-5.7 ka (Polyakova, 1992)

In the Late Holocene the stabilization of the modern hydrological regime occurred. However, rythmical fluctuations of the diatom abundance in the sediments reflects an alternative influence of Atlantic and Arctic waters and parallel north-south changes of the polar fronts.

Acknowledgments

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BIOSTRATIGRAPHY OF UPPER CENOZOIC SEDIMENTS OF THE PECHORA SEA BY OSTRACODES

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Introduction

Crustacea of the ostracode subclass are a widespread group in the Cenozoic. As other fossils they are used in stratigraphy for dating the deposits and for correlation. The distribution of Cenozoic benthic ostracodes is depending on the bottom environments of the respective basin. The main external factors influencing ostracodes and determining their taxonomic composition are: salinity, substrate, mobility of waters, depth, contents of organic calcite and oxygen, and temperature. This circumstance makes ostracodes reliable paleoenvironmental indicators (Karrow et al., 1975; Cronin, 1977, 1981; Brookes et al., 1982).

Ostracodes are practically omnifacial, they are met in all types of both marine and continental deposits. In deposits of continental basins they are often the only present microfauna group, which makes their findings very valuable for reconstructions of hydrological conditions of the past.
In Neogene-Quaternary deposits of the extreme North of Russia, ostracodes amount to 80 species, among which 60 species are typically benthic. In fossil state they occur both on the shelf and continental surroundings of the shelf and the arctic islands. Ostracodes have a migration origin. Their thanatocoenoses composition is determined chiefly by hydrological conditions which depend on the water masses of the Atlantic, Pacific and Arctic oceans. The history of distribution of Late Cenozoic ostracodes on the Arctic shelves reflects the stages of Arctic basin development in the Neogene and Quaternary periods.

Recent data obtained on the stratigraphy of Upper Cenozoic deposits of the Pechora Sea including the results of the drilling in the eastern Pechora Sea allow to consider the major stages of the development of this region at a new level.

This paper reports on results and conclusions from ostracode analysis executed for the Cenozoic deposits obtained from the wells 117, 210, 212, and 218 in the Pechora Sea (Fig.1). Characteristic ostracode assemblages with representative species subdivide the sedimentary cover into three major horizons (intervals) and allow to attribute the marine deposits to different transgressive-regressive cycles of sedimentation and to reconstruct the paleoecological conditions of the basin (Aksenov and Dunaev, 1987; Trushnikov and Salnikov, 1985).

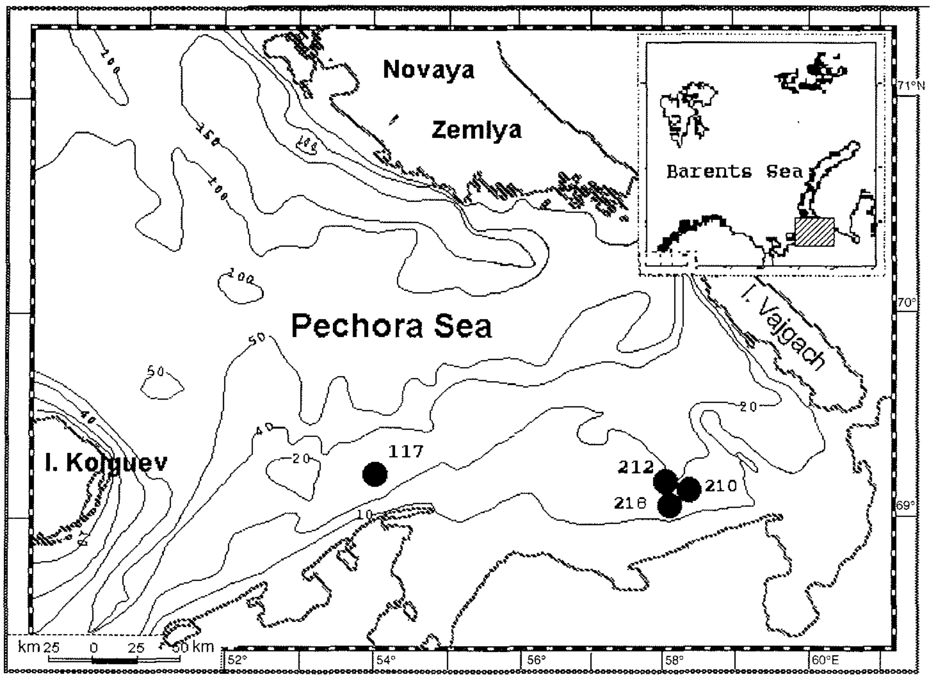

Fig. 1: Bathymetry (m) and drill sites in the Pechora Sea.

Materials and Methods

Biostratigraphic studies and correlation analyses were carried out for two important areas in the south-eastern part of the Barents Sea. The first drilling site (117) was located in the western part of the Pechora Sea in the East Guljaevsk field (69°15'N, 56°41'E; water depth 17 m). Sites 210, 212 and 218 were located in the eastern part of Pechora Sea, Prirazlomnoye oil field. Holes were drilled by drilling vessel "Bavenit" in 1991. Revealed thickness of sediments were 130.5 m (well 210), 80.0 m (well 218), 74.0 m (well 212) and 72.0 m (well 117). On these sites, detailed micropaleontological (foraminifers (Samojlovich et al, 1992), ostracodes, diatoms (Samojlovich et al, 1992; Kagan, 1989), spore and pollen (Samojlovich et al, 1992) and lithological studies of the Cenozoic sections of the offshore wells were conducted. Studies also included a seismostratigraphic subdivision of the Upper Cenozoic cover by the data of high resolution seismic profiling (Gritsenko, 1986; Gritsenko and Krapivner, 1989). The present paper gives results of the biostratigraphic subdivision and correlation analysis of ostracodes.

Samples were dissolved in 100 ml of water. If a sample was not totally dissolved, it was boiled under alkaline conditions. In cases of hard clays, boiling occurred with 3-15% of H_2O_2. Each sample was boiled until complete disintegration and was then washed and poured off above a sieve with mesh sizes from 0.15 to 0.01 mm. Then deposits from the glass and the sieve were carefully poured off into marked cups and dried in an oven.

Dried samples were sifted with sieves of mesh sizes from 0.01 to 0.5 mm, dividing them into fractions. Sampling of ostracodes was done usually under a binocular and microscope with a wet small brush N0 or N1. Picked shells were sorted according to genus and than species to compile the collection. Further scientific investigations included: the study of the inner structure of shells under a microscope, photographing, drawing and compilation of paleontological tables. The ostracode study will be finished with monographic description of species using support from the available scientific literature. Photos of individual species are given on plates 1 and 2.

Results and Discussion

The drill holes 117, 210, 212, and 218 in the Pechora Sea revealed a thick sequence of unconsolidated Upper Cenozoic sediments. The maximum thickness of these sediments was found in well 210 (130.5 m). The most detailed biostratigraphic studies were carried out on the core from the well 117, where 56 samples with ostracodes were analyzed (Annex 1). The sampling interval for microfaunal analyses was 0.5 m. The preservation of the ostracodes is good. A lot of whole shells and single valves were found; fragments are rare. The high content of juvenile forms demonstrates that the assemblages was formed during the ostracod living period.

The variable quantitative distribution of ostracodes in the section and the concentration of certain species in specific intervals of the section (see Annex 1) allows to recognize 3 intervals with remarkable assemblages of ostracodes (Fig. 2).

Well 117 (Pechora Sea)

The interval 59.5-42.5 m (Fig. 2) is represented by black dense aleuro-pelites (loams) with coarse-grained material inclusions, sand lenses and interlayers. The lower unconformity is well traced on seismic lines because of the deep erosion of the bedrock surface. The upper boundary is difficult to determine, most often it can be done after the micropaleontological and geochemical studies (Gritsenko, 1986).

The interval 59.5-42.5 m is characterized by rare ostracodes (1-4 specimens per sample) with only *Paracyprideis pseudopunctillata* Swain, *Sarsicytheridea punctillata* (Jones), and *Krithe glacialis* Brady, Crosskey et Robertson (Annex 1, Fig. 2). They represent arctic-boreal and arctic species which were formed under relatively cold conditions in the sublittoral zone. The distribution of ostracodes shows stable depositional conditions except the interval 58.0-59.0 m, where the ostracode association is more representative. It holds up to 5 species with up to 15 specimens per sample. Formation of the association was possibly associated with a small change of the hydrological regime in the basin. This ostracode assemblage is called a poor assemblage with *Paracyprideis pseudopunctillata* Swain (the most common species).

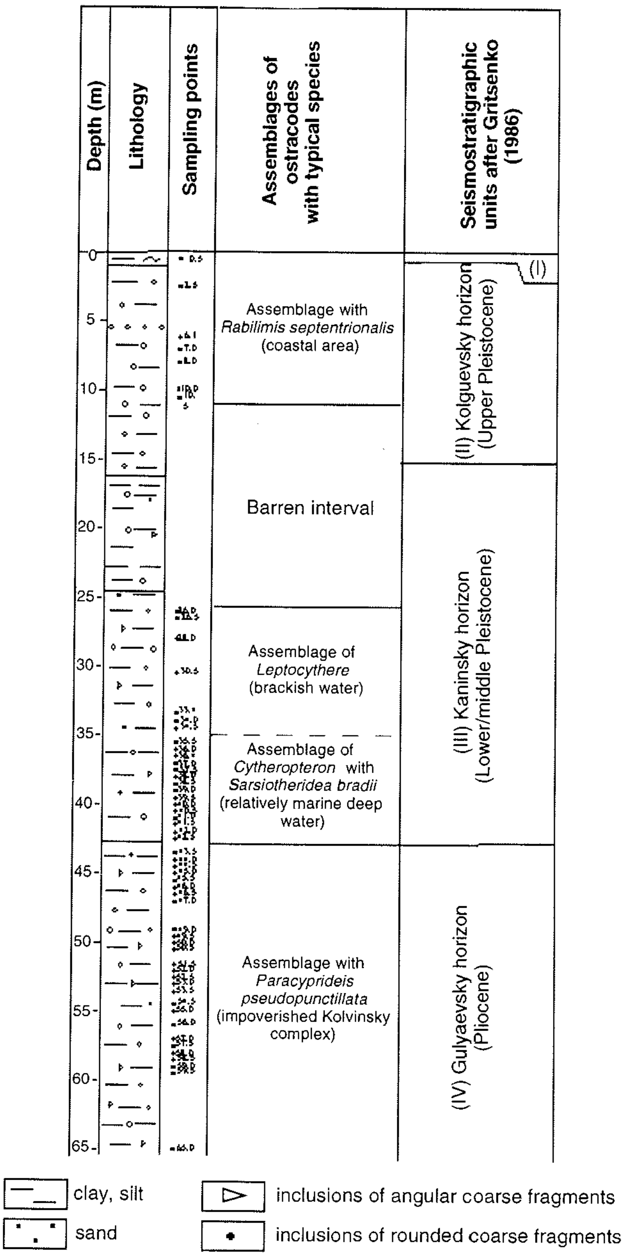

Fig. 2: Biostratigraphic dismemberment by ostracodes and comparison with seismostratigraphic data by section of well 117.(Pechora Sea; East-Gulaevskaia area; 69°15'N, 56°41'E; water depth 17 m; recovery 72 m).

All ostracodes present in the interval 59.5-42.5 m are species with a wide stratigraphic range within Late Cenozoic. The composition of the ostracode assemblage is mostly close to the one of Kolvinskaya suite in the Pechora basin, especially for its upper part depleted in ostracodes, which appears to correspond to a regressive stage of sedimentation (ostracodes of transgressive part of the suite are usually characterized by substantially higher amounts and varieties of species). This interval of moraine-like loams was identified as a Quaternary seismic sequence called the "Gulyaevsky horizon", but dated as Pliocene by Gritsenko (Gritsenko, 1986; Gritsenko and Krapivner, 1989).

The interval 42.0-26.0 m is represented mainly by moraine-like loams and clays, the same as in underlying unit (Fig. 2). Although there are often no lithological boundaries between the layers, they can nevertheless be distinguished by ostracode assemblages which are characterized by a rich variety of species, but low amounts (Annex 1). Some samples contain up to 11 species among 20 specimens. Along with species which are common for the whole section, the ostracodes attributed to the genus *Cytheropteron (C. inflatum, C. cham-plainum, C. preudomontrosiense, C. montrosience, C. punctatum, C. timefactum*) are widespread in this interval. The appearance of these species from above 42.0 m shows different sedimentary conditions, which were probably warmer and deeper if compared to the deposits from the lower part of the section.

In the upper part of this interval (37.0-26.0 m) several species gradually disappear, but some species which are not characteristic for the lower part are present: *Leptocythere castanea* (Sars), *Cluthia clutae* Brady, Crosskey et Robertson, *C. Complanata* Brady, Crosskey et Robertson (Annex 1). These are shallow-marine species, which were formed in saline waters with a small input of fresh water (18-20‰). The existence of the ostracode assemblage in the upper part of the interval can be explained by near-shore conditions with a weak influence of fresh waters. The generally transgressive stage of the marine basin formation corresponds to the lower part (42.0-37.0 m) of this interval with a characteristic ostracode assemblage containing *Cytheropteron* and the common species *Sarsicytehridea bradii (Norman)* which appears above 42.0 m and is present throughout the section. The regressive stage is characterized by a poor ostracode assemblage with rare *Leptocythere.* The complex which contains *Cytheropteron* is well known in the literature (Lev, 1983). It is associated with sediments of the Padimeyskaya unit revealed in the Pechora lowland (wells in the area of Khonguray settlement, Nizhnyaya Kamenka etc. and outcrop Vastyansky Kon).

The interval 42.0-26.0 m as characterized by ostracodes is a constituent of the Kaninsky regional horizon within the limits of the third seismic sequence of the Lower-Middle Pleistocene.

In the interval of 10.5-2.5 m few ostracodes were found (Fig. 2). It consists of a shallow sand facies (Fig. 2). This interval is characterized by a poor ostracode assemblage (rare species and specimens, up to 4-6 per sample). A common species in this interval is *Rabilimis septentrionalis* Brady (Annex 1). It is an arctic-boreal species, which is widespread under near-shore depositional conditions; it is present in modern sediments of the Beaufort Sea, Franz-Josef

Land, New Siberian Islands and in fossils in the Gubik Formation in Northern Alaska.

Analysis of core from well 117 for ostracodes made it possible to recognize several intervals with characteristic ostracode assemblages and to reconstruct the depositional conditions. A correlation of the biostratigraphic division for Cenozoic ostracodes with seismic stratigraphic data (Krapivner et al., 1986) is given in the scheme "Correlation of biostratigraphic and seismic stratigraphic data in the core from well 117, Pechora Sea".

Wells 210, 218, and 212 (Pechora Sea)

The Upper Cenozoic sedimentary cover revealed by drilling holes 210, 218 and 212 in the eastern part of the Pechora Sea was sampled in details for microfaunal investigations (Annexes 2-4). The studied ostracode assemblages allow to divide the Upper Cenozoic sequence into several horizons. The succession of this sequence formation is the same in all three sections, and the sediments in the three wells can be correlated for the compilation of a generalized section (Fig. 3).
Ostracode assemblages are most completely represented in well 212. Within the interval 60.0-66.5 m the depleted ostracode assemblage with *Paracyprideis pseudopunctillata* is found. For the ostracode facies this interval is well correlated with the interval 62.1-99.0 m of well 210 and interval 62.4-66.5 m of well 218 where this assemblage was also found (Fig.3). Upwards, the section in these wells contains the assemblage with *Cytheropterones* and the representative species *Sarsicytheridea bradii.* The boundary between these complexes is well-pronounced in this section, which suggests the onset of a new sedimentation cycle in the basin.

Upwards in the section there is thick interval which was not sampled for microfauna analysis.

The interval 11.5-17.8 in well 212 is characterized by a complex with rthe epresentative species *Rabilimis septentrionalis* which is correlated with the interval 2.8-4.0 m of well 218.

Samples for absolute dating were taken from these cores: 9 samples for radiocarbon analyses and 2 samples for oxygen isotope analyses. Results are given in the compiled scheme "Biostratigraphic divisions and correlation according Late Cenozoic ostracodes of cores from wells 210, 218, 212, Pechora Sea".

Conclusions

Upper Cenozoic sediments revealed in the eastern (wells 210, 218, 212; Prirazlomnoye structure) and western (well 117; East-Guljaevsk field) parts of Pechora Sea are divided by ostracode analysis into three main horizons, which are characterized by similar compositions:

Interval 1 is characterized by a poor ostracode assemblage with *Paracyprideis seudopunctillata.*

Interval 2 contains an assemblage with *Cyteropteron* and *Sarsicyteridea bradii.* (shallow-marine with small influence of fresh waters, relatively warm-water conditions).

Interval 3 contains an assemblage with *Rabilimis septentrionalis* (shallow water conditions).

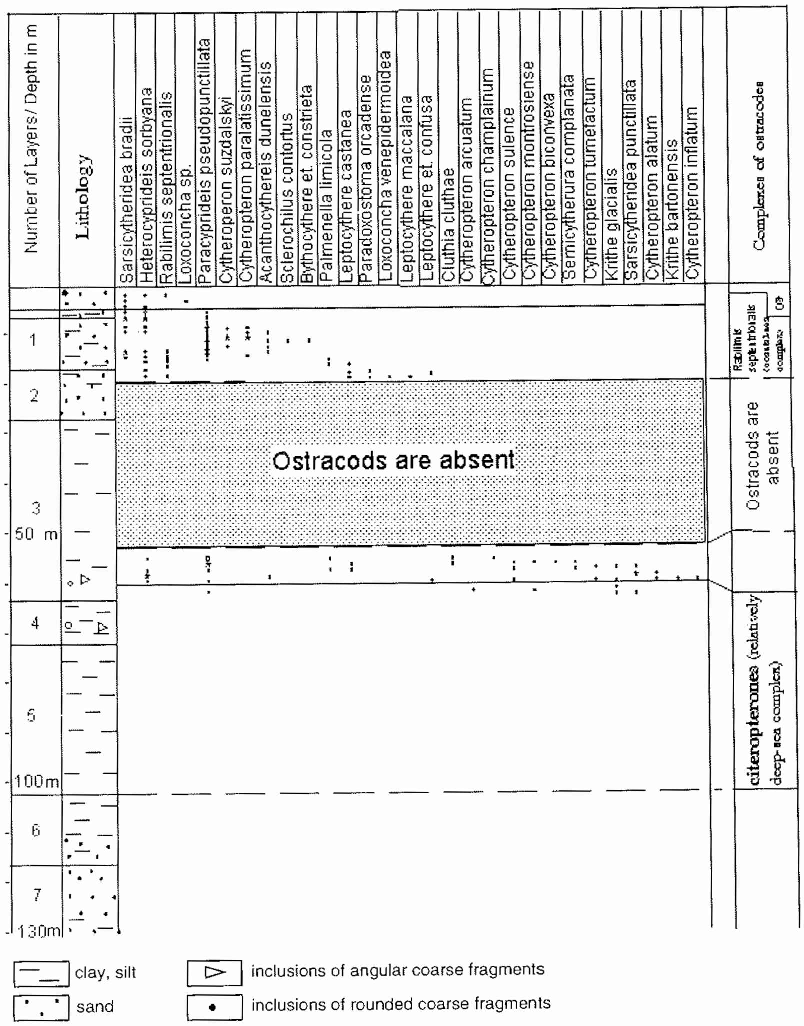

Fig. 3: Biostratigraphic dismemberment and correlation of Late Cenozoic ostracods in well 212 (Pechora sea, Prirazlomnay area, recovery 74.0 m).

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Plate 1

1 *Rabilimis septentrionalis* (Brady, 1866) - Well 117, 10.5 m, left valve, 36 x.

2 *Rabilimis mirabilis* (Brady, 1868) - Well 117, 58.5 m, right valve, 36 x.

3 *Heterocyprideis sorbyana* (Jones, 1856) - Well 212, 7.5 m, right valve, 40 x.

4 *Heterocyprideis fascis* (Brady et Norman, 1889) - Well 117, 54.5 m, right valve, 44 x.

5 *Paracyprideis pseudopunctillata* (Swain, 1963) - Well 117, 46,0 m, left valve, 48 x.

6 *Paracyprideis pseudopunctillata* (Swain, 1963) - Well 117, 46,0 m, right valve, 48 x.

7 *Sarsicytheridea punctillata* (Brady, 1865) - Well 117, 46,0 m, left valve, 42 x.

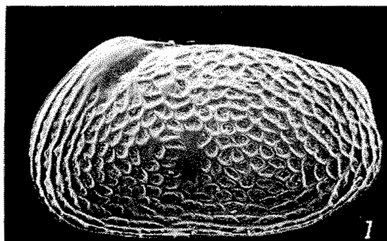
8 *Bythocythere bicristata* (Brady et Norman, 1889) - Well 212, 10.4 m, left valve, 56 x.

9 *Krithe bartonensis* (Jones, 1856) - Well 117, 58.5 m, left valve, 42 x.

10 *Krithe glacialis* (Brady, Crosskey et Robertson, 1874) - Well 117, 58.5 m, right valve, 42 x.

11 *Palmenella limicola* (Norman, 1865) - Well 210, 54.8 m, left valve, 64 x.

12 *Acantocythereis dunelmensis* (Norman, 1865) - Well 210, 54.8 m, right valve, 44 x.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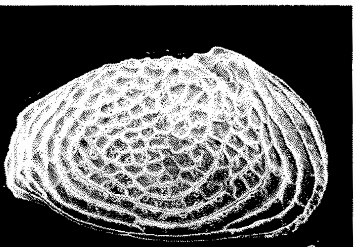
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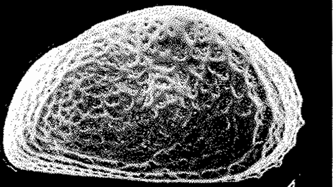
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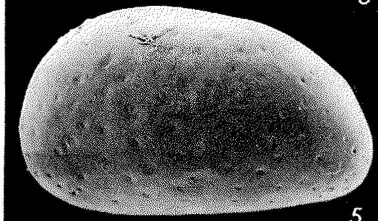
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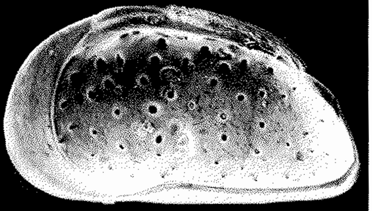
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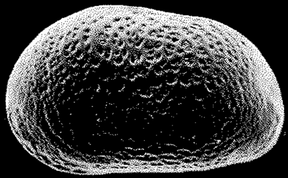
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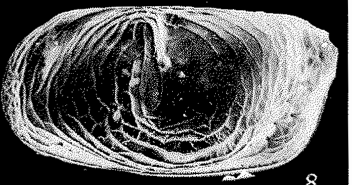
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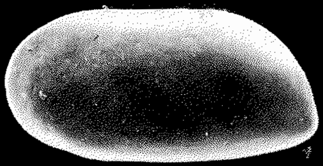
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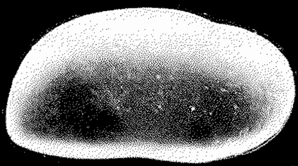
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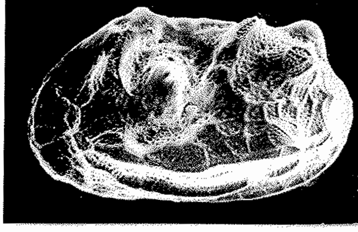
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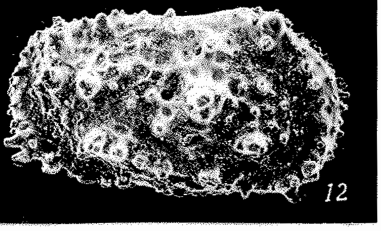
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Plate 2

1 *Cytheropteron alatum* (Sars, 1865) - Well 212, 58.2 m, left valve, 36 x.

2 *Cytheropteron champlainum* (Cronin, 1981) - Well 117, 34.0 m, right valve, 65 x.

3 *Cytheropteron montrosiense* (Brady, Crosskey et Robertson, 1874) - Well 117, 41.0 m, left valve, 54 x.

4 *Cytheropteron suzdalskyi* (Lev, 1972) - Well 212, 12.0 m, right valve, 64 x.

5 *Cytheropteron biconvexa* (Whatley et Masson, 1979) - Well 212, 56.5 m, left valve, 58 x.

6 *Cytheropteron tumefactum* (Lev, 1972) - Well 212, 57.0 m, right valve, 64 x.

7 *Cytheropteron punctatum* (Brady, 1868) - Well 210, 61.8 m, right valve, 64 x.

8 *Cytheropteron pseudomontrosiense* (Whatley et Masson, 1979) - Well 212, 56.5 m, right valve, 62 x.

9 *Cytheropteron paralatissimum* (Swain, 1963) - Well 212, 9.9 m, right valve, 58 m.

10 *Cytheropteron arcuatum* (Brady, Crosskey et Robertson, 1874) - Well 117, 35.5 m, right valve, 62 x.

11 *Semicytherura complanata* (Brady, Crosskey et Robertson, 1874) - Well 212, 57.0 m, right valve, 62 x.

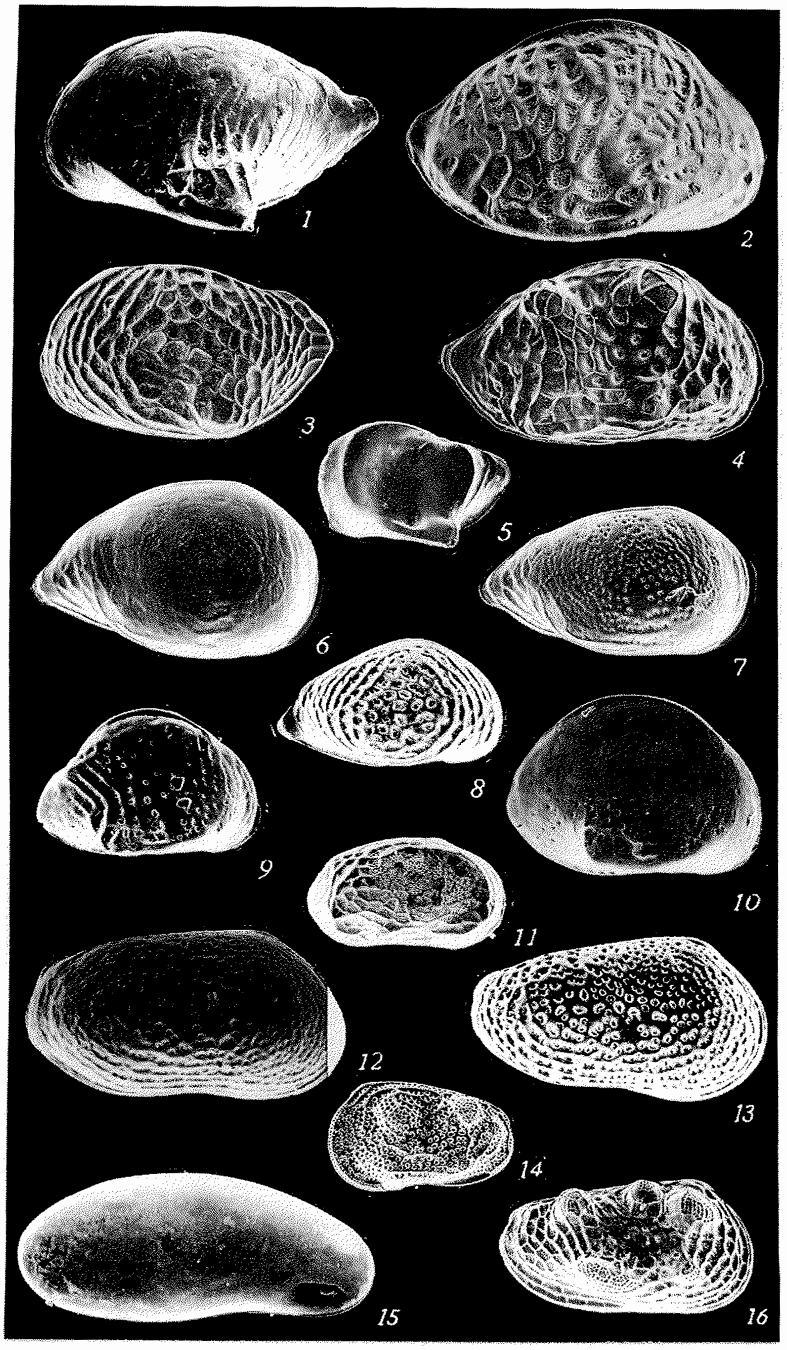
12 *Leptocythere macalla* (Brady et Robertson, 1869) - Well 212, 17.8 m, right valve, 60 x.

13 *Leptocythere castanea* (Sars, 1865) - Well 210, 58.0 m, right valve, 64 x.

14 *Cluthia cluthae* (Brady, Crosskey et Robertson, 1874) - Well 212, 56.5 m, right valve, 59 x.

15 *Sclerochilus contortus* (Norman, 1862) - Well 117, 43.0 m, left valve, 64 x.

16 *Roundstonia globulifera* (Brady, 1868) - Well 210, 58.0 m, right valve, 59 x.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Annex 1

Ostracodes in sediments from well 117

P-1: Relation to salinity (marine: m, brackish water: b);
P-2: Relation to depth (vertical distribution): Phytals (Ph),
Benthos - a) sublittoral (Sb; upper sublittoral: Sb1; lower sublittoral: Sb2), deep-water (H);
P-3: Biogeographical range - Arctic (A), Arcto-boreal (A-B), Boreal-Arctic (B-A), Boreal (B).

				Sample numbers										
Species name	P-1	P-2	P-3	1	2	3	4	5	6	7	8	9	10	11
Acanthocythereis dunelmensis, Norman,1865	m	sb1	ab											
Cluthia cluthae, Brady, Crosskey et Rob., 1874	m	sb1	ab											
Cytheropteron alatum Sars, 1865	m	sb1	ab											
Cytheropteron arcuatum Brady, Crosskey et Rob., 1874	m	sb1	ab											
Cytheropteron champlainum Cronin,1981	m	sb1	ba											
Cytheropteron inflatum, Brady, Crosskey et Rob., 1874	m	sb1	ba											
Cytheropteron montrosiense,Brady, Crosskey et Rob., 1874	m	sb1	a										1	
Cytheropteron punctatum, Brady, 1868	m	sb1	ab											
Cytheropteron subcircinatum, Sars, 1865	m	sb1	ba											
Cytheropteron sulense, Lev, 1983	m	sb1	ab											
Cytheropteron suzdalskyi, Lev, 1972	m	sb1	ab											
Cytheropteron tumefactum, Lev, 1972	m	sb1	a											
Heterocyprideis fascis, Brady, Norman, 1889	m	sb1	a											
Heterocyprideis sorbyana, Jones, 1856	m	sb1	ab		2			1	1					
Krithe glacialis, Brady, Crosskey et Rob., 1874	m	sb1,h	a											1
Leptocythere castanea, Sars, 1865	b	sb1	ab								2			
Paracyprideis pseudopunctill., Swain, 1963	m	sb1	ab											
Rabilimis mirabilis, Brady, 1868	m	sb1	a											
Rabilimis septentrionalis, Brady, 1866	m	sb1	a		3	3	1	1	1	1				
Sarsicytheridea bradii, Norman, 1865	m	sb1,h	ab	3			1	1	1			1		
Sarsicytheridea macrolaminata, Elofson, 1939	m	sb1	ab		1	2								
Sarsicytheridea punctillata, Brady, 1865	m	sb1, h	ab					1	1					
Semicytherura complanata, Brady, Crosskey et Rob., 1874	m	ph	ab											

	Sample numbers																						
Species name	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
A. dunelmensis							2				1			4			1						1
C. cluthae	1		1									2											
C. alatum												2				1							
C. arcuatum		1	2	2								3		1			1						
C. champlainum		1															1						
C. inflatum																1							
C. montrosiense												2			2			1					
C. punctatum												13	1			2					1		
C. subcircinatum																	1						
C. sulense				2					1								1						
C. suzdalskyi																	1						
C. tumefactum							3	1	1	2		1					1					1	
H. fascis																							
H. sorbyana		6			2		5	6	7	2	1	7	5	4	2	7	3			1			
K. glacialis	2					1	2	1		5		2	2	1	3	1	2						
L. castanea		1																					
P. pseudopunctill.	1		2		1																1	2	
R. mirabilis																			1				2
R. septentrionalis																							
S. bradii							2	5	2					2		4	4						
S. macrolaminata																							
S. punctillata		2			2			4	5	2	3	14	5	3	2	1	1	1					
S. complanata				1																			

	Sample numbers																					
Species name	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
A. dunelmensis																						
C. cluthae																						
C. alatum																						
C. arcuatum																						
C. champlainum																						
C. inflatum																						
C. montrosiense																			1			
C. punctatum																						
C. subcircinatum																						
C. sulense																						
C. suzdalskyi																						
C. tumefactum																						
H. fascis													1									
H. sorbyana		1	1				1					3		2	1	2		7	1	2		
K. glacialis						1		1	1						1			1	1	2	3	
L. castanea																						
P. pseudopunctill.	3				2	2	2										1			1		
R. mirabilis		1				1	1		1		1		1					3	2	1		
R. septentrionalis																						
S. bradii																						
S. macrolaminata																						
S. punctillata	3			1						1				1				2		1		
S. complanata																						

Annex 2

Ostracodes in sediments from well 210

P-1: Relation to salinity (marine: m, brackish water: b);
P-2: Relation to depth (vertical distribution): Phytals (Ph),
Benthos - a) sublittoral (Sb; upper sublittoral: Sb1; lower sublittoral: Sb2), deep-water (H);
P-3: Biogeographical range - Arctic (A), Arcto-boreal (A-B), Boreal-Arctic (B-A), Boreal (B).

	P-1	P-2	P-3	Sample numbers				
				1	2	3	4	5
				Depth (m)				
Species name				51.7	53.3	54.0	54.8	58.0
Acanthocythereis dunelmensis, Norman,1865	m	sb, h	ab				5	1
Cluthia cluthae, Brady, Crosskey et Rob., 1874	m	sb1, ab				2		1
Cytheropteron alatum, Sars, 1865	m	sb1, ab	ab					
Cytheropteron arcuatum, Brady, Crosskey et Rob., 1874	m	sb1, ab	ab					
Cytheropteron inflatum, Brady, Crosskey et Rob., 1874	m	sb1, ab	ba					
Cytheropteron montrosiense, Brady, Crosskey et Rob., 1874	m	sb1, ab	a			1	2	
Cytheropteron punctatum, Brady, 1868	m	sb1, ab	ab		1			1
Cytheropteron sedovi, Schneider, 1868	m	sb1, ab	ab					
Cytheropteron sulense, Lev, 1983	m	sb1, ab		1		11	1	10
Cytheropteron tumefactum, Lev, 1972	m	sb1, ab	a	1				2
Heterocyprideis sorbyana, Jones, 1856	m	sb	ab			21	5	13
Krithe bartonensis, Jones, 1875	m	sn, h	ba					
Leptocythere castanea, Sars, 1865	b	sb1, ab	ab			4		3
Palmenella limicola, Norman, 1865	m	sb1, ab	a			3	3	9
Paracyprideis pseudopunctill., Swain, 1963	m	sb1, ab	a	7		15	19	39
Roundstonia globulifera, Brády, 1868	m	sb1, ab	ab					1
Sarsicytheridea punctillata, Brady, 1865	m	sb, h	ab					
Semicytherura complanata, Brady, Crosskey et Rob., 1874	m	ph	ba			2		3

	Sample numbers							
	6	7	8	9	10	11	12	13
	Depth (m)							
	59.0	61.8	62.1	62.6	90.0	95.0	97.0	99.0
A. dunelmensis		7	1					
C. cluthae	2							
C. alatum		2						
C. arcuatum				1		1		1
C. inflatum	1							
C. montrosiense	4	3						
C. punctatum		2						1
C. sedovi	1							
C. sulense	1	4						
C. tumefactum								
H. sorbyana		4				1	1	1
K. bartonensis	2		1					1
L. castanea							1	
P. limicola	2							
P. pseudopunctill.		1			1		2	2
R. globulifera								
S. punctillata		3	1	2		2	1	1
S. complanata								

Annex 3

Ostracodes in sediments from well 212

P-1: Relation to salinity (marine: m, brackish water: b);
P-2: Relation to depth (vertical distribution): Phytals (Ph),
Benthos - a) sublittoral (Sb; upper sublittoral: Sb1; lower sublittoral: Sb2), deep-water (H);
P-3: Biogeographical range - Arctic (A), Arcto-boreal (A-B), Boreal-Arctic (B-A), Boreal (B).

				Sample numbers							
	P-1	P-2	P-3	1	2	3	4	5	6	7	8
				Depth (m)							
Species name				2.8	3.2	4.6	5.3	5.5	6.3	6.5	7.0
Acanthocythereis dunelmensis, Norman,1865	m	sb, h	ab								
Bythocythere constricta, Sars, 1865	m	sb1	ab								
Cluthia cluthae, Brady, Crosskeyet Rob., 1874	m	sb1	ab								
Cytheretta teshekpukensis, Swain, 1963	m	sb1	a								
Cytheropteron alatum, Sars, 1865	m	sb1	ab								
Cytheropteron arcuatum, Brady, Crosskeyet Rob., 1874	m	sb1	ab								
Cytheropteron biconvexa, Whatey, Masson, 1979	m	sb1	ab								
Cytheropteron champlainum, Swain, 1963, Cronin,1981	m	sb1	ba								
Cytheropteron montrosiense, Brady, Crosskeyet Rob., 1874	m	sb1	a								
Cytheropteron paralatissimum	m	sb1	ab								
Cytheropteron sulense, Lev, 1983	m	sb1	ab								
Cytheropteron suzdalskyi, Lev, 1972	m	sb1	ab								
Cytheropteron tumefactum, Lev, 1972	m	sb1	a								
Heterocyprideis sorbyana, Jones, 1856	m	sb	ab	1		2	14	4	9	4	3
Krithe glacialis, Brady, Crosskeyet Rob., 1874	m	sb, h	a								
Leptocythere castanea, Sars, 1865	b	sb1	ab								
Leptocythere confusa, Brady, Norman, 1889	b	sb1	ab								
Leptocythere macallana, Brady, Crosskeyet Rob., 1874	b	sb1	ab								
Loxoconcha venepidermoidea, Swain, 1963	m	sb1	ab								
Loxoconcha sp.	m	sb1	ab		1						
Palmenella limicola, Norman, 1865	m	sb1	a								
Paracyprideis pseudopunctill. Swain, 1963	m	sb1	ab				3		1		5
Paradoxostoma orcadense	b	sb1	ab								
Rabilimis septentrionalis, Brady, 1866	m	sb1	a	1							
Sarsicytheridea bradii, Norman, 1865	m	sb, h	ab	1	4	1	4	5	2	1	
Sclerochilus contortus, Norman, 1862	m	ph	ba								
Semicytherura complanata, Brady, Crosskeyet Rob., 1874	m	ph	ba								

	Sample numbers																
	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Depth (m)																
Species name	7.5	8.2	9.4	9.9	10.4	10.9	11.5	12.0	12.2	12.4	13.3	13.8	14.5	14.8	15.1	15.6	16.2
A. dunelmensis				31	4			1		1	1						
B. constricta					3												
C. *cluthae*																	
C. teshekpukensis																	
C. alatum																	
C. arcuatum																	
C. biconvexa																	
C. champlainum																	
C. montrosiense																	
C. paralatissimum		1	1	6	1	1					3	3					
C. sulense																	
C. suzdalskyi		1		6				1									
C. tumefactum																	
H. sorbyana	3	1					6					1	2	1	4	2	1
K. glacialis																	
L. castanea															1		1
L. confusa																	
L. macallana																	
L. venepidermoidea																1	1
Loxoconcha sp.																	
P. limicola													1		1		
P. pseudopunctill.	4	5	1	34	8			14	2	7		6	2				
P. orcadense																1	
R. septentrionalis												1	1	1	1		
S. bradii	1	4										6	11	7			
S. contortus					1												
S. complanata																	

	Sample numbers															
	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
	Depth (m)															
Species name	16.8	17.3	17.8	55.0	56.0	56.5	57.0	57.8	58.2	58.5	59.0	59.5	60.0	60.5	63.6	66.5
A. dunelmensis									2							
B. constricta																
C. cluthae				1	4	1										
C. teshekpukensis																
C. alatum									1			1				
C. arcuatum				1											1	
C. biconvexa					1											
C. champlainum				1												
C. *montrosiense*					1										1	
C. paralatissimum																
C. sulense					10		2			1		1				
C. suzdalskyi																
C. tumefactum							1					3				
H. sorbyana			2	15				1	5	3		1				
K. glacialis							1	1	4	1		1	1	1		
L. castanea	1		2		2		1									
L. confusa	1									1						
L. macallana			1													
L. venepidermoidea																
Loxoconcha sp.																
P. limicola				4			1									
P. pseudopunctill.		1		33	6	5	2				4	2		1		1
P. orcadense			1													
R. septentrionalis			1													
S. bradii																
S. *contortus*																
S. complanata					2		2				1					

Annex 4

Ostracodes in sediments from well 218.

P-1: Relation to salinity (marine: m, brackish water: b);
P-2: Relation to depth (vertical distribution): Phytals (Ph),
Benthos - a) sublittoral (Sb; upper sublittoral: Sb1; lower sublittoral: Sb2), deep-water (H);
P-3: Biogeographical range - Arctic (A), Arcto-boreal (A-B), Boreal-Arctic (B-A), Boreal (B).

				Sample numbers									
	P-1	P-2	P-3	1	2	3	4	5	6	7	8	9	10
				Depth (m)									
Species name				0.6	1.2	2.3	2.8	3.4	3.7	4.0	62.4	62.6	66.6
Acanthocythereis dunelmensis	m	sb, h	ab										
Bythocythere constricta	m	sb1	ab										
Cluthia cluthae	m	sb1	ab										
Cytheretta teshekpukensis	m	sb1	a	1									
Cytheropteron alatum	m	sb1	ab								1		
Cytheropteron arcuatum	m	sb1	ab										
Cytheropteron biconvexa	m	sb1	ab										
Cytheropteron champlainum	m	sb1	ba										
Cytheropteron montrosiense	m	sb1	a										
Cytheropteron paralatissimum	m	sb1	ab										
Cytheropteron sulense	m	sb1	ab								1		
Cytheropteron suzdalskyi	m	sb1	ab										
Cytheropteron tumefactum	m	sb1	a										
Heterocyprideis sorbyana	m	sb	ab				1	2	10	3			
Krithe glacialis	m	sb, h	a										
Leptocythere castanea	b	sb1	ab										
Leptocythere confusa	b	sb1	ab										
Leptocythere macallana	b	sb1	ab										
Loxoconcha venepidermoidea	m	sb1	ab										
Loxoconcha sp.	m	sb1	ab										
Palmenella limicola	m	sb1	a										
Paracyprideis pseudopunctill.	m	sb1	ab									1	1
Paradoxostoma orcadense	b	sb1	ab										
Rabilimis septentrionalis	m	sb1	a					3	2				
Sarsicytheridea bradii	m	sb, h	ab	1	2	2		9	5				
Sclerochilus contortus	m	ph	ba										
Semicytherura complanata	m	ph	ba										

DIATOM DISTRIBUTION IN SURFACE SEDIMENTS OF THE ST. ANNA TROUGH (KARA SEA, ARCTIC)

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Abstract

20 samples from surface sediments of the St. Anna Trough and adjacent regions served as the basis of this study. 91 recent species (29 genera) were identified, of which 30 belong to the class *Centrophyceae* and 61 belong to the class *Pennatophyceae*. Besides that 17 reworked Paleogene species were found. True marine planktic diatom species constitute 92-98% of all specimens in the surface sediments. The biogeographical composition of the thanatocoenoses corresponds to biocoenoses inhabiting the water masses of the Arctic seas. Arctoboreal and bipolar planktic and kryopelagic species, reflecting the low temperatures and the ice-covered character of the water masses prevail: *Melosira arctica*, *Fragilariopsis oceanica*, *Poroira glacialis*, *Thalassiosira gravida*, *T. antarctica* (spores), *T. kryophila*, *T. hyalina*, *T. nordenskioldii*. Warm-water species are absent in the sediments, as Atlantic waters have significantly cooled before they enter the St.. Anna Trough.

Introduction

The St. Anna Trough is a subbathyal depression with depths down to 620 m, separating the northern Kara Sea and Barents Sea shelves (Figure 1). The hydrological regime (Rudels et al., 1994) of the northern Kara Sea is controlled by the inflow of several water masses into the St. Anna Trough area. Atlantic waters derived from the North Atlantic Drift flow across the Barents Sea, further along the St. Anna Trough, and finally enter the intermediate waters of the Arctic Ocean. Another branch of Atlantic water, turning east around northern Svalbard and sinking below the low-salinity surface layer while flowing along the Barents Sea continental margin, reaches the St. Anna Trough from the North at depths of 100-450 m. Another important water mass is constituted from freshwater transported mainly by the large Siberian rivers Ob and Yenisei. According to data obtained during cruise 9 of RV "Professor Logachev" in 1994, the upper water layer in the central and southern St. Anna Trough has temperature between 1-2.4°C, while in the North and Northeast they vary from -0.1 to -1.2°C (Ivanov et al, 1995).

The surface watersalinity shows a significant freshening due to summer melting of sea ice. In summer 1994, the salinity changed between a minimum of 30.00‰ and a maximum of 33.75‰.

Materials and Methods

Diatoms were studied in 20 samples of surface sediments collected during cruise 9 (1994) of RV "Professor Logachev" and (1992) ìGeolog Fersmanî in the St. Anna Trough and adjacent regions from stations with water depths of 100-605 m (Fig. 1). The treatment of diatom valves was carried out only slightly changed according to the method described by Schrader and Gersonde (1978). Dried and weighed sediment (15-20 g) was boiled first with H_2O_2 (30%), then with HCl (30%) and then rinsed with distilled water. The sediment was cleaned of clay by washing out 5-6 times with $Na_3PO_4 * 12H_2O$ (5%). To extract the diatom frustules, the sediment was treated by heavy liquid (2.6 g/cm^3) according to the method described in "The diatoms of the USSR" (Glejzer et al., 1974). The counting of diatoms per 1 gram of dry sediment was done according to a formula proposed by Kvasov and Jakovshikova (1971):

$K= b * n * y / a * m * x$
where
b = dilution in ml
n = the number of rows in a slide
y = the number of counted frustules
a = weight of sediment in grams
m = the volume of a drop (0.02-0.03 ml)
x = the number of analyzed rows.

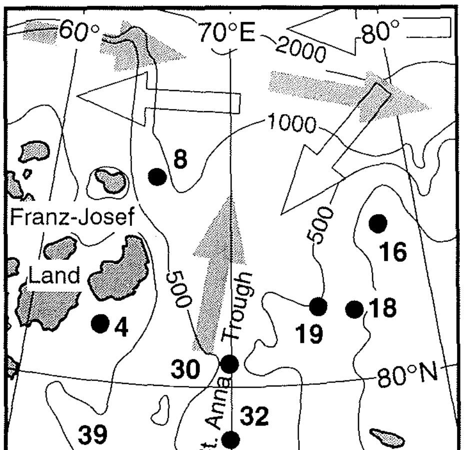

Fig. 1: Core locations and currents in the St. Anna Trough area. Bathymetry is given in meters below sea level. White arrows mark the flow direction of low saline Arctic surface water; gray arrows mark the flow of Atlantic water (submerged north of 80°N). Figure taken from Djinoridze et al. (in press).

Results and Discussion

Bottom sediments of the northern part of the Kara Sea contain relatively low amounts of diatoms. The number ranges from 10 to 750 frustules per gram of dry sediment. Silty pelite sands from stations 4, 16, 19, and 30 contain rich assemblages of recent diatoms with a slight admixture of Paleogene species. Silty pelites from cores 33, 34, 35 have a poor composition of recent and Paleogene diatoms and in cores 8, 18, 32, 37, 39, 50 they contain only reworked Paleogene species. 93 recent species and varieties (29 genera) and 17 reworked species (9 genera) were identified. Among the "recent" diatoms, 30 taxons belong to the class *Centrophyceae* and 63 taxons belong to the class *Pennatophyceae*.

The representatives of phytoplankton are mainly centric species such as: *Thalassiosira gravida* Cl. and *Th. antarctica* Comber (16-25%), *Th. nordenskioldii* Cl (10-16%) , *Th. kryophila* (Grun.) Iorg. (16%), *Th. hyalina* (Grun.) Gran. (1-8%), *Porosira glacialis* (Grun.) Iorg.(20%) and *Coscinodiscus oculus-iridis* Ehr.(10-11%). The second group, present in lower amounts, is a group of kryopelagic and kryointersticial species, dwelling on lower and marginal sea ice surfaces: *Melosira arctica* Dickie (2-4%) , *Fragilariopsis oceanica* (Cl.) Hasle (2-12%) , *F. cylindrus* (Grun.) Hasle (>1%), *Nitzschia frigida* Grun. (2%), *N. polaris* Grun. (>1%), *Navicula cancelata* var. *gregori* Ralfs (2%), *Nav. directa* W. Sm. (1%), *Nav. reinhardtii* var. *tschuktschorum* Grun. (4%). Species of the genera *Thalassiosira* (9 taxons) , *Navicula* (11 taxons), *Diploneis* (10 taxons) and *Nitzschia* (10 taxons) are the most numerous. Microscopical photos of important species are given in plates 1 and 2.

All species found in sediments from the St. Anna Trough have been found previously already in the Kara Sea and are enclosed in the list of Kara Sea diatoms (148 species and varieties) compiled by Makarevich and Koltsova (1989) from own investigations and literature data (Zabelina, 1930, 1946; Kiselev, 1935; Usachev, 1938, 1949, 1968). Observations of ice diatoms the deep Arctic Basin (Horner, 1982; Abelmann, 1992) showed that the bloom near the ice margin mainly consists of pennatic diatoms, whereas the bloom of phytoplankton in ice-free areas is dominated by centric diatoms. *Fragilariopsis oceanica* and *F. cylindrus* are abundant in both habitats. In spring plankton, the most abundant species are *Thalassiosira gravida*, *Th. nordenskioldii*, *Fragilariopsis oceanica* and *Porosira glacialis* (Usachev,1968; Grant and Horner, 1976). All these species are dominant in the assemblage composition in surface sediments of the St. Anna Trough. They are also typical for diatom compositions found in sediments under pack ice (Sancetta, 1982; Williams, 1986).

The true marine diatoms in the described assemblage constitute 92-98% (cf. Fig. 2). Brackishwater euryhaline species, dwelling on sea ice are also present (up to 7%): *Thalassiosira hyperborea* var. *septentrionalis* (Grun.) Hasle, *Achnanthes taeniata* Grun., *A. brevipes* Ag., *Diploneis interrupta* (Ktz.) Cl., *D. stroemii* Hust., *D. smithii* (Breb.) Cl. et var., *Nitzschia hybrida* var. *kryokonites* Cl., *Amphora laevis* var. *laevissima* (Greg.) Cl., and *Navicula kjellmanii* Cl.. Freshwater species such as *Aulocosira islandica* subsp.

helvetica (O. Mull.) Simonsen, *A. granulata* (Ehr.) Simonsen, and *Amphora ovalis* Ktz. contribute up to 3% to the sediment assemblage.

The existence of brackishwater species may be explained by a freshening effect of melting sea ice. The salinity in a thin layer below the sea ice can be strongly variable from 15 to 29‰ (Melnikov, 1989). This fact may allow algae with different salinity tolerances to exist below sea ice. In 1994 during cruise 9 of RV "Professor Logachev" the surface water salinity at some stations had decreased to 13-16‰, probably from increased atmospheric precipitation. The presence of freshwater diatoms in the assemblages allows to suggest that they had lived in sea ice, which was formed in a proximal freshwater-dominated environment and then drifted to the open sea. A current transport from the southern Kara Sea to the St. Anna Trough seems rather unlikely.

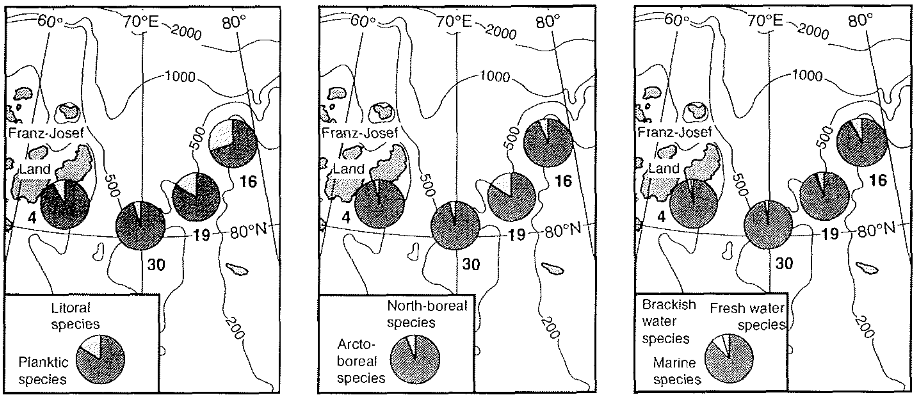

Fig. 2: Diatom species composition of surface samples from stations 4, 16, 19, and 30 according to habitat (left), biogeography (center), and facies types (right). Figure taken from Djinoridze et al. (in press).

In sediments from the majority of stations, the frustules of planktic, mostly neritic species are prevailing (92-98%; Fig. 2). Panthalassic species constitute up to 12% (*Coscinodiscus oculus-iridis*, *C. curvatulus* var. *kariana*, *Actinocyclus curvatulus*). In samples from stations with a water depth of about 100 m, the littoral species constitute up to 30%. This may be explained by a mechanism of ice flora forming on the account of planktic and benthic species (Melnikov, 1989). In shallow waters the species distribution and quantitative composition of ice algae is dominated by benthic species, whereas in deep sea regions it is dominated by planktic species.

In general, the composition of thanatocoenoses in the analyzed sediments corresponds to the biogeography of biocoenoses inhabiting the water masses of Arctic shelves. Bipolar and arctoboreal diatoms constitute 83-97% (Figure 2). In this region the temperatures of the surface waters reach 0-1°C in summer and sink to -1.8°C in winter.

The diatom assemblage of analogous species composition was established by Koc Karpuz and Schrader (1990) in surface sediments of the Nordic Seas by factor analysis. They called it "sea-ice assemblage" (Factor 3) and it is confined to the maximum ice expansion in the Norwegian and Greenland seas.

The structure of the diatom assemblage in surface sediments from the St. Anna Trough is similar to the structure of the thanatocoenosis found in the northern regions of the Barents Sea (Djinoridze,1986). We propose that this is a consequence of the strong water exchange between these basins and the very similar hydrological characteristics of the predominant water masses.

Some differences are traced in the structure of thanatocoenoses in the St. Anna Trough (Fig.2). In sediments of the western part, arctoboreal, bipolar planktic and kryopelagic species are more abundant. In sediments of the eastern part, bordering on shoal water, the littoral species are present in higher amounts.

The diatom analysis of surface sediments from the St. Anna Trough revealed their low content of diatoms. Only 30% of the studied samples contained representative diatom assemblages (38-60 taxa) in numbers of 100-750 frustules per 1 gram sediment. Only a small part (about 25%) of the known species variety of the planktic diatom flora of the Kara Sea is preserved in sediments. Spores of only 5 out of 34 species of the genus *Chaetoceros*, present in modern plankton, are found in sediments. Spores of *Melosira arctica*, *Porosira glacialis*, *Thalassiosira gravida* and *T. antarctica* have the highest amount in sediments. The low amount of diatoms in sediments of the St. Anna Trough is a result of the unfavourable conditions for accumulation, promoting the dissolution of valves during their precipitation: the deficite of silicious acid, the density stratification of the waters, and the strong bottom currents. The small number of diatoms in the thanatocoenoses of the Kara Sea was also noted by Polyakova (1997).

The occurrence of reworked Paleogene and Cretaceous species throughout the sediments is a peculiarity of the diatom thanatocoenoses of surface sediments in the St. Anna Trough. In sediments from stations 149, 152, 154, 155 reworked species occur only sporadically. At stations situated north of 80°N the reworked species constitute 2-11% (Figure 2). At stations situated south of 80°N the number of reworked species increases up to 40-56%. They are represented most variously at station 159 near Novaya Zemlya (17 taxa). The reworked Cretaceous and Paleogene diatoms were already found by A. Grunow (1884) near Franz Josef Land. The fossil diatoms are always present in sediments of the north-western Barents Sea region, and strait connecting the Barents Sea with the Kara Sea, and also in the Kara Sea itself (Djinoridze, 1978; Polyakova, 1977).

The quantitative distribution of reworked diatoms at the investigated stations (Figure 2) shows that they appeared in recent sediments in consequence of erosion from underlying deposits and dispersion by currents from the southern regions of the Kara Sea and from Novaya Zemlya.

Acknowledgments

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Plates 1 and 2

Diatoms in surface sediments of the Saint Anna Trough

Plate 1

1 *Melosira arctica* (spore)

2 *Bacterosira fragilis* (spore)

3 *Actinocyclus curvatulus*

4 *Chaetoceros furcellatus* (spore)

5 *Chaetoceros mitra* (spore)

6 *Thalassiosira angulata*

7 *Thalassiosira nordenskioldii*

8 *Thalassiosira latimarginata*

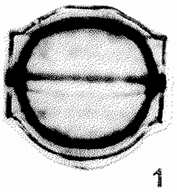
9 *Thalassiosira gravida* (spore)

10 *Thalassiosira gravida*

11 *Thalassiosira anguste-linneata*

12 Thalassiosira hyperborea var. *septentrionalis*

Scale bar = 10 µm



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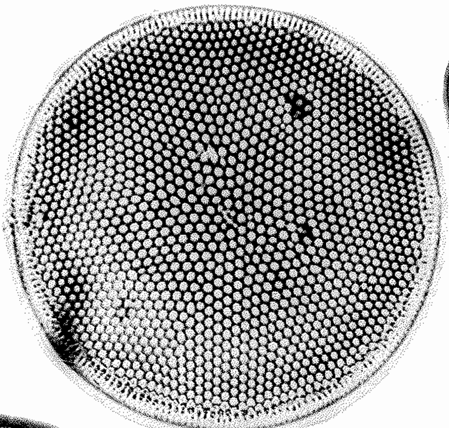

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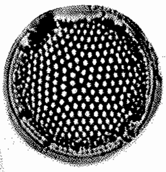

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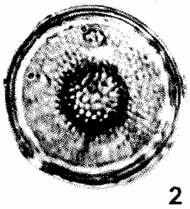

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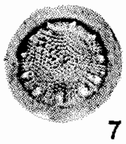

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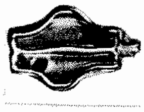

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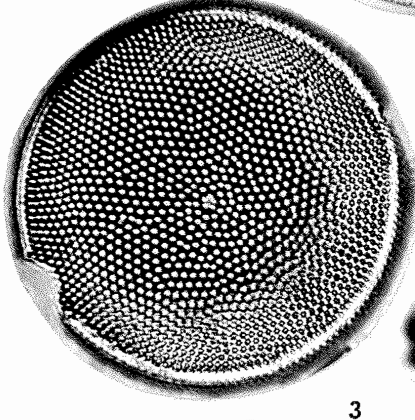

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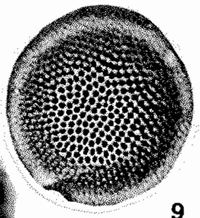

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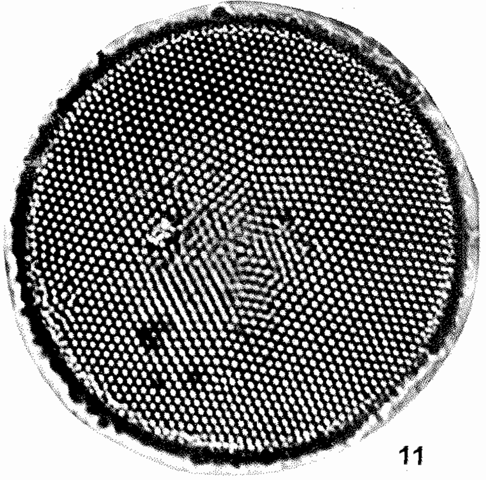

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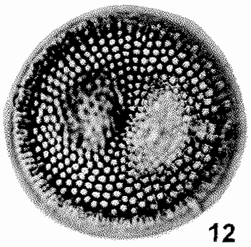

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Plate 2

1 *Porosira glacialis* (spore)

2 *Fragilariopsis oceanica*

3 *Diploneis interrupta*

4 *Diploneis smithii*

5 *Diploneis smithii* var. *rhombica*

6 *Diploneis subcincta*

7 *Grammatophora arcuata*

8 *Grammatophora arcuata* (septae)

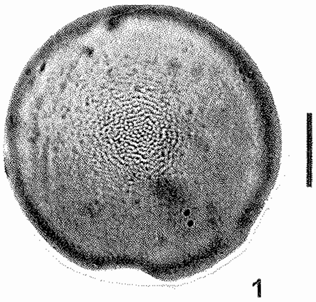
9 *Grammatophora angulosa*

10 *Navicula distans*

11 *Cocconeis costata*

12 *Odontella aurita*

Scale bar = 10 µm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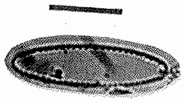
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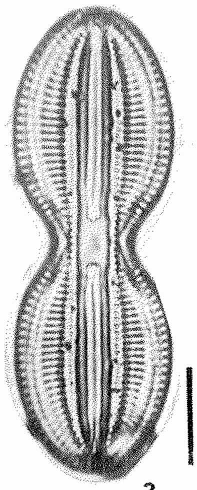
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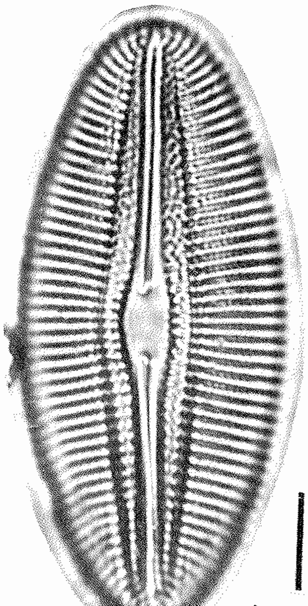
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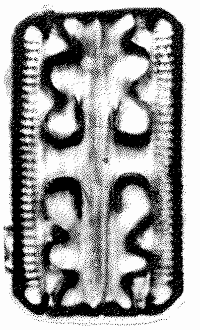
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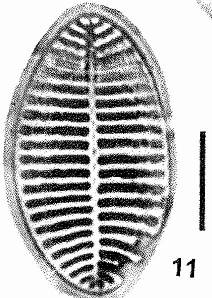
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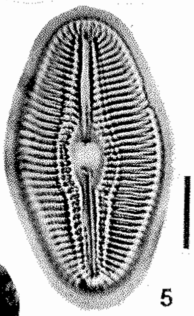
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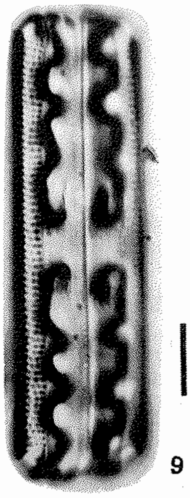
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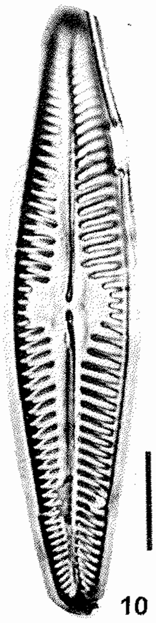
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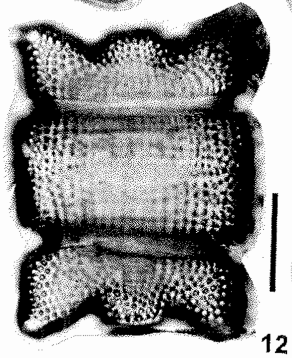
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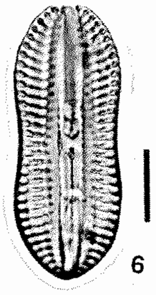
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Appendix 1

Modern diatoms

Facies: m = marine; b = brackishwater; fr = freshwater; e = euryhaline
Habitat: n = neretic; p = panthalassic; l = lithoral;
Biogeography: ar = arctic; ab = arcto-boreal; bp = bipolar; nb = north-boreal; sb = south-boreal;
cp = cosmopolitan; na = north-alpic;

Genus and species name (1)	Secondary species name (2)	Author (1)	Author (2)	Facies	Habitat	Biogeography
Achnanthes arctica			Cl.	m	l	ar
Achnanthes brevipes			Ag.	b	l	cp
Achnanthes septata			A.Cl.	m	l	ab
Achnanthes taeniata		(Cl.)	Grun.	e	n	ar
Actinocyclus curvatulus			Janich	m	p	nb
Amphora eunotia			Cl.	m	l	ab
Amphora laevis	var. laevissima	(Greg.)	Cl.	b	l	ab
Amphora ovalis			Kutz.	fr	l	cp
Amphora proteus			Greg.	m	l	ab
Amphora terroris			Ehr.	m	l	ab
Aulacosira granulata		(Ehr.)	Simonsen	fr	l	cp
Aulacosira islandica	subsp. helvetica	(O.Mull.)	Simonsen	fr	l	cp
Aulacosira italica		(Ehr.)	Kutz.	fr	l	cp
Bacillaria socialis		(Greg.)	Grun.	m	l	cp
Bacterosira fragilis			Gran.	m	n	ab
Campylodiscus thuretii			Breb.	m	l	nb
Chaetoceros debilis			Cl.	m	n	ab
Chaetoceros furcellatus			Bail.	m	n	ab
Chaetoceros karianus			Grun.	m	n	ab
Chaetoceros mitra		(Bail.)	Ralfs	m	n	ab
Chaetoceros diadema		(Ehr.)	Gran	m	n	ab
Cocconeis californica			Grun.	m	l	ab
Cocconeis costata			Greg.	m	l	cp
Cocconeis placentula			Ehr.	fr	l	cp
Cocconeis scutellum			Ehr.	m	l	cp
Coscinodiscus asteromphalus			Ehr.	m	p	sb
Coscinodiscus curvatulus	var. kariana		Cl.et Grun.	m	p	ab
Coscinodiscus marginatus			Ehr.	m	p	nb
Coscinodiscus oculus-iridis			Ehr.	m	p	ab
Diploneis coffaeformis		(A.S.)	Cl.	m	l	nb
Diploneis interrupta		(Kutz.)	Cl.	m	l	ab
Diploneis litoralis		(Donk.)	Cl.	m	l	ab
Diploneis litoralis	var. clathrata	(Ostf.)	Cl.	m	l	ar
Diploneis smithii		(Breb.)	Cl.	b	l	cp
Diploneis smithii	var. borealis		Grun.	b	l	cp
Diploneis smithii	var. rhombica		Mer.	b	l	cp
Diploneis stroemii			Hust.	m	l	nb
Diploneis subcincta		(A.S.)	Cl.	m	l	ab
Diploneis suborbicularis		(Greg.)	Cl.	m	l	nb
Entomoneis hyperborea		(Grun.)	Gran.	m	n	ar
Entomoneis kjellmanii	var. kariana	(Grun.)	Cl.	m	n	ab
Fragilaria lapponica			Grun.	fr	l	cp
Fragilariopsis cylindrus		(Grun.)	Hasle	m	n	ar
Fragilariopsis oceanica		(Cl.)	Hasle	m	n	ar
Gomphonema exguum	var. arctica		Grun.	m	l	ab
Grammatophora angulosa			Ehr.	m	l	ab
Grammatophora arctica			Cl.	m	l	ar
Hantzschia weyprechtii			Grun.	m	l	ab
Lycmophora jurgensii			Ag.	m	l	ab
Melosira arctica			Dickie	m	n	ar
Navicula abrupta			Greg.	m	l	ab
Navicula cancellata			Donk.	m	l	ab
Navicula cancellata	var. gregori		Ralfs	m	l	ab
Navicula directa			W.Sm.	m	l	ab
Navicula distans			W.Sm.	m	l	ab

Genus and species name (1)	Secondary species name (2)	Author (1)	Author (2)	Facies	Habitat	Biogeography
Navicula glacialis			Cl.	m	l	ar
Navicula kariana			Grun.	m	l	ab
Navicula kjelmannii			Cl.	m	l	ab
Navicula palpebralis	var. angulosa		Greg.	m	l	nb
Navicula reichardtii	var. tschuktschorum		Grun.	m	l	ab
Navicula spectabilis			Greg.	m	l	nb
Nitzschia frigida			Grun.	m	n	ar
Nitzschia hybrida			Grun.	b	l	ar
Nitzschia hybrida	var. kryokonites		Cl.	b	l	ab
Nitzschia insignis			Greg.	m	l	nb
Nitzschia insignis	var. arctica		Grun.	m	l	ar
Nitzschia mitcheliana			Grun.	m	l	ab
Nitzschia polaris			Grun.	m	l	ar
Nitzschia seriata			Cl.	m	n	ab
Nitzschia triblionella	var. levidensis	(W.Sm)	Grun.	b	l	cp
Nitzschia triblionella	var. victoriae		Grun.	b	l	ar
Odontella aurita			Ag.	m	n	ab
Pinnularia lata		(Breb.)	W.Sm.	fr	l	na
Pinnularia quadratarea	var. baltica		Grun.	m	l	nb
Pinnularia quadratarea	var. stuxbergii		Cl.	m	l	ab
Porosira glacialis		(Grun.)	Jorg.	m	n	bp
Rhizosolenia hebetata	f. hiemalis		Gran.	m	p	ab
Rhizosolenia setigera	var. arctica		I.Kiss.	m	n	ar
Scoliotropis laterostrata		(Breb.)	Cl.	m	l	ab
Stephanodiscus rotula		(Kutz.)	Hendey	fr	p	cp
Synedra kamtschatica	var. finmarchica		Grun.	m	l	ab
Tetracyclus lacustris			Ralfs	fr	l	na
Thalassiosira angulata		(Greg.)	Hasle	m	n	nb
Thalassiosira anguste-lineata		(A.S)	Frix. et Hasl	m	p	cp
Thalassiosira antarctica			Comber	m	n	bp
Thalassiosira hyperborea		(Grun.)	Hasle	m	n	ab
Thalassiosira gravida			Cl.	m	n	bp
Thalassiosira hyalina		(Greg.)	Grun.	m	n	ab
Thalassiosira kryophila		(Grun.)	Jorg.	m	n	ab
Thalassiosira latimarginata			Makarova	m	n	ab
Thalassiosira nordenskiodii			Cl.	m	n	ab
Thalassiothrix longissima			Grun.	m	n	ab
Trachyneis aspera		(Ehr.)	Cl.	m	l	ab

Appendix 2

Paleogene diatoms

Facies: m = marine
Habitat: n = neretic; p = panthalassic; l = lithoral;
Biogeography: ab = arctoboreal; (r) = resedimented

Genus and species name (1)	**Secondary species name** (2)	**Author** (1)	**Author** (2)	**Facies**	**Habitat**	**Biogeography**
Coscinodiscus payeri			Grun.	m	p	(r)
Costopyxis broschii		(Grun)	Streln. et Nikolaev	m	n	(r)
Costopyxis schulzii		(Stein.)	Gles.	m	n	(r)
Grunowiella gemmata		(Grun.)	V.H.	m	n	(r)
Hemiaulus polymorphus			Grun.	m	l	(r)
Hyalodiscus radiatus		*(O.Meara)*	*Grun.*	m	l	ab
Paralia ornata			Grun.	m	l	(r)
Paralia sulcata	var. biseriata		Grun.	m	l	(r)
Pyxidicula polaris		(Grun.)	Streln. et Nikolaev	m	n	(r)
Pyxidicula turris		(Grev. et Arn.)	Streln. et Nikolaev	m	n	(r)
Pyxilla gracilis			Temp. et Forti	m	n	(r)

SEDIMENTARY ENVIRONMENT IN THE ST. ANNA TROUGH

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Abstract

During a joint Russian-American-Norwegian expedition in August-September 1994, the Association Sevmorgeologia performed multidisciplinary investigations of the St. Anna Trough in the scale 1:1,000,000 in a regular network. The complex character of the investigations consists of a study of all main links of the ecosystem - aerosols, sediment fluxes, suspended matter, water column, bottom sediments, pore waters, and benthic communities. The general aim was to study the modern and Late Quaternary environments. 70 complex stations were visited, of which the northernmost site was at 82°N. Grain-size analysis of 13 subfractions was done at laboratories of VNIIOkeangeologia. The data of hydrophysical measurements (Neil Brown CTD) have allowed to analyze the conditions of the oceanographic field and to determine the character of the geostrophic (density) circulation and the characteristics of water and heat exchange in the St. Anna Trough and in the adjacent area. Our data give evidence for a sediment formation under predominantly deep-sea conditions. Lateral diversity (4 maps of distribution different fractions and grain size integral parameter) correspond well to the circumcontinental zonation, water depths, and water circulation patterns.

Introduction

The Arctic Ocean and its marginal seas are key areas for understanding the global climate system and its variability through time. The water exchange between the Arctic and Atlantic Oceans, for example, is a major driver of the global thermohaline circulation controlling global heat transfer and climate. The permanent Arctic sea ice cover with its strong seasonal variations in the marginal areas has a strong influence on the earth's albedo, the marine ecosystem and oceanic circulation, which are also the major mechanisms affecting the global climate. The Eurasian parts of the Arctic Ocean are surrounded by wide and shallow shelf areas. Input of sediment and water delivery are controlled by the major river systems.

Special attention is paid to the St. Anna Trough for several reasons. First, this area is a large transition zone between the Arctic Ocean and Barents and Kara seas. Second, the Novaya Zemlya and Franz Josef Land (FJL) archipelagos are the largest ice-sheet centers in northern Eurasia today.

Third, this area is the main pathway of the terrigeneous supply from lthe arge Ob and Yenisey rivers. The data allow to reconstruct the oceanic circulation patterns, the river discharge and the influence of the sea-ice transport.

The joint Russian-German research program included detailed sedimentological investigations, e.g., determinations of bulk and clay minerals, heavy minerals as well as grain size distributions, performed on the sediments from the Kara Sea to characterize and quantify the terrigeneous supply and to identify source areas and transport pathways of the terrigeneous matter. Furthermore, stable isotope measurements of planktic foraminifers were performed in collaboration with GEOMAR and the Leibniz Laboratory of Kiel University to investigate the reflection of the water mass distribution in the St. Anna Trough area in the surface sediments. To interpret these stable isotope data, a detailed knowledge of the hydrodynamic system and the sedimentary environment in the area is necessary. An overview of these basic data is given in this report.

Data and methods

Investigations in the St. Anna Trough were performed in a regular network (Ivanov et al., 1995). The complex investigations consisted of a study of all main links of the ecosystem - aerosols, sediment fluxes, suspended matter, water column, bottom sediments and pore waters, and benthic communities (Ivanov et al., 1996).

Hydrophysical measurements were performed by a Neil Brown CTD (Annex 1) with subsequent water sampling for hydrochemical analyses by a 10 l bottle. Whereever possible, it was tried to sample surficial, halocline, Atlantic, and bottom waters. Bottom sediments were recovered by gravity cores 3 or 5 m long and by a box-corer (35x35 cm area recovery). 70 complex stations were carried out (Fig. 1), of which the northernmost site was at 82°N.
Analyses were performed at laboratories of VNIIOkeangeologia in St. Petersburg. Grain-size analysis of 13 subfractions was done according to a standard method described by Petelin (1967) and modernized by Lapina (1977).

Results and discussion

Water circulation

The data of hydrophysical measurements (Fig. 2) have allowed to analyze the oceanographic field conditions and to determine the character of the geostrophic (density) circulation and the characteritsics of the water and heat exchange in the St. Anna Trough and in the adjacent area.
The structure of the calculated field of geostrophic currents represents the combination of water mass transfers of various trends and scales. The largest and highest-velocity flow extends southward above the eastern flank of the trough between 70° and 75°E (Figs. 3 and 4).

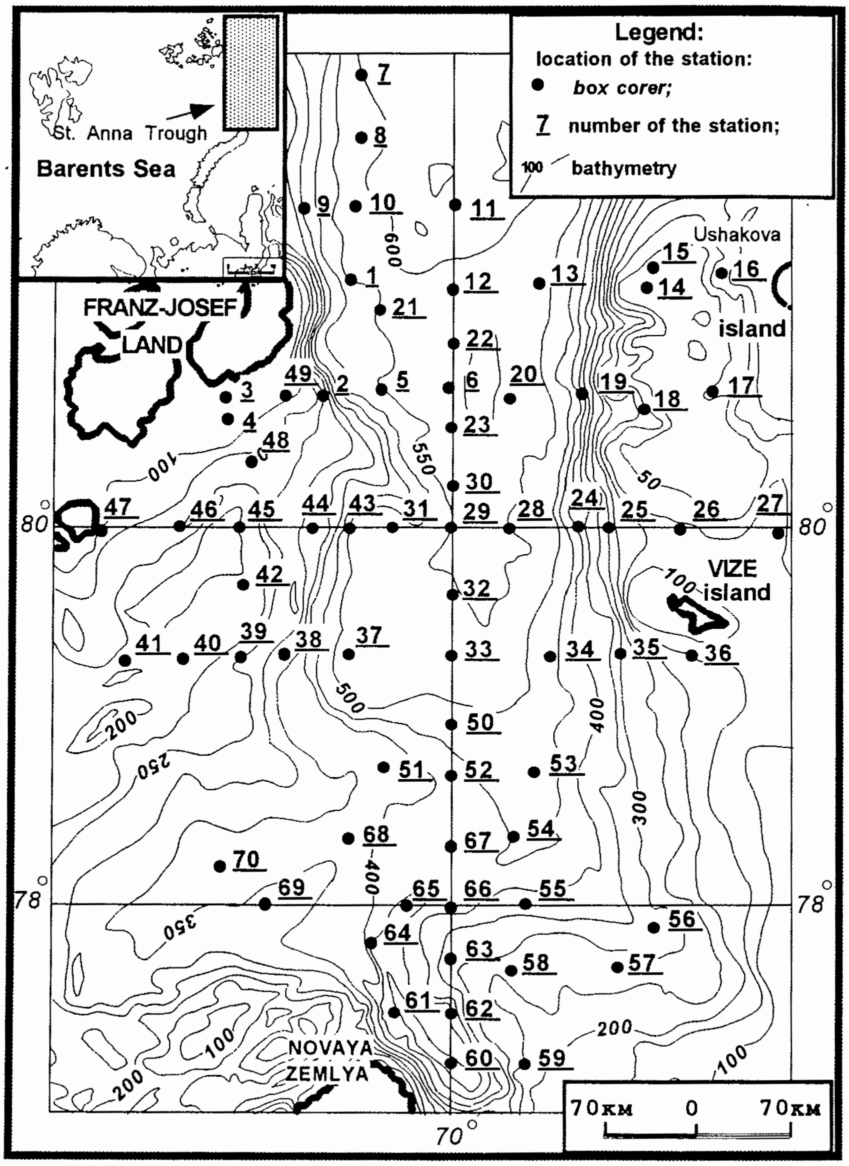

Fig. 1: Location of sampling stations in the St. Anna Trough (RV "Professor Logachev", cruise 9, 1994).

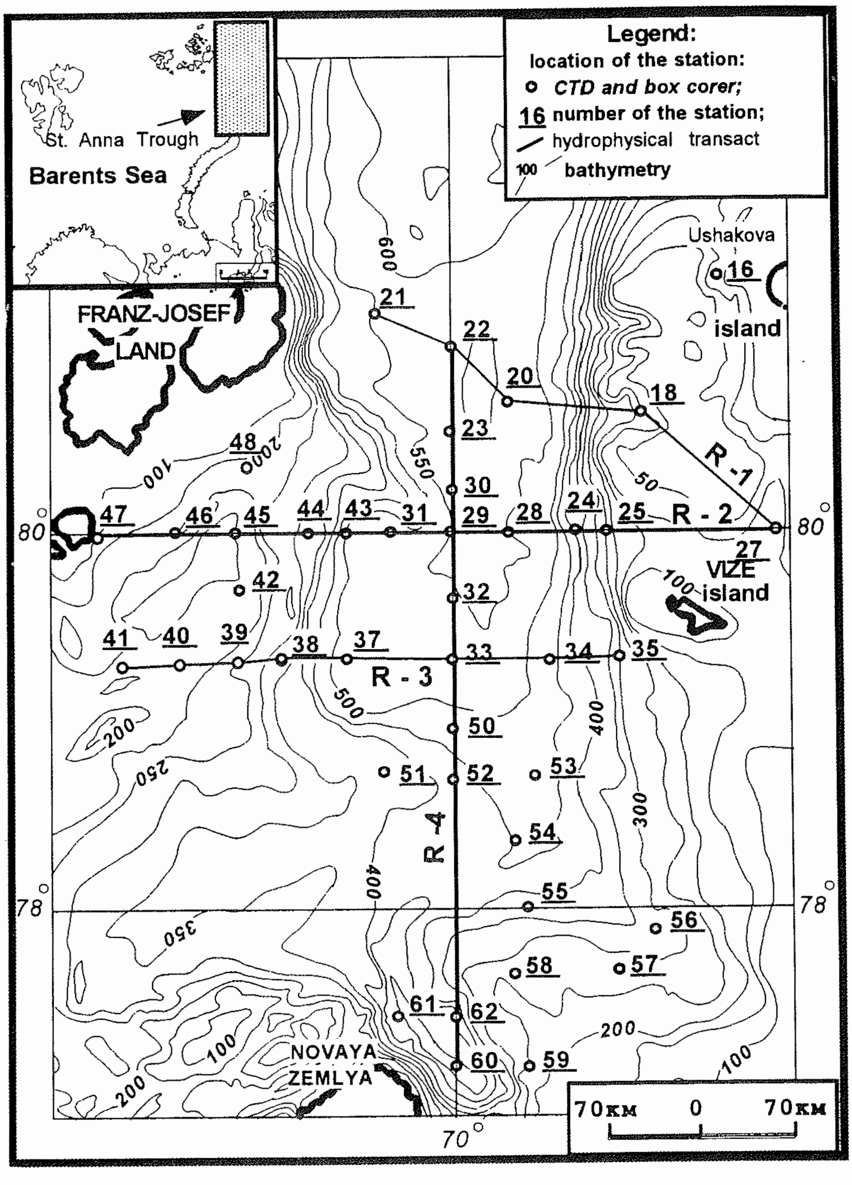

Fig. 2: Location of hydrophysical stations and transects in the St. Anna Trough (RV "Professor Logachev", cruise 9, 1994).

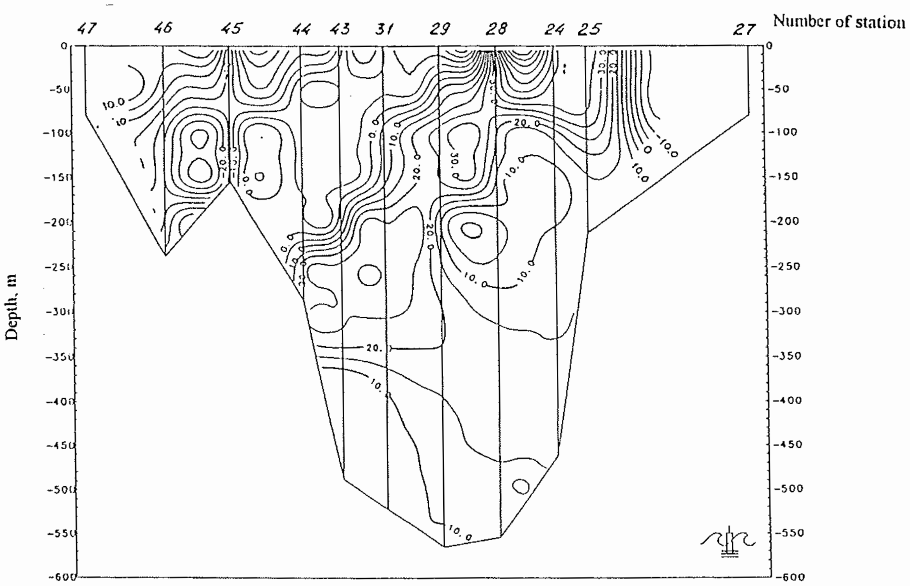

Fig. 3: Vertical distribution of geostrophic currents along transect N2 in the St. Anna Trough (RV "Professor Logachev", cruise 9, 1994). Legend: projection of current speed on the plane of the figure; - into figure, + out of figure.

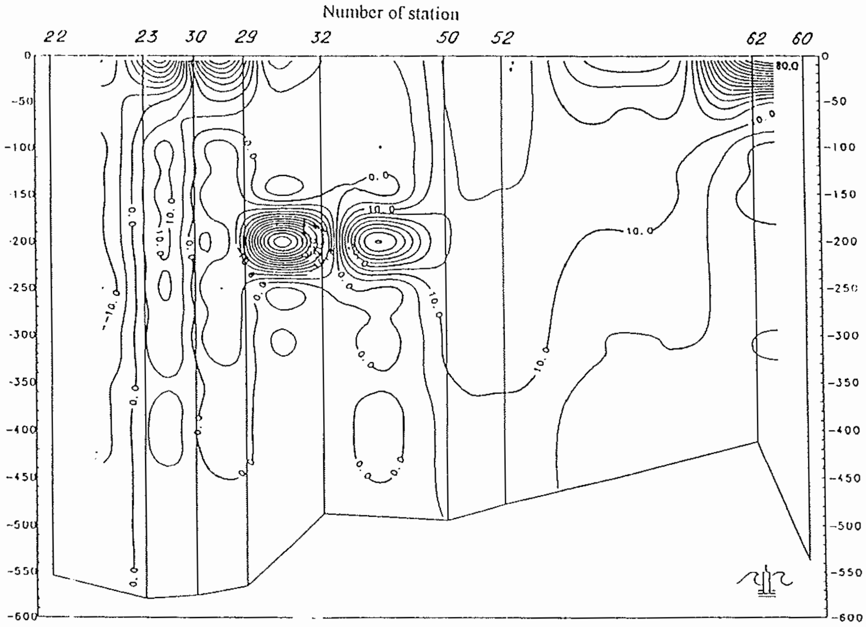

Fig. 4: Vertical distribution of geostrophic currents along transect N4 in the St. Anna Trough (RV "Professor Logachev", cruise 9, 1994). Legend: projection of current speed on the plane of the figure; - into figure, + out of figure.

The origin of these waters is connected with the Western-Spitsbergen Current (WSC) which is a constituent of the "Gulf Stream" system. By means of this current, the advection of Atlantic-derived Water (ADW) into the Arctic Ocean occurs. North of Svalbard, the ADW interacts with cold waters of the Transarctic drift, subsides to the level of a "density niche" and turns eastwards. Moving further in eastern direction, the ADW proceeds to northeast of FJL, where it enters the St. Anna Trough and moves southwards. Most probably, the decisive contribution for the southward reorientation of the ADW is provided by the hydrodynamic interaction of local currents and the bottom topography (Fig. 5).

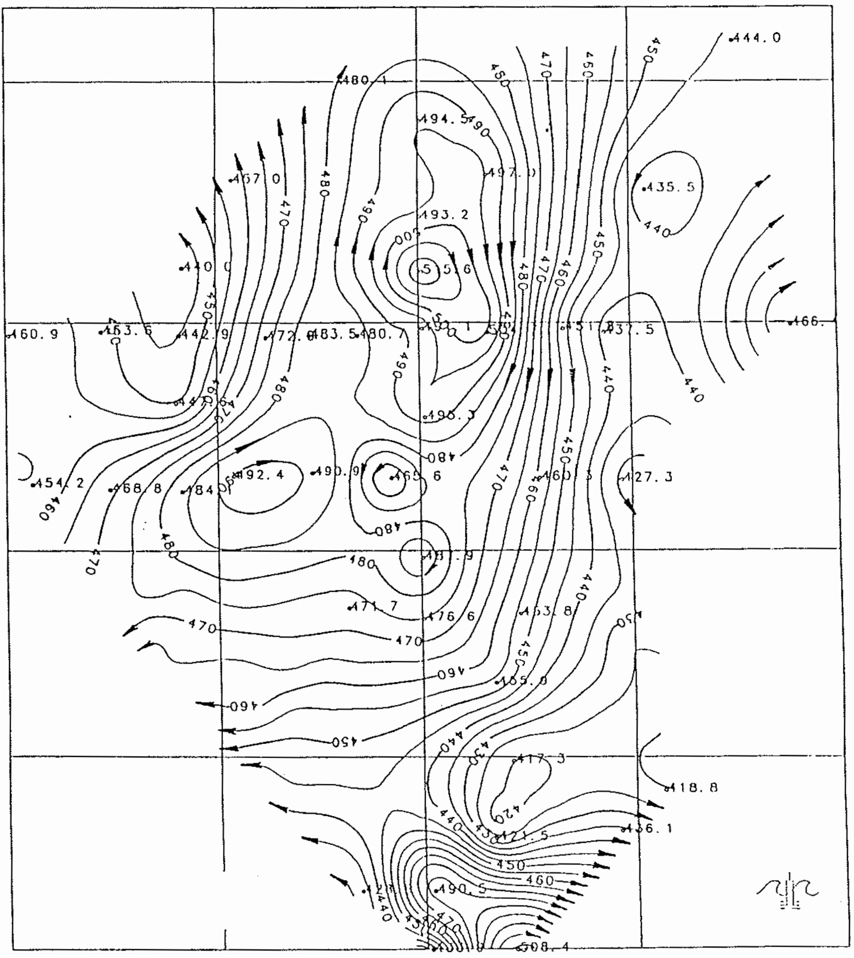

Fig. 5: Relative dynamical topography 0 - 570 dbar of the St. Anna Trough (RV "Professor Logachev", cruise 9, 1994). Legend: Dynamical heights in conventional dynamical mm.

The southward current accounts for the velocity and the transport of masses and properties of central Arctic Ocean waters into the St. Anna Trough area. Moving southwards, this flow experiences the deforming influence of the bottom topography along the western slope of the Central Kara Plateau. Flowing southward along this slope, it turns to the west and then to the north in the area of 78°20'N. Then it leaves the St. Anna Trough in its northwestern part. As a result, the water flow from the central part of the Arctic Ocean forms quasi-closed loop circulation with an anticyclonic turbulence in the St. Anna Trough. Control of the velocities in this circulation is apparently by the redistribution of dense waters in the bottom topography field, by bottom friction and by the Coriolis force. This assumption is confirmed by the good correlation between the isobaths and isotachs in the maps of the relative dynamic topography (Fig. 6).

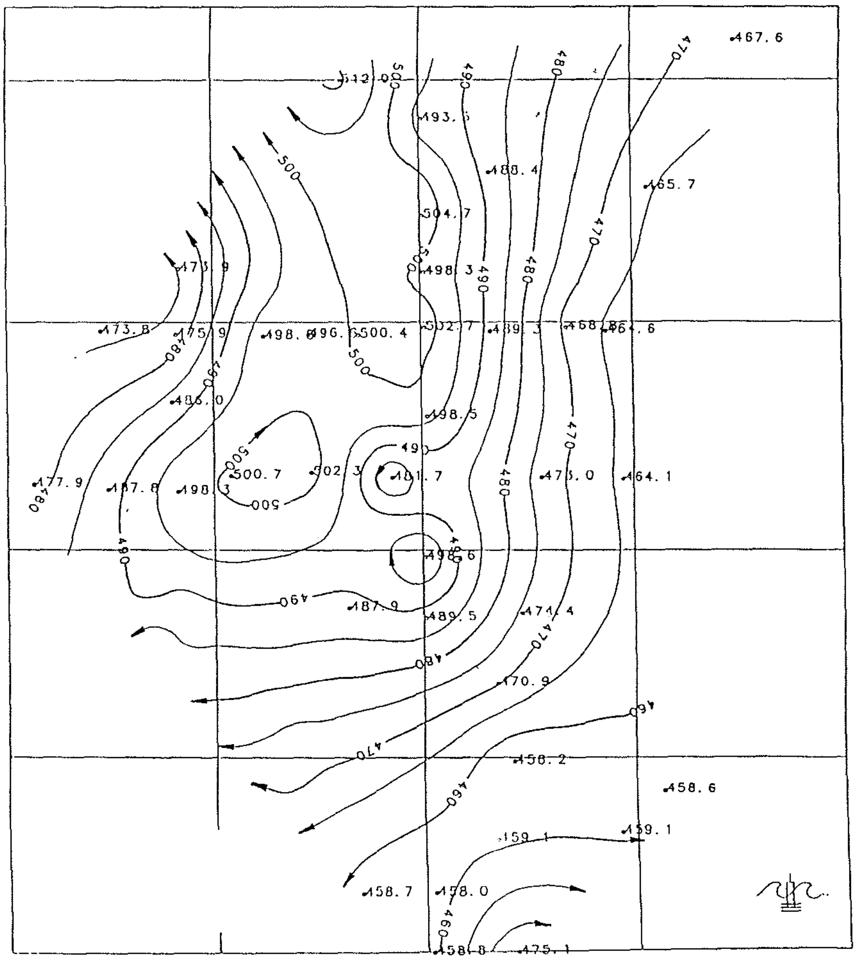

Fig. 6: Relative dynamical topography 150-570 dbar of the St. Anna Trough (RV "Professor Logachev", cruise 9, 1994). Legend: dynamical heights in conventional dynamical mm.

The waters of the eastern periphery of the loop (the slope and shallow waters of the Central Kara Plateau) penetrate southwards to 77°30'N, where they meet a flow from the Kara Sea, which moves to the north along the east coast of Novaya Zemlya. When in contact with Arctic Ocean waters, this flow diverges, causing one part of these Kara Sea waters to be included in the hydrodynamic system of an anticyclone loop, and the other to turn eastward and to come back to the Kara Sea (Fig. 5).

In addition, several minor important flows were observed in the St. Anna Trough. For example, near Vise Island the Kara Sea water transfer is directed towards the central part of the Arctic Ocean, and in the FJL area the waters of the western flank of the anticyclone loop influence the coastal cold waters, involving them in the northward movement.

It is noteworthy that the described water circulation system is observed both in the surficial oceanic layer and in the deep layers (Fig. 6). The spatial variability of a velocity field is characteristic only for regions with well developed inter-structural eddies, where the horizontal and vertical inhomogeneity of the density field in a nonlinear interaction result in local circulation of variable scales and with variable turbulence. The area with the maximum occurrence of such eddies is confined to the axial part of the loop. This zone is dominated by the eddies because of an instability of a velocity field within the loop. Usually they are fragmentary with a vertical amplitude of less than 50-75 m, and with a living period probably corresponding to mesoscale variability. In the layer of 175-225 m the mesoscale eddy (Fig. 6) with a center at stn. 32 was observed with the maximum current velocity in the studied area. The eddy generated by the hydrodynamic instability of the loop was observed in the area of stns. 37/38 and was associated with the loop top.

Bottom sediments

Surface sediments from the St. Anna Trough are mainly composed of clay and silty clay with occasional occurrences of significant amounts of sandy particles. The content of sand (fraction >0.1 mm) varies in a very broad range from 0.1 to 90.8%; the mean value is relatively low (8.6%). The coefficient of variation is 1.70. The content of silt fraction (0.1 - 0.01 mm) varies in the same range, however, the mean value is significantly higher (18.8%). The coefficient of variation is 49%. The clay fraction (<0.01 mm) ranging between 7 and 92.3% (mean value 72.5%) dominates in the St. Anna Trough deposits (Annex 2 and 3). The clay fraction is characterized by the lowest coefficient of variation (24%). The grain size integral parameter (Ivanov, 1983), which characterizes the average size of particles, accounts for 252, which corresponds to the pelite fraction <0.01 mm (range of variation from 212 to 408). All deposits are relatively well-sorted. The coefficient of normalized entropy varies from 0.49 to 0.89 (mean value 0.63).

The distribution map of sand fraction maxima (>0.1 mm) shows a sublongitutal zonation controlled by the main features of the morphological structure of the trough (Fig. 7). The content of sand fraction in the axial zone of the trough is usually <5%. Only close to the Franz Joseph Land archipelago and near the Vize and Ushakov islands at water depths of about 200-250 m, the content of sand fraction increases, but usually does not exceed 25%. In a few areas (especially in shallow water depths) the content of the sand fraction may reach values up to 50%. In the southern part of the trough in shallow water areas (depths <200 m) near the northern island of Novaya Zemlya archipelago, the content of the sand fraction is also high (up to 30-40%).

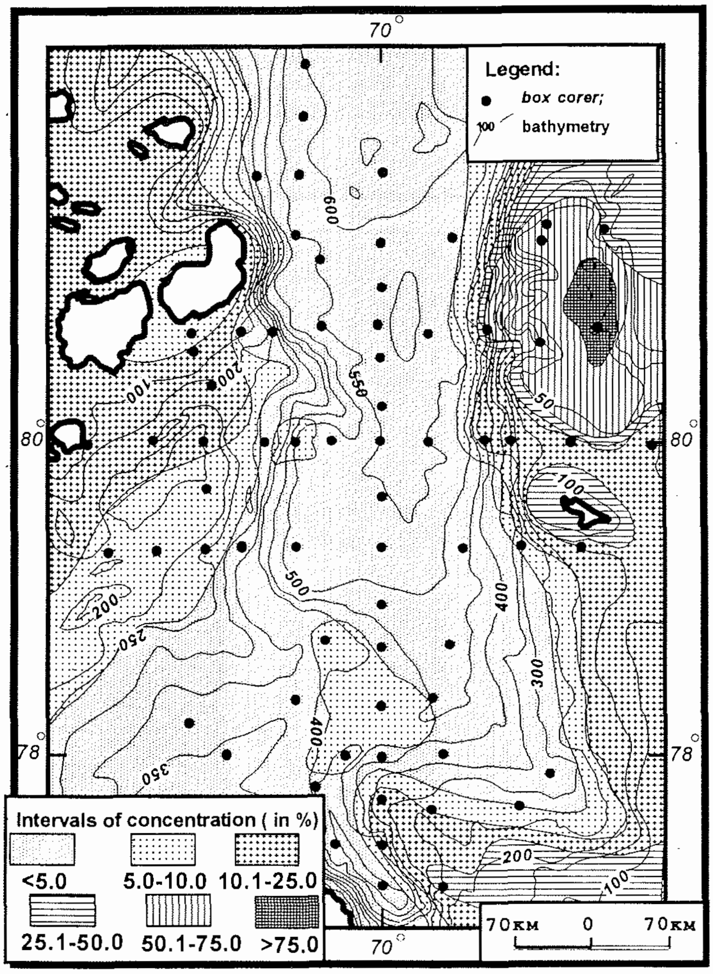

Fig. 7: Distribution of sand fraction content (>0.1 mm, % of bulk sediment) in surface sediment of the St. Anna Trough (RV "Professor Logachev", cruise 9, 1994).

The distribution map of the silt fraction (0.1-0.01 mm) is similar to the distribution of sand fraction (Fig. 8). In the deepest central part of the trough the content of silt fraction is <10%; only southwards it slightly increases up to 25%. In shallow water areas adjacent to Franz Joseph Land and the Vize and Ushakov islands, values are significantly higher (up to 50%). The narrow zone in the northern part of the trough can be related to an increased near-bottom water velocities. The southern part of the trough is covered by deposits characterized by silt fraction contents of 10 to 25%; generally, the longitudinal zonation is still preserved.

The distribution map of the clay fraction (<0.01 mm) in the surface sediments shows a longitudinal zonation similar to those of the silt and sand fractions, but higher gradients of concentration variability are common (Fig. 9). One of the characteristic features of the northern part of the trough are clay fraction contents varying between 92% and 4%. The broad central longitudinal zone is characterized by clay contents >75%, indicating a stable circulation over a long time interval.

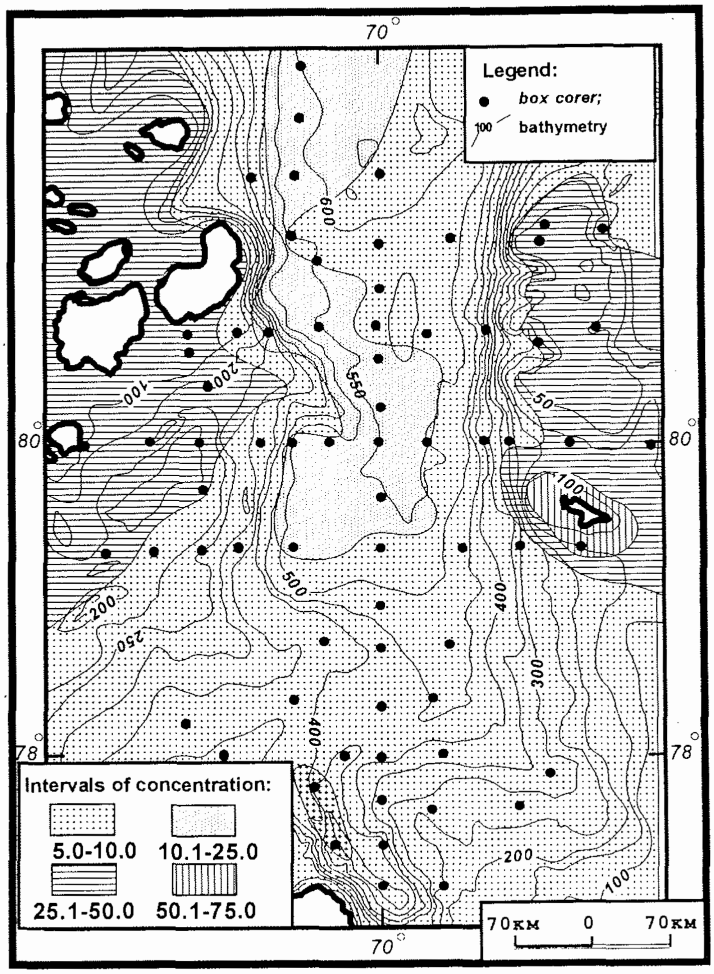

Fig. 8: Distribution of silt fraction content (0.1-0.01 mm, % of bulk sediment) in surface sediment of the St. Anna Trough (RV "Professor Logachev", cruise 9, 1994).

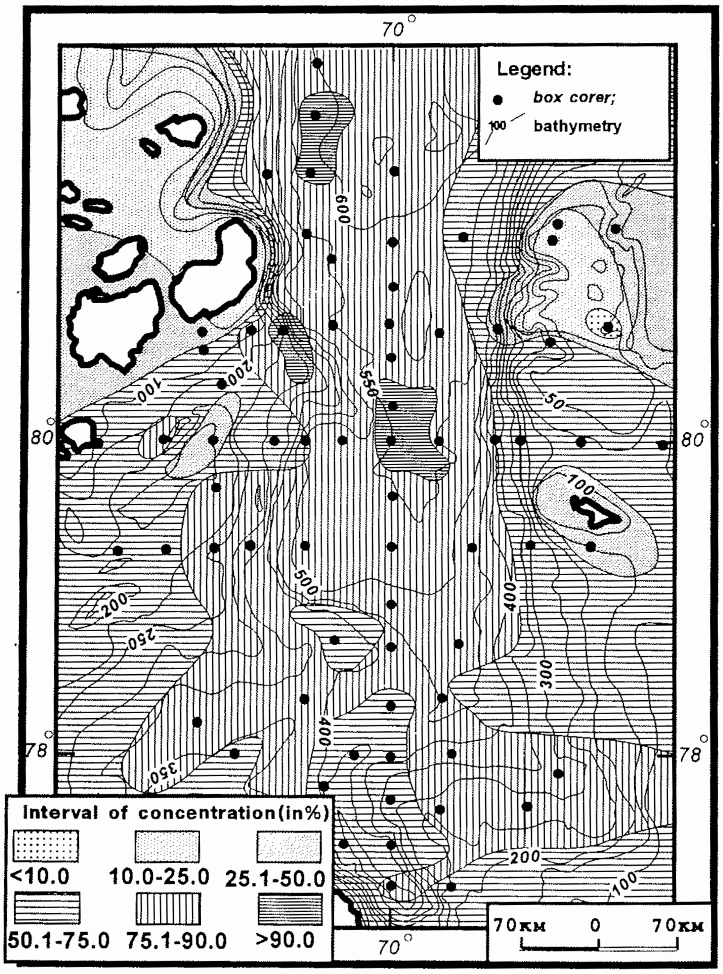

Fig. 9: Distribution of clay fraction content (<0.01 mm, % of bulk sediment) in surface sediment of the St. Anna Trough (RV "Professor Logachev", cruise 9, 1994).

The distribution of grain size integral parameters (fraction structure parameter which evaluates average size of grains) is very similar to the distribution of size fractions (Fig. 10), which characterizes the circumcontinental and vertical zonation complicated by the hydrological regime. Coarse-grained material from the northern shore of Novaya Zemlya and the Kara Sea is deposited in the south-eastern part of the trough.

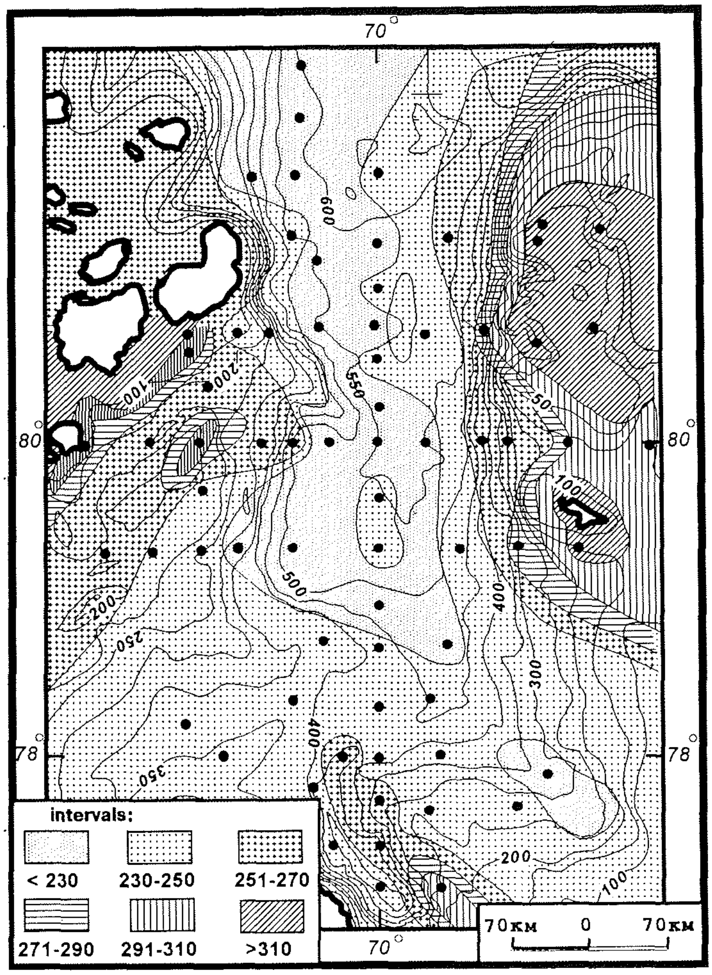

Fig. 10: Distribution of integral grain-size parameter (Gi) in surface sediment of the St. Anna Trough (RV "Professor Logachev", cruise 9, 1994).

Conclusions

Our data are evidence for a sediment formation under predominantly deep-sea conditions. The lateral diversity corresponds to a circumcontinental zonation, water depths, and water circulation patterns.

Main sources of sediment supply are the islands of FJL, Vize, Ushakov, and Novaya Zemlya. The southern part of trough experiences an impact of sediment flux from the Kara Sea.

Acknowledgments

We thank the German Bundesministerium für Bildung und Forschung (BMBF) for financial support within the "German-Russian Cooperation" program (grants 03F10GUS and 03F19GUS).

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Appendix 1

Character of measurement channels of CTD/ASM-2.

Parameter	Unit	Range	Error (accuracy)	Resolution
Pressure	dB	0 - 6500	+/- 6.5	0.1
Temperature	°C	-32 - +32	+/- 0.005	0.0005
Electric conductivity	mS/cm	1 - 65	+/- 0.005	0.001
Oxygen				
Current	mA	0 - 2.047	+/- 0.001	0.0005
Temperature	°C		+/- 0.256	0.128
Stream				
Rate	cm/s	-250 - 250	+/- 1.0	0.15
Direction	°	0 - 360	+/- 2.0	
Light passing	%	0 - 100	+/- 0.5	0.024

Appendix 2

Statistic parameters of surface sediments in the St. Anna Trough

	Sand % >0.1mm	**Silt** % 0.1-0.01	**Clay** % < 0.01	**Gi**	**Hr**
No. of cases	66	66	66	66	66
Minimum	0.40	2.0	7.0	212	0.49
Maximum	90.8	60.4	92.3	408	0.89
Mean	8.6	18.8	72.5	252	0.63
Standard deviation	14.5	9.3	17.7	35	0.01
C. V.	1.70	0.49	0.24	0.14	0.16

Sand: >0.1 mm; silt: 0.1-0.01 mm; clay: <0.01 mm
Gi: Grain-size integral parameter (Ivanov, 1983)
Hr: Normalized entropy (Romanovsky, 1986)

$$Gi = \sum_{i=1}^{n=i} (5 + \log(di)) * Xi$$

di - last diameter of fraction
Xi - contents of fraction (in %)

Appendix 3

Statistical parameters of grain size distribution in surface sediments in the St. Anna Trough.

	Fractions (mm) 1.00-0.63	063-0.4	0.40-0.315	0.315-0.2	0.2-0.16	0.16-0.1
No. of cases	67	67	67	67	67	67
Minimum	0.0	0.0	0.0	0.0	0.1	0.2
Maximum	2.0	4.0	7.5	43.4	13.0	22.5
Mean	0.1	0.3	0.4	2.1	1.4	4.2
Standard deviation	0.3	0.7	1.1	5.8	2.5	5.0
C. V.	2.6	2.5	2.6	2.8	1.8	1.2

	Fractions (mm) 0.1-0.063	0.063-0.05	0.05-0.01	0.01-0.005	0.005-0.001	< 0.001
No. of cases	67	67	67	67	67	67
Minimum	0.1	0.1	0.1	1.3	1.1	4.6
Maximum	27.3	9.0	25.9	32.3	53.7	54.2
Mean	4.3	1.5	13.1	14.3	25.3	32.4
Standard deviation	5.2	1.6	5.3	4.6	8.7	13.5
C. V.	1.2	1.0	0.4	0.32	0.35	0.42

DIATOMS IN BOTTOM SEDIMENTS OF THE LAPTEV AND KARA SEAS

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Introduction

During the last decade, the scientific interest to study the Arctic seas, including the Laptev and Kara seas, has increased considerably in connection with the economic exploration of the arctic natural resources and with the recognition of several ecological problems. Diatoms can be used in these investigations as unique paleoceanological indicators, because they are the main source of organic matter in the Arctic seas. The habitats of diatoms are exceptionally variable: soils, freshwater lakes, rivers, littoral and pelagic zones of seas and oceans. The composition and quantitative distribution of diatoms are connected with hydrochemical, hydrobiological and sedimentological conditions. At present, modern diatom biocoenoses of the Laptev and Kara seas are well established. However, the study of diatom thanatocoenoses is only just beginning. In this study, we report on our investigations of diatom thanatocoenoses from the Kara and Laptev seas in order to document the present state of knowledge and to establish a data base for further investigations.

Laptev Sea samples

Diatoms were studied in 38 bottom surface sediment samples (stations 1-19) and in 35 samples of two sediment cores (stations 4 and 7) from the Laptev Sea (Fig. 1). The samples were obtained during the Russian-French expedition of R/V "Jakov Smirnitzky" in 1991.Our results must still be regarded as preliminary, because diatoms were studied using the smear-slides. All data are semiquantitative.

The diatom abundance in the surface sediments is not very high. Their distribution is irregular. This is probably connected with the relatively low diatom productivity in the surface water, with a considerable dissolution of silica frustules of diatoms, and with a strong dilution of biogenic components by terrigenous material. The diatom abundance and diversity in bottom sediments near river mouths (up to 74°N) are high in comparison to the open sea. The preservation of diatom frustules is poor.

The composition of the diatom associations is rather specific. They include cold and moderate-cold species which live in freshwater, brackish, and marine environments. In the surface bottom sediments from near-estuary areas (st.1-6), rare specimens of marine species (*Thalassiosira bramaputra v. septentrionalis, T. antarctica, Rhizosolenia hebetata, Chaetoceros* sp.(spores)) were identified.

There are also numerous mesohalobous, which lived in brackish- water (5-20‰) and oligohalobous, which lived in fresh water (0-5‰): *Aulacosira, Asterionella, Achnanthes, Diatoma, Fragillaria, Eunotia, Navicula, Cymbella, Pinnularia, Stephanodiscus, Tabellaria* and other. The presence of river diatoms in these sediments indicates that they were transported by river water or river ice.

Marine and brackishwater diatoms dominate in the surface sediments of northern regions (stations 7-19): *Thalassiosira bramaputra v. septentrionalis, T. hyalina, T. exentrica, Chaetoceros subsecundus, Ch. mitra, Ch. furcellatus, Ch. holsaticus, Navicula distans, Fragilariopsis oceanica, Paralia sulcata.* No freshwater diatoms were found.

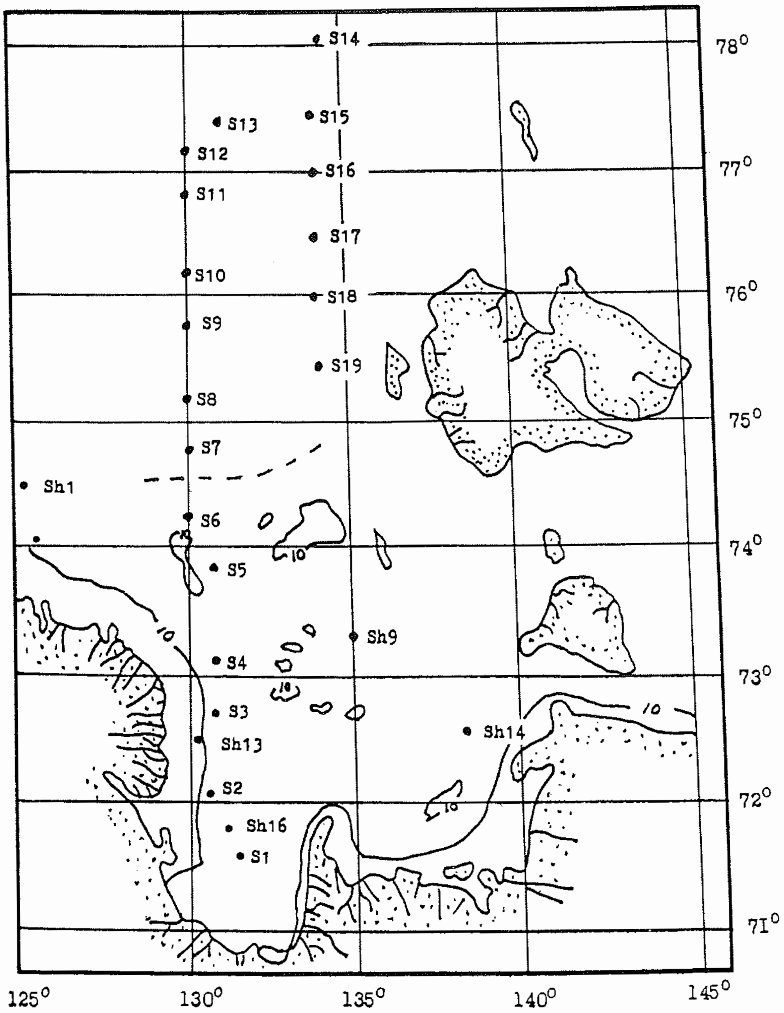

Fig. 1: Laptev Sea: Map of stations.

Two sediment cores were investigated (station 4: 73°N,131°E, water depth 26 m, core length 300 cm, and station 7: 74o°N, 129°E, water depth 37 m, core length 295 cm). Fresh- and brackishwater diatoms in core 4 and marine diatoms in core seven are predominant. Evolutionary changes in the composition of the diatom complexes were not found. But changes in the relative species abundances indicate paleoceanographic changes. Up to 3 layers were identified in the sediments, which must be of Holocene age, because the Laptev Sea shelf was subaerially exposed during the Weichselian glacial.

The oldest layer 3 was found both in cores 4 (300-120 cm) and 7 (295-80 cm). The diatom complex of this layer is highly abundant and diverse. We found a maximum content of marine species. Moderate warm-water species (*Proboscia alata, Chaetoceros mitra* and others) were identified in the samples at 130-115 cm at station 7.These species are not typical for modern Arctic waters.Layer 2 was found in cores 4 at 120-20 cm and 7 at 80-10 cm. A low diatom quantity and diversity and an increase of freshwater diatoms (in core 7) were determined in this layer.The diatom complex of the uppermost layer. (core 4: 20-0 cm, core 7,: 10-0 cm) reflects the modern oceanographic conditions of investigated shelf sea area.

Based on our results, we suppose that the studied sequences were formed since the time of the Holocene climatic optimum (which offered the most favourable conditions for the development of marine algae). For the interval following the climatic optimum, a progressive sea level drop and a decrease of the water temperature are reconstructed from the decrease of the diatom number in the sediments and the increase of freshwater and sublittoral species. Finally, the surficial sediment layers, which contain diatom complexes identical to the modern shelf sea complexes, reflect the modern conditions.

Kara Sea samples

From the Kara Sea, 45 samples of the surface sediments and 91 samples from 7 sediment cores were analysed. They were taken during the "International High Latitude Expedition to the Kara Sea" within the 49th cruise of R/V "Dmitriy Mendeleev", 1993 (samples 1-40), and during the cruise of R/V "Storm" (samples 41-45). The station map is shown on Fig. 2.

In the Kara Sea, the maximum content of diatoms has been found in the surface sediments of the Yenisei estuary area. The abundance of diatoms and relations between the different groups at the individual points are shown on Fig. 3. The number of diatoms in sediments of the Ob inlet is 4-5 times lower. An extremely high silica content in the upper layers of the river waters characterizes the near-estuary regions (up to 83-84 mg per liter in the Yenisei river and up to 50 mg per liter in the Ob river). The content of other biogenic elements in these waters is relatively low. The relatively high annual temperature and the low salinity are typical for this region. High diatom abundances in the bottom sediments were found also in the western part of the Kara Sea (sample 11). The low salinity of the surface water (9-12‰) is probably explained by the intensive transport of freshwater to this region. This region of low salinity water is separated from the river estuaries by the Yamal current with saltier waters (more than 20‰).

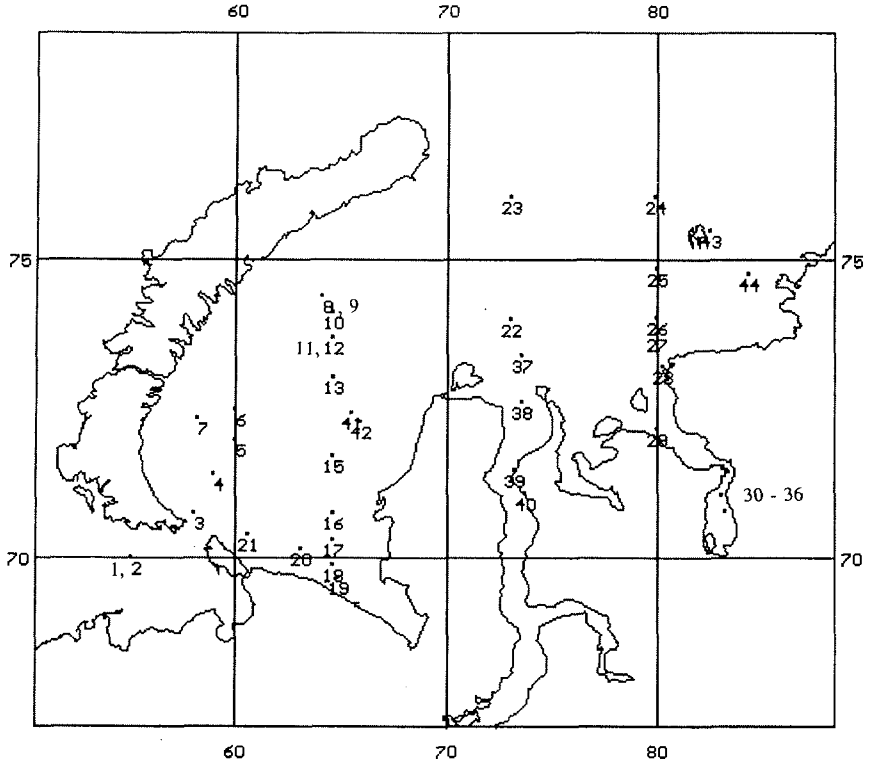

Fig. 2: Kara Sea: Map of stations.

The bottom sediments of the western and central open Kara Sea are extremely impoverished of diatoms. Here, the content of biogenic elements (phosphates and nitrates) is near the analytic zero. The waters in this region are oligothrophic. A high salinity of the surface water and a low primary production of organic carbon (30-80 mg C/m^2 per day) are typical for this region. In the Kara and Laptev seas, an inverse relationship between primary production and salinity of the surface waters was observed.

The taxonomic composition of Kara Sea diatoms is rich and distinct. Diatoms typical for the fresh, brackish and marine cold water occur in the Kara Sea sediments. 190 diatom species have been identified: 116 species (30 genera) of freshwater diatoms, 28 species (10 genera) of brackish water diatoms, 26 species (11 genera) of marine diatoms, and 20 ancient redeposited marine species (8 genera). A high diversity of diatoms characterizes the especially bottom sediments of the near-estuary regions.

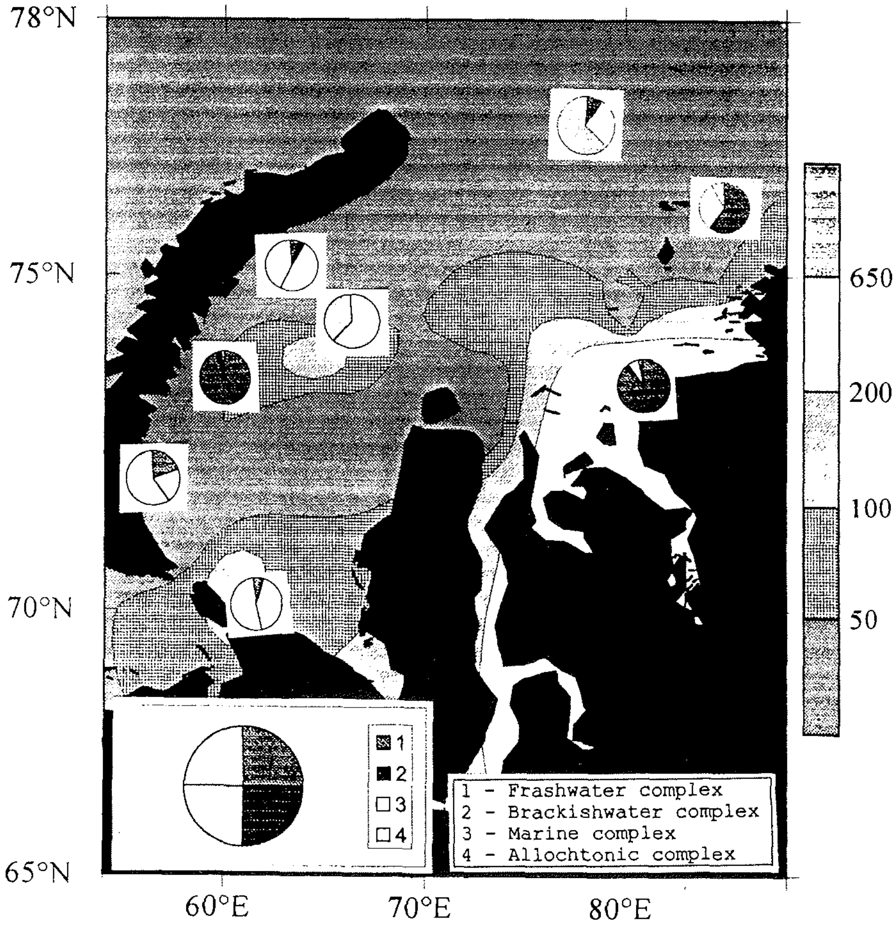

Fig. 3: Kara Sea: Scheme of the abundance (boxes, specimens/g) of diatoms and the relationships of different diatom complexes (circograms).

Lake-river species are the main component of the diatom thanatocoenoses of the bottom sediments in the Yenisei Bay and Ob inlet (up to 98% of all diatoms). Among them there are *Aulacosira* (8 species), *Cymbella* (12), *Epithemia* (4), *Eunotia* (7), *Fragilaria* (8), *Navicula* (13), *Nitzschia* (5), *Pinnularia* (14), *Synedra* (6), and *Tabellaria* (2). A sharp hydrologic front at 74°N divides river and sea water along the Yenisei meridional track. The content of fresh water diatoms in the bottom sediments decreases strongly north of this front. Less than 10% freshwater diatoms have been identified in the central and western regions of the open Kara Sea.

The diatom diversity in the western region, the Baidara Bay, and the central part of the open sea is 2-5 times lower in comparison with the near-estuary regions. In the latter, neritic and sublittoral species prevail both in composition and in number (27-79.4%). Among them, *Paralia sulcata, Thalassiosira* *bramaputra v.septentrionales*, and *Cocconeis scutellum* dominate. Cold-water arctoboreal and bipolar species are rare: *Thalassiosira gravida, T. hyalina, T. kryophila, T. nordenskioldii*, and *Chaetoceros* (spores).

We identified also single warm-water species of wide geographic distribution in the sediments of the western and south-western regions of the Kara Sea (samples 6, 7, 8, 19). These diatoms are non-peculiar for arctic water. They are *Chaetoceros lorenzianus, Ch. mitra, Coscinodiscus radiatus, C. stellaris, Thalassiosira decipiens*, and *T. pacifica*. These species are probably transported to the Kara Sea with relatively warm North Atlantic water through the southern straits.

A considerable number of redeposited Cretaceous-Paleogene marine diatoms and silicoflagellates was found in all sediments of the Kara sea. They are: Diatoms - *Paralia sulcata var.siberica, P. sulcata var. crenulata, Hemiaulus polymorphus, H. proteus, Pyxilla gracilis, Stephanopyxis turris, S. broschii, Stephanopyxis sp., Grunoviella gemmata. Coscinodiscus payeri, C. decrescens, C. argus, C. symbolophorus, Coscinodiscus sp., Pseudopodosira wittii* and other; Silicoflagellates - *Naviculopsis biapiculata, N. constricta, Corbisema triacantha, Bachmannocena diodon, Dictyocha* sp., *Mesocena* sp. and other. Exclusions from this rule are the Ob and Yenisei estuaries.

One of the methods of numerical hierarchical classification was used to investigate the similarity and difference between sediment samples from various geographical points. The information about the distribution of about 190 diatom species in the surface sediment of the Kara Sea was used as a data base. The Euclidean matrix and the flexible strategy were chosen as a distance measure and a union strategy.

All samples were divided into several groups. The main groups were the "marine group" and the "freshwater group" (Fig. 4). The freshwater group consists of a group of Yenisei samples, Ob samples and some additional samples from a region strongly influenced Yenisei water. There is an intermediate group which consists of two eastern samples. They are from the open sea but quite near to the influence zone of the Yenisei. The composition of sample 11, which is far from river water influence, can probably be explained by a stream transition of freshwater or by meltwater from Novaya Zemlya glaciers.

Seven sediment cores from different facial zones of the Kara Sea were investigated. The sediment cores from the area near the estuaries of the Yenisei and Ob rivers and the near-shore southern part of the Western Kara sea contain only upper Holocene sediments, because of the relatively high sedimentation rates. Divisions within the Holocene sediments are generally based on changes of diatom numbers. The species composition and percentages of ecological and biogeographical groups allowed to identify 3 layers.

Layer 3 (Fig. 5) was found in core 27 at 410-340 cm. The diatom complex of this layer is rich and characterized by a high taxonomic diversity. In the Ob-Yenisei region, more than 90% of the diatoms are corresponded to freshwater conditions. *Aulacosira* spp. dominates in these complexes.

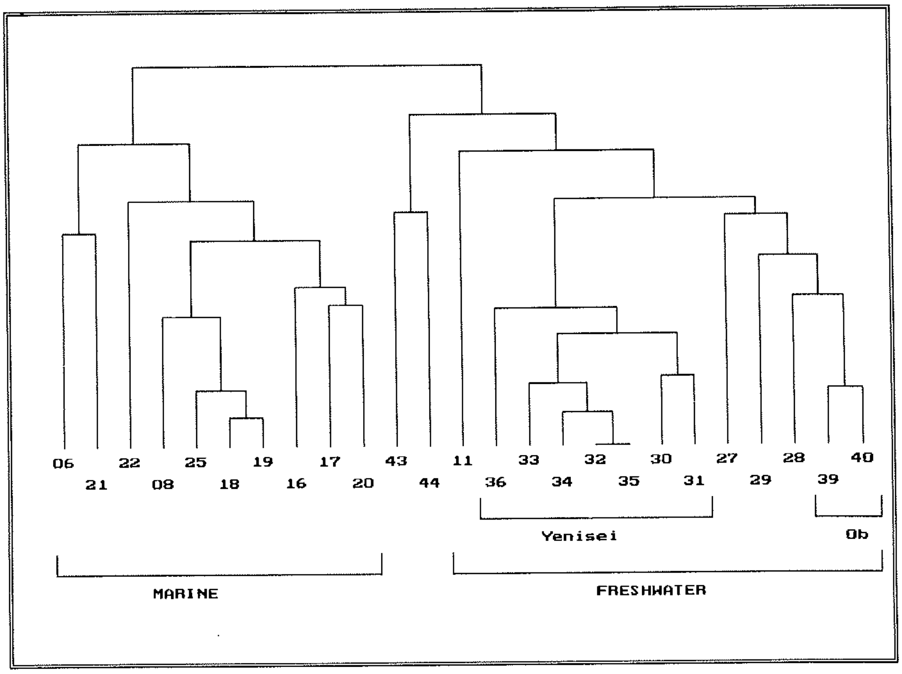

Fig. 4: Clusters of Kara Sea sediment samples. The samples are grouped according to the dominance of marine or freshwater diatom complexes.

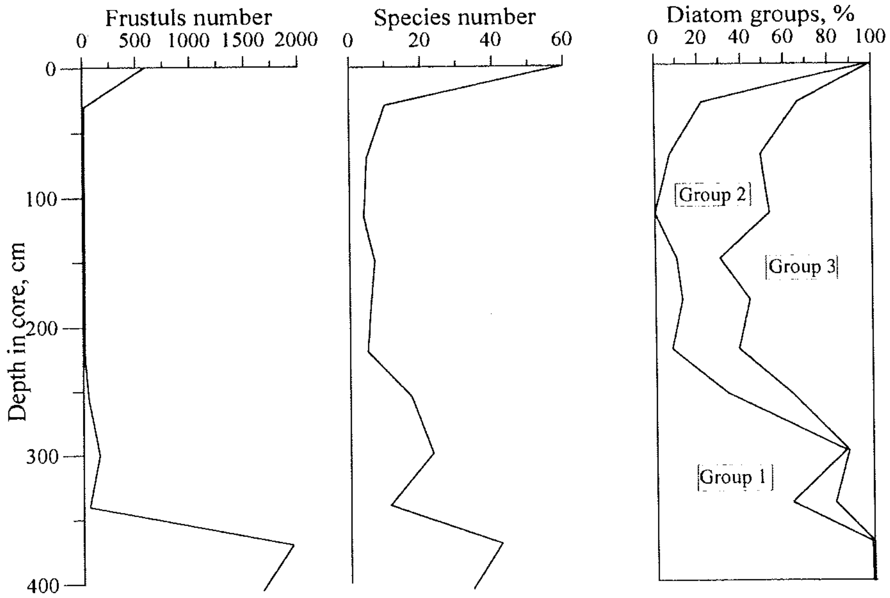

Fig. 5: Kara Sea: Core 27, Group 1: freshwater diatoms, Group 2: marine diatoms, Group 3: allochthonous diatoms.

The diatom complex of layer 2 (Fig.6) was found in cores 27 (340-330 cm) and 39 (370-380 cm). The diatom quantity and diversity are lower in comparison to the modern complex. In the Ob-Yenisey region diatoms of this complex are enriched by marine species (up to 30-40% of all diatoms) and by redeposited Cretaceous-Paleogene diatoms (up to 70%) in comparison with diatoms of layer 3. This indicates a decrease of river outflow and the increase of erosional processes during the formation of layer 2. We believe that this time was characterized by a lower surface water temperature and a lower sea level.

As a rule the sediments of the surface layer (core 27, 20-0 cm and core 39, 80-0 cm) include the diatom complex corresponding of the present-day hydrobiological and sedimentological conditions of the Kara Sea.

The sediment core from the north-western part of the Kara Sea (station 7; Fig. 7) probably includes pre-Holocene sediments (at 355-200 cm). The diatom complex here is poor and includes mainly allochthonous marine Cretaceous-Paleogene species. The Holocene sediments (horizon 200-20 cm) are virtually barren. Modern diatoms were found in the surface layer of bottom sediments (0-20 cm).

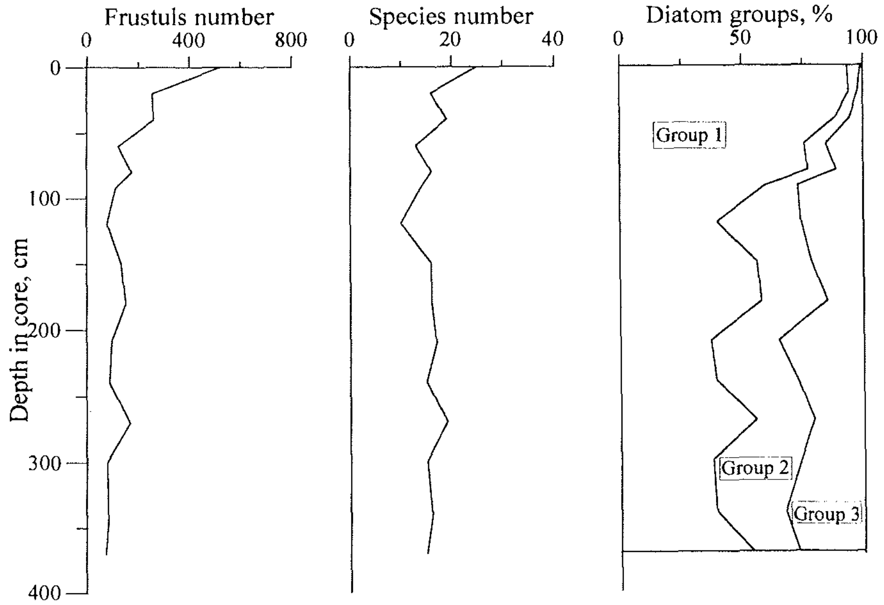

Fig. 6: Kara Sea: Core 39, Group 1: freshwater diatoms, Group 2: marine diatoms, Group 3: allochthonous diatoms.

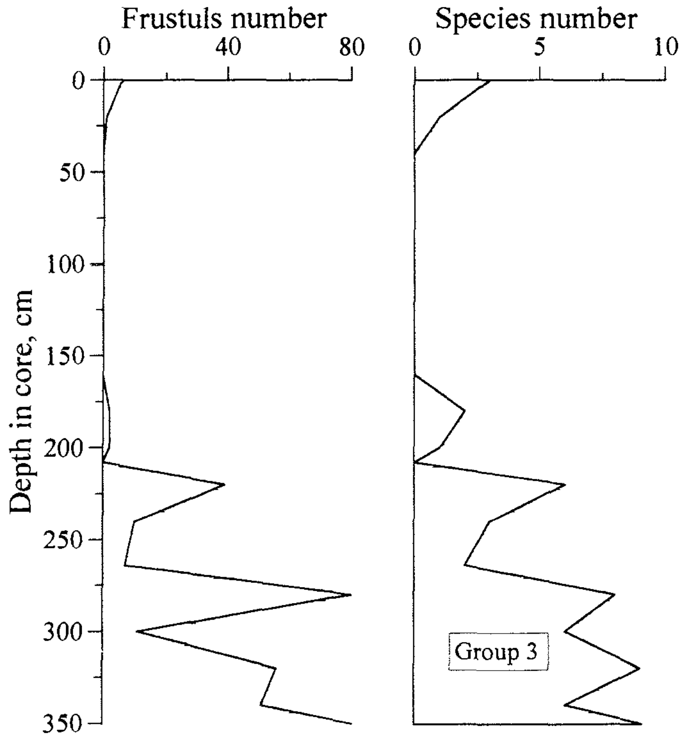

Fig. 7: Kara Sea: Core 7, Group 3 - allochthonous diatoms

Conclusions

The study of the fossil microflora in the Kara sea showed that the river flows (Yenisei and Ob) are main factors which determine the quantitative distribution and composition of diatom thanatocoenoses in the bottom sediments. Diatoms are abundant and diverse in surface sediments of the near-estuary regions (up to 74°N). High abundances of freshwater diatoms were found also in the western part of the Kara Sea (73°56'N, 63°34'E). This is probably due to the intensive transport of river water in this area. The bottom sediments of the open sea in the western and central parts are extremely impoverished by diatoms. 190 diatom species have been identified in the Kara sea surface sediments. Three diatoms groups (freshwater, brackishwater and marine) are revealed according to their salinity requirements. In the Kara Sea sediments also the group of the redeposited Cretaceous-Paleogene diatoms is defined which shows on conditions of active erosion processes. The proportions between these groups were determined along the cores. These floral changes reflect Late Quaternary climatic and eustatic changes. According to the lithological and biostratigraphic data two facies regions were found in the Kara sea: Western Kara and Ob-Yenisei (Levitan et al.). The southern areas of these regions (stations 4401, 4404, 4416) are characterized by the sedimentation rates 2-4 times more than in northen area (station 4381).

Acknowledgments

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DISTRIBUTION OF POLYCYSTINE RADIOLARIANS FROM RECENT AND PLEISTOCENE SEDIMENTS OF THE ARCTIC-BOREAL ZONE

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Introduction

In the present World Ocean polycystine radiolarians are one of the most widely distributed marine microzooplankton groups as well as an important part of the food chain in the World Ocean. There are probably some thousand different species of Radiolaria. They dwell from the sea surface down to the greatest water depths and from the Arctic to the Antarctic. Only the members of the two order *Spumellaria* and *Nassellaria*, which have siliceous skeletons, can be found in the sediments.

Radiolarians are very important for paleoreconstructions, because they have a very high diversity, a wide distribution, a high sensitivity to changes of environmental conditions and good preservation also at high latitudes. A number of works have been devoted to the study of radiolarians from the Arctic (Bernstein, 1932, 1934; Bogarov, 1946; Hülsemann, 1963; Tibbs, 1967; Kruglikova, 1989), North Pacific (Kruglikova, 1969, 1977; Nigrini, 1970; Hays, 1970; Kling, 1973; Sachs, 1973), Okhotsk Sea (Reshethjak, 1953, 1955; Kruglikova, 1975) and Bering Sea (Reshethjak, 1953, 1955; Blueford, 1983) and others, which essentially dealt with biostratigraphical problems. They worked only with parts of the radiolarian assemblage and therefore could not report on imagination, distribution, abundance, diversity and taxonomy of the polycystine radiolarian fauna from the Arctic-Boreal Zone.

However, recent radiolarians are still one of the less studied groups of microfossils in terms of taxonomy, ecology and biogeography. There is a lot of taxonomic confusion and lot of mistakes in the identification of radiolarians, therefore the conclusions which have been made on the base of these data are not correct. The goal of this work was to study taxonomy and biogeography of as many radiolarian species as possible from sediments of the regions in question and to compare them with other regions of the World Ocean.

Methods

Polycystine radiolarians have been studied for both a taxonomical and a quantitative approach from more than 400 surface sediments of the North Pacific (NP), Okhotsk Sea (OS), Bering Sea (BeS), Central Arctic Basin (CAB), Chukchi Sea (ChS), Barents Sea (BS), Kara Sea (KS), Japan Sea (JS) and the Greenland-Iceland-Norwegian seas (GIN) and Norwegian fjords (in cooperation with Prof. K. R. Bjørklund, Oslo) and some cores from the NP, OS and BeS. Material from all regions except GIN seas were collected by the Russian research vessels "Vityaz" (NP, OS and JS), "Dmitry Mendeleev" (NP, OS, BeS and KS), "Professor Stokman"(BS), Ice drift stations "SP-15", "SP-16"

(CAB), "SP-22" (ChS), the American R/V "Vema" and the Norwegian F/F "Haakon Mosby" (GIN seas and Norwegian fjords) (fig. 1). All radiolarian slides, except those from the GIN seas, were prepared according to the procedure described in Kruglikova (1969), those from the GIN seas according to the method described in Goll and Bjørklund (1974). Radiolarians were studied with the light microscope, and magnifications 10-15 x 20 were used. Data on radiolarians made it possible to map their abundances, ranges of some radiolarian species and associations, as well as a preliminary cluster analyses of the radiolarian associations.

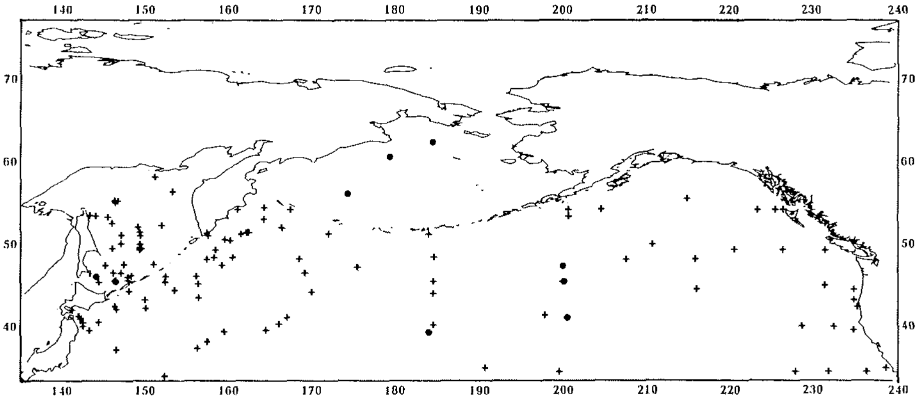

Fig. 1: Map of samples studied in the North Pacific and Far Eastern seas.

Results and Discussion

About 200 species of Polycystine radiolarians were identified from the surface sediments of the Arctic basin (AB) and the Arctic-Boreal zone north of 37-40°N in the NP. The distribution of about 140 species was analysed in Quaternary sediments from the studied cores. Special attention was paid to the taxonomy and distribution of such species which are very useful for modern biostratigraphic and paleooceanographic studies like *Cycladophora davisiana* typ., *C. davisiana* "marina", *Amphimelissa setosa*, *Lithomitra arachnea*, *L. linneata*, *Stylochlamidium venustum*, *Cromyechinus borealis* (= *Actinomma boreale*), *Cr. antarctica* and some other.

On the base of my previous research of radiolarians in different regions of the World Ocean and from literature data, I have observed that Arctic and Arctic-Boreal faunistic associations from the NP are composed of species from 3 biogeographical groups: cosmopolitic, endemic of the Arctic-Boreal zone (amphiboreal and endemic of NP and probably OS) and bipolar.

Knowledge of these biogeographical groups of species and their present distribution is necessary for making reconstructions of their position in the past. Species from different biogeographical groups of the same climatic associations probably occupied different depth zones and therefore have a different immigration history into the studied areas. Such biogeographical analysis has not been done before and may be the basis for future paleoreconstructions.

Data on the abundance of radiolarians permit me to define three quite different regions. In the Arctic Basin the number of radiolarians is from 1 specimen/5 g to 16 specimens/g of dry bulk sediment. Radiolarians in the sediments of the KS are almost absent (except some stations); in the OS and nearshore regions of the NP the highest number of radiolarians fluctuates from tens to a couple of thousands/g of dry sediment. In open ocean the abundance of radiolarians can vary from several thousands up to several hundred thousands of specimens/g bulk sediment (Fig. 2).

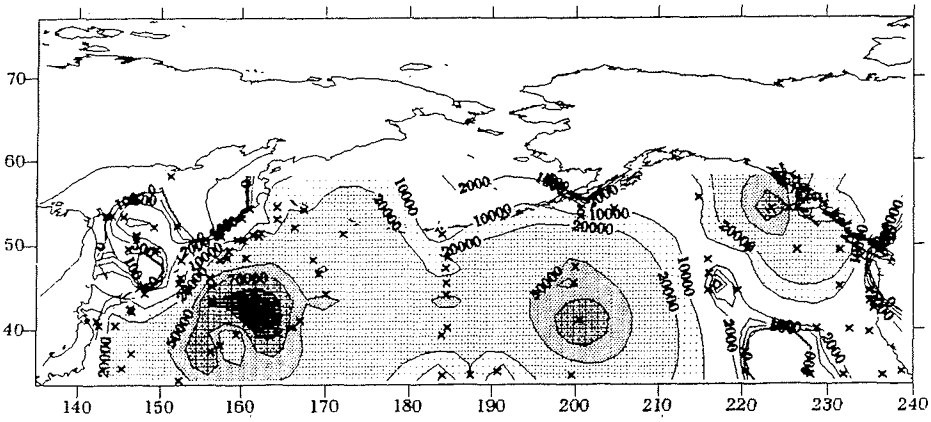

Fig.2: Abundance of radiolarians in the surface layer of sediments of the NP and OS (specimens/g dry sediment).

Three different species assemblages can be recognised from the studied area: arctic, arctic-boreal and transitional (to tropical). The Arctic assemblage is distributed in sediments of the CAB and Low Arctic seas.

In roughly half of the samples analysed from the CAB, four Polycystine species were identified (*Actinomma leptodermum*, *Spongotrochus glacialis*, *Pseudodictyophimus gracilipes*, and *Lophophaena?* sp.). In the ChS and BS the species number increased to ca. 30 species. In the Low Arctic seas *Amphimelissa setosa* (68-70%) and *Actinomma leptodermum* are dominating. *Lithomelissa setosa*, *Pseudictyophimus gracilipes*, *Spongotrochus glacialis* and some other species, which are abundant in the GIN seas and fjords, are rather widely distributed in the Arctic sediments. My results allow the following conclusions:

1) Some species have an almost cirumpolar distribution in the CAB (*Actinomma leptodermum, Spongotrochus glacialis, Pseudodictyophimus gracilipes*, and *Lophophaena*? sp.).

2) Polycystine radiolarians are more diverse in the Amerasian than in the Eurasian part of the Arctic region.

3) The structure of the radiolarian associations in the Arctic Basin is more similar to the associations in the surrounding Low Arctic seas and the North Atlantic than to those of the NP. *Amphimelissa setosa* and *Actinomma leptodermum* are the dominant species, as in the GIN seas. It should be mentioned that *Amphimelissa setosa* is completely missing in sediments of the CAB.

4) Characteristic for the CAB association is the low number of species as well as specimens. In the Arctic Basin no endemic Polycystine radiolarians have been found. The same accounts for some other animal and plant groups, e. g. Foraminifera and Coccolithophoridae. The level of endemicity of the recent fauna of the Polar basin is not very high. There are many endemic bathyal and pseudoabyssal species of fish, but according to Andrijashev (1953), no endemic genera have been reported on. This suggests that the radiolarian fauna in the High Arctic is quite young. This statement is in good agreement with Jouse *et al.* (1979) and Petrushevskaya (1979) who studied the GIN seas biota and they believe that these biota and those of the Arctic evolved recently.

The arctic-boreal assemblage of radiolaria is found north of 41°N (at latitude 142°E) and north of 54°N (at 140-142°W). Normally, only 20-50 species are found at each station, except for the nearshore stations where associations do not exceed 10 species. The 5-6 most abundant species do often make up to 50% of the total radiolarian assemblage. The assemblages of the NP and the Far Eastern seas are dominated by other species than those in the Arctic.

The geographical ranges of some species were mapped, as well as the different biogeographical assemblages, which are widely distributed in the NP and OS. The species that are most common are the cosmopolitic ones (Fig. 3). Of the about 70 species that are widely distributed in sediments of the Arctic-Boreal zone of the NP, about 20 cosmopolitic species dominates the fauna. Cosmopolitic species like *Lithomitra arachnea*, *Artostrobus annulatus*, *Cycladophora davisiana* (typ.), *Lithocampe platycephala*, *Pseudodictyiophimus gracilipes*, *Cornutella* spp., *Artostrobium auritus-australis* gr., *Artostrobium tumidulum* and some others are common not only in the NP regions and the Far Eastern seas, but also in the Antarctic, however they are only rarely found in the CAB. Modern biogeographers call them by "bionomical bipolar species" and believe that this is a result of equatorial submergence, forming an equatorial deep water assemblage.

The cosmopolitic species are more common in the Amerasian than in the Eurasian part of the Arctic region and may indicate an intrusion of waters and a faunal exchange with the North Pacific Ocean. Only five species, or may be a few more, are recognised as endemic for the NP (*Clathrocyclas* sp., *Saccospyris robusta*, *Tholospyris borealis*, *T. spinosus*, *Spongurus pylomaticus borealis*), while 15-16 are bipolar (*Stylochlamidium venustum*, *Echinomma delicatulum*, *E. quadrisphaera*, and others). It is important to note that the typical form of *S. venustum* is widely distributed in the Antarctic deposits, but is absent in the GIN seas. Some of the species from the arctic-boreal assemblage are probably amphiboreal, for example *Botryocampe* *inflata*. Most of the above mentioned species have the widest distribution in the NP, however, some of them are more abundant in the Eastern NP, others in the Western NP.

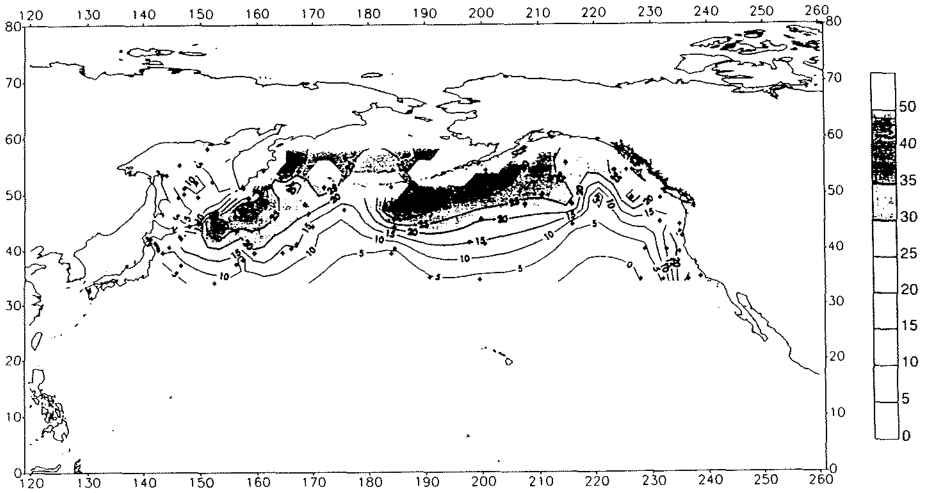

Fig. 3: Total content of the most numerous cosmopolitic species (%).

The transitional assemblage includes (besides members of the NP arctic-boreal fauna) rare specimens of some widely distributed tropical species, and species found only in the sediments underlying the zone of mixing waters of the North Polar Front and the North Pacific Drift, such as: *Heliodiscus asteriscus, Pterocorys cranoides, P. junonis, Spongocore puella, Spongaster tetras irregularis, Tholospira* sp., *Actinomma medianum* and others. (Fig. 4a-d)

Data on the quantitative distribution of polycystine assemblages in the NP and OS, which have a different biogeographical status, can be used as an environmental indicator. The total content of cosmopolitic species, more than 25 % and 35 % of the total fauna, probably correlates with an average annual surface water temperatures of ca. 4-12°C and ca 4-8°C, respectively. When the endemics only make up ca 10%, the association probably corresponds to a surface water temperature of ca 4-6°C.

A maximum concentration of specific species can indicate an even more precise surface temperature range. The cosmopolitic species *Lithomitra arachnea* roughly corresponds to ca. 5-9°C; *Tholospyris borealis* (endemic of the NP and OS) corresponds to ca 4-7°C; amphiboreal *Botryocampe inflata* corresponds to ca 4-6°C and a content of the bipolar *Stylochlamidium venustum* of more than 2% corresponds to a temperature of 5-7°C.

The abundance of radiolarians and quantitative boundaries of species ranges and their associations are intimately connected with the hydrological parameters such as boundaries between water masses, primarily between currents.

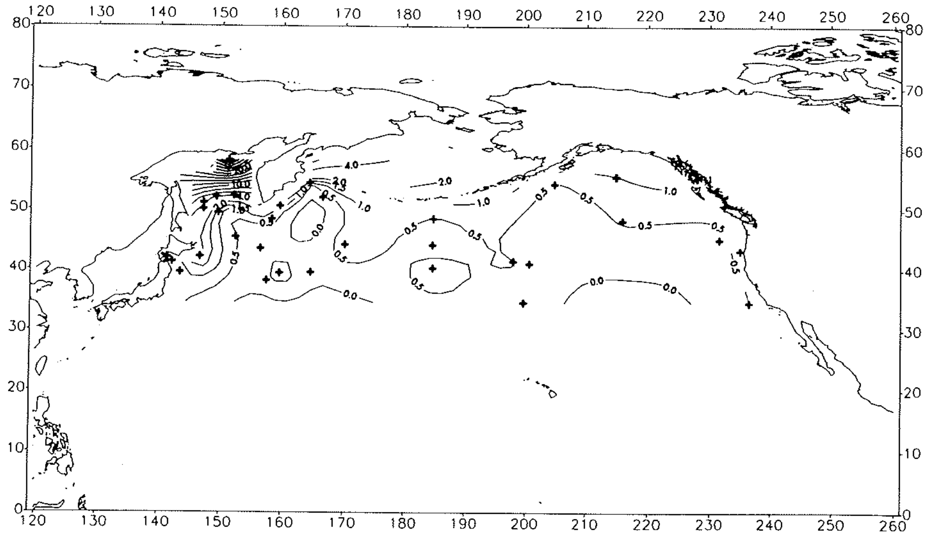

Fig. 4a: Distribution of the amphiboreal species *Botryocampe inflata* (%) in the surface layer sediments of the NP and OS.

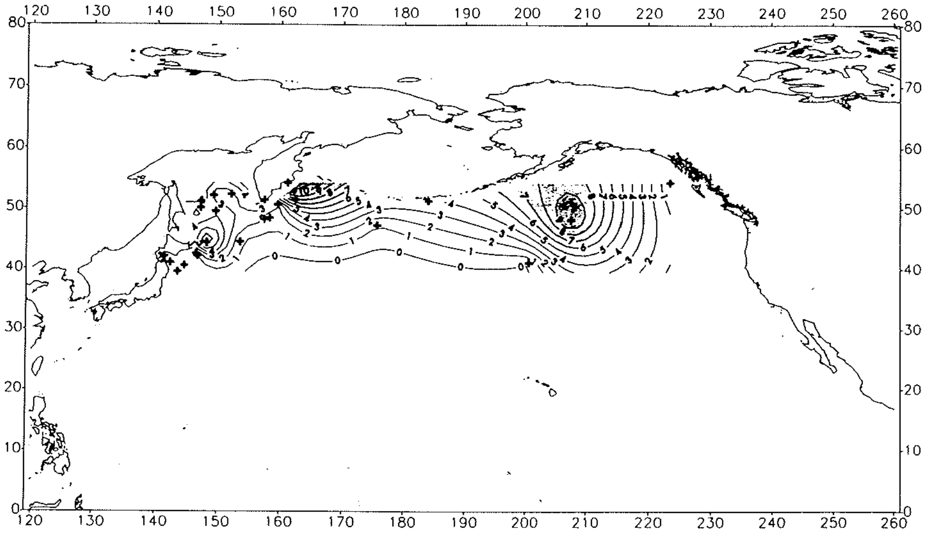

Fig. 4b: Distribution of the arctic-boreal zone endemic species *Tholospyris borealis* (%) in the surface layer sediments of the OS, BeS. and NP

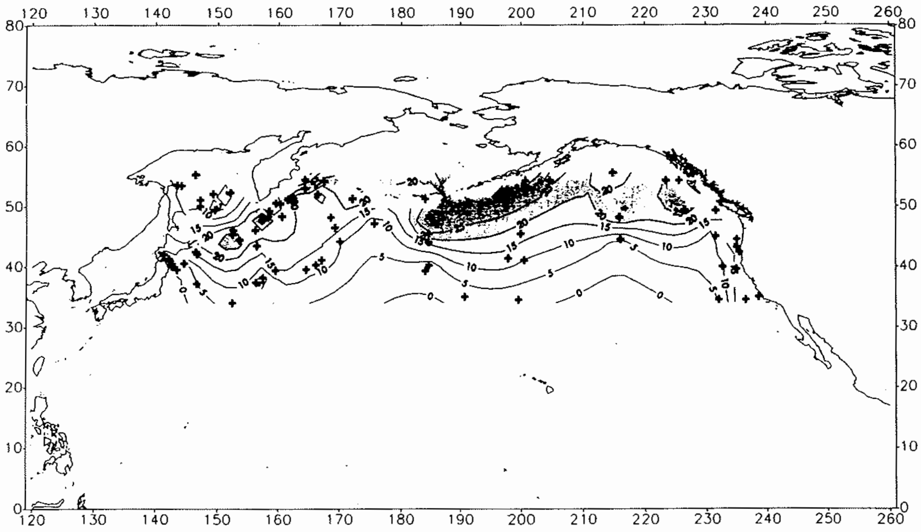

Fig. 4c: Distribution of the cosmopolitic species *Lithomitra arachnea* (%) in the surface layer sediments of the NP and OS.

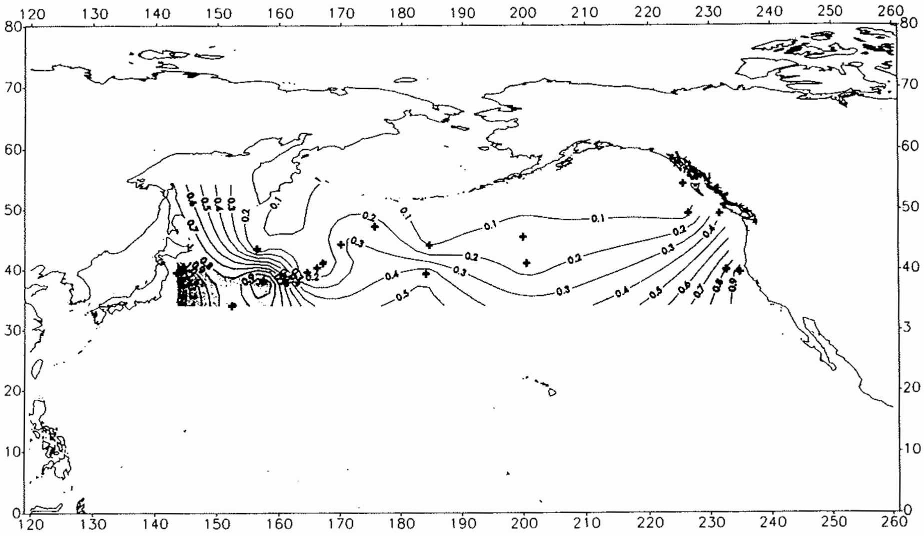

Fig. 4d: Distribution of the tropical species *Pterocorys cranoides* (%) in the surface layer sediments of the NP and OS.

When species distribution maps for the North Pacific are compared with the distribution of the dominant polycystine associations,or factors (Sachs 1973), there is a rather good correlation of these boundaries.

Preliminary cluster analyses, which have been done on the base of the distribution of 113 species from 110 stations, show a strong difference between the arctic samples and all others. The latter can further be divided into the following groups:
(1) the Subarctic Gyre,
(2) the Western Subarctic and the Okhotsk Sea gyres
(3) a group which probably may be connected with the zone of water mixing of Kuroshio and Oyashsio;
others correspond to the California Current and the transitional zone of the North Pacific.

From the OS sediments almost 70 species have been recognised, of which ca 22-24 species are regularly found, while only ca 11-12 species are common and widely distributed. Another 11 species are rare in the OS, however, they are common in the NP. In the surface sediments of the OS two different associations can be recognised:

(1) "The Okhotsk Sea Assemblage" is connected with the continental shelf and is characterised by ca 16 species, a rather low number. Characteristic for this fauna is the presence of some very peculiar morphological forms of *Phormacantha hystrix*(?), *Arachnocorys dubius* and *A. pentacantha*. and others (Kruglikova, 1975), and a rather high level of dominance of some species. These forms are also often found on the shelf, or at nearshore stations in the NP, in the Arctic region and in Norwegian fjords. It is possible to suggest that these morphologies are associated to the neritic province.

(2) "The Pacific Ocean Assemblage" is usually found off the shelf in the OS, at deeper stations, with an assemblage of ca. 50-60 species. However, most of these species are also found in the deep NP sediments. The above mentioned peculiar morphological forms are only sporadically present in the deeper parts of the OS. Characteristic for this association is the variable morphology of many species that are well known also from the NP, such as *Tholospyris borealis* and *Cycladophora davisiana* forma "marina". The level of dominance is lower.

The "Pacific Ocean Assemblage" of the Okhotsk Sea can further be subdivided into two associations. In the southern part of the South Basin, the assemblage differs from the northern part only by presence of rare specimens of *Stylochloclamidium venustum, Stylodictya stellata stellata* (= *S. validispina*?), *Tholospyris borealis,* and *Botryocampe inflata*. The assemblage is dominated by *Cycladaphora davisiana* forma "marina" and other *Cycladaphora*-related morphogroups, the *Peridium* group, the *Phormacantha* group, and others. *Lithomitra linneata* is in general characteristic for the OS, BeS and the GIN seas associations. Such species as *Lithomitra arachnea*, the typical form of *Cycladaphora davisiana*, and *Lithomelissa borealis* are very rare in the OS and most abundant and widely distributed in the NP. Their presence in the OS is an indicator of the inflow of deep or intermediate Pacific waters.

Radiolarians which were found in the sediment surface layer of the BeS are more diverse than those from the OS and certainly more intimately connected with the NP fauna. The abundances and numbers of cosmopolitic species are higher, but the most widely distributed species are *Stylochlamidium venustum* (as in some samples of the OS) and *Spongotrochus glacialis*, *Lithomelissa setosa, Phormacantha hystrix, Tholospyris borealis, Stylodictya validispina, Lithomitra arachnea, Botryocampe inflata* and others.

The study of taxonomy and distribution of such species as *Cycladophora davisiana* typ., *C. davisiana* "marina", *Amphimelissa setosa, Lithomitra arachnea, L. linneata, Stylochlamidium venustum, Cromyechinus borealis* (= *Actinomma boreale*), *C. antarctica* etc. is very useful for modern biostratigraphy and paleooceanography. The following conclusions can be made:

(1) *C. davisiana* is widely used in paleoreconstructions. This species has quite a variable morphology, probably related to different subspecies or ecological forms, which inhabit different ecological niches. Thus, *C. davisiana* (I call it forma "marina"; widely distributed in the OS) differs by morphology and distribution from *C. davisiana* (I call it "typical") and was described by Ehrenberg. This form can be found quite often in the open ocean and is rather rare in the neritic areas.

(2) It is important to note that the typical *S. venustum* is distributed mainly in the North Pacific and the Far Eastern seas (where it is more abundant than in the open Pacific Ocean) as well as in the Antarctic deposits. It is absent in the GIN seas, but related species as *Stylochlamidium* sp. were found in two very short intervals (in K. Bjørklund's slides of DSDP, site 646, Labrador Sea): During the first interval, around ca. 1 Ma B.P., it occurred with only ca. 3.5%, while during the second interval, around ca. 120 ka B.P., it reached a little more than 26% (ages were calculated on the base of paleomagnetic and micropaleontological dating points, K. Bjørklund, 1998, pers. comm.). Today such high occurrences or species dominance can only be found in neritic environments or in nearshore areas.

(3) *Lithimitra arachnea* Ehr. (*L. arachnea, L. linneata* and *L. nodosaria* were all combined by Riedel, 1958) should definitely be divided into three different species. *L. arachnea* is widely distributed in the NP and in the Antarctic, but it is very rare in the North Atlantic (if present at all), but *L. linneata* is very abundant in the OS, BS and the GIN seas.

The arctic-boreal associations from the NP and the Far Eastern seas along the same latitudes have in common the majority of species (more than 70 species), but differ considerably in terms of the relative abundance of the species, the composition of dominant species, and their number and level of dominance. Species dominant for the OS have a stronger morphological variability than those from the NP. Species such as *Stylochlamidium venustum, Botryocampe inflata, Cycladophora davisiana* (forma "marina"), *Lithomitra arachnea* and *Tholospyris borealis, Cromyechinus borealis* (= *Actinomma boreale*) are often dominant in the assemblages of the Far Eastern seas.

The polycystine radiolarian association from the GIN seas surface sediments makes it possible to conclude that the Arctic-Boreal zone, including the GIN seas and fjords and the Far East seas, have many species in common. The Atlantic and Pacific oceans have their different endemic species, and they differ strongly in the distribution of some dominant species. Based on my data and data provided by K. Bjørklund (pers. comm.), it is possible to suggest that the following species are endemic for the GIN seas: *Ceratospyris hyperborea, Nephrospyris knutheiri, Amphimelissa setosa*; endemics of the NP are mentioned above. The GIN seas population consists of only ca. 70 species, a significantly lower number than in the Arctic-Boreal NP where ca. 200 species can be found. The richest association hitherto found in one GIN seas sample consisted of 43 species.

The relative abundance of the higher ranking radiolarian taxa in the OS differs from that in the NP. In the OS the dominant higher taxa are *Cyrtidae, Discoidea, Acanthodesmidae,* and *Cannobotryidae* while in the NP the *Acanthodesmidae* and the *Cannobotryidae* are significantly less abundant. High rank taxa of radiolaria from the GIN seas are also different from those in the NP, and they are very much different from all other regions of the World Ocean. One characteristic feature is the rather high abundance of *Phaeodaria* in the GIN seas, a group which is hardly seen in the OS, JS (Kruglikova and Zasko, 1997) and NP. Furthermore, the number of *Discoidea* is very low in the Norwegian Sea, in contrast to the NP and the Far Eastern seas. The GIN seas can, based on higher taxa, be divided into three areas. In the west, at the Iceland Plateau area, where cold Arctic water predominates, the *Cannobotryidae* (*Amphimelissa setosa*) make up 66-79 % of the total fauna. In the fauna in the western part of the Norway Basin, where the mixing of cold and warm water takes place, the assemblage is characterised by *Plagiacanthidae, Cannobotrydae, Eucyrtidae,* and *Astrosphaeridae*, which fluctuate between 66 and 100 %. Finally, in the eastern Norway Basin, influenced by the warm Norwegian Current, the family of *Lithelidae* makes up 46 % of the total fauna (if this is not connected to preservation (?)); this is a percent value that never occurs in the NP, but can be exceeded, up to 70-90 % of the assemblages in the southern part of the JS sediments.

The sediments in the cores from the South Basin of the OS may be older than those from the BeS. The diatom *Rhizosolenia curvirostris* (last appearance datum at about 270 ka) could often be found in the OS. The BeS sediments from the Navarin and Aleuthian basins, were younger. However, the age, based on radiolarians, is older than indicated by the diatoms. In the basal part of the BeS cores, *Lychnocanium grande* can be found quite often as well as abundant *Amphimelissa setosa. L. grande* is not abundant but rather widely distributed in the OS, but *A. setosa* is very rare. This means that the studied sediments from the OS cores are not younger than 50 ka and most likely older than 270 ka. The age of the BeS deposits is therefore Late Pleistocene, not Holocene.

Data on the distribution of 140 species and the biogeographical associations (based on the total content species) were used to study the Quaternary deposits in 4 sediment cores from the central part of the NP. The northernmost core corresponds to the position of the northern boundary of the transitional zone of the Pacific waters. The southernmost corresponds to the northern boundary of Subtropical zone (Fig. 1). Findings of *Stylatractus universus, Rhizosolenia curvirostris, Stylacontarium aquilonium, Amphimelissa setosa* and *Lychnocanium grande* make it possible to calculate the age of the deposits and the sedimentation rates. The fluctuations in the content of the biogeographical associations through time, in a south-north profile of the NP, are connected with climatic fluctuations. On the base of these down core observations it is possible to identify the periods of warming and cooling in the region. The warmest stages, on the base of radiolarians, were (besides Holocene time) around 250 ka and around 400 ka, correlating probably with the Riss interstadial and Mindel-Riss interglaciation (Fig. 5).

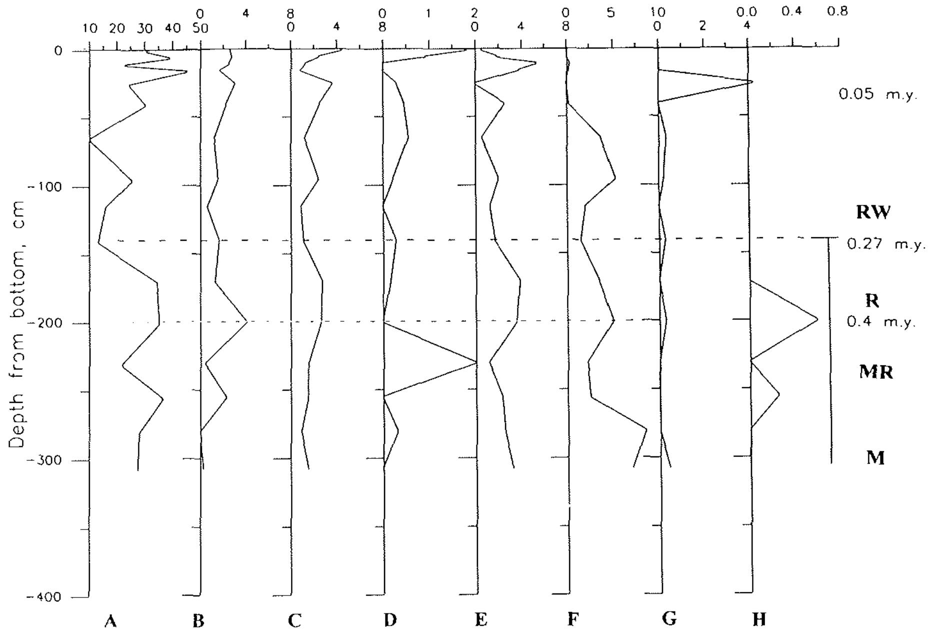

Fig. 5: Downcore distribution of different biogeographical radiolarian groups and species (%) in core 4110 from the NP (45°47'N, 160°10'):
A - cosmopolitic, B - endemic of OS and NP, C - bipolar and endemic of NP, D - tropical, E - *Cycladophora davisiana*, F - *Amphimelissa setosa*. G - *Lychnocanium grande*, H - *Stylatractus universus.*

Conclusions

1. Three different regions can be defined based on the abundance distributions of radiolarians : I) the Arctic basin , II) the Okhotsk Sea and the nearshore regions of the Pacific Ocean, and III) the open Pacific.

2. About 200 species of Polycystine radiolarians were identified from the surface sediments of the Arctic Basin and Arctic-Boreal zone north of 37-40°N in the North Pacific.

3. The biogeographical analyses which have been done for the first time in the North Pacific area will be the base for future paleoreconstructions. Comparison of these radiolarian assemblages with those from other regions of the World Ocean shows that associations from the Arctic and Arctic-Boreal zone of the North Pacific are composed of 3 biogeographical types of species: cosmopolitic, endemic (of the Arctic-Boreal Zone of the North Pacific and probably Okhotsk Sea, endemic of the GIN seas and amphiboreal species) and bipolar. These groups of species have a different biogeographical status and probably occupy different depth layers and have a different migration history into the studied region.

4. Three different species assemblages can be recognised in the study area: Arctic, arctic-boreal and transitional. Few polycystine species, which were identified in the High Arctic region and that probably have a circumpolar distribution, and others that are dominated and widely distributed in the Low Arctic Seas, are numerous in the GIN seas and the Norwegian fjords. It is suggested that the majority of them, except *Amphimelissa setosa*, migrated very recently into the Arctic Basin from the North Atlantic. However, the absence of *A. setosa* in the North Atlantic deposits in the interval from 1 Ma to ca. 13.4 ka and in the North Pacific at ca. 80-100 ka, permits to propose that their migration into the Arctic could have had different routes at different times. Polycystine radiolarians are more numerous and diverse in the Amerasian than in the Eurasian part of the Arctic Region. This suggests that the majority of the species in the Arctic assemblage (especially the cosmopolitic species) in the Amerasian part of the Arctic Basin came from the Pacific. No endemic species from the Arctic Basin have been recognised.

5. The assemblages from the North Pacific and the Far Eastern seas are characterised by other species than in the Arctic Basin.

6. In the surface sediments of the Okhotsk Sea two different associations can be recognised: I) The Okhotsk Sea Assemblage is connected to the continental shelf and characterised by a low number of species and the high abundance of some peculiar morphological forms typical for the shelf or nearshore deposits of the North Pacific, the Arctic Basin and the Norwegian fjords. It is possible suggest that these are neritic morphogroups. II) The Pacific Ocean Assemblage can usually be found at deeper stations in the Okhotsk Sea and is interpreted as indicators of deep Pacific water being introduced to this area.

7. Radiolarians which were found in the surface sediment layer of the Bering Sea are more diverse than those from the Okhotsk Sea, and certainly more intimately connected with the North Pacific fauna, *Amphimelissa setosa* is absent just as in the Okhotsk Sea and North Pacific. This species is abundant in Pleistocene deposits of the Bering Sea and may have migrated from the Bering Sea a little later than from the North Pacific.

8. The arctic-boreal associations from the North Pacific and the Far Eastern seas along the same latitude have most species in common (more than 70), but differ considerably in terms of relative abundance of species, the most dominant species, their number, and level of their dominance.

Acknowledgments

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DIATOMS IN RECENT AND HOLOCENE SEDIMENTS OF THE NORTH PACIFIC AND THE BERING SEA

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Introduction

Diatoms, unicellular algae with thin silica shells, are well preserved and widely distributed in marine sediments. They have a high evolutionary and biogeographic variability. Data on diatom abundance and composition of their assemblages in sediments are used in paleoceanography as proxies for reconstruction of paleoenvironmental conditions.

For the North Pacific and the Bering Sea, preliminary studies of the taxonomic composition of the subfossil diatom flora in surface sediments were carried out. Data on the quantitative content of diatom shells, the taxonomic structure of assemblages and the distribution of certain most typical species in the surface and subsurface sediments have been published (Jouse et al.1969; Sancetta, 1979, 1981; et al.). However, the progress of the diatom systematic during the last years and the introduction of mathematical processing into micro-paleontological research requires a revision of diatoms from the collection of bottom sediments obtained during many earlier Russian expeditions to the different basins of the world ocean. The main point of this work is the refinement and detailed elaboration of records on the diatom biogeography and the definition of the relationship between the species occurrence in sediments and the oceanographic parameters.

Methods

We have analyzed 96 samples of surface sediments from the North Pacific and the Bering Sea and more than 150 samples of sediment cores from the Bering Sea, available in the core collection of the P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences, Moscow. Sediment samples were obtained by grabs and piston cores (0-5 cm core top samples) during the 31th and 33th cruise of R/V "Vitjaz" and the 29th cruise of R/V "Dmitriy Mendeleev" (Fig. 1).

Sediment material was treated according to standard procedures used in the Laboratory of paleoecology and biostratigraphy, P.P.Shirshov Institute of Oceanology: 0.5 g of air-dried sediment is heated in 10% solution of natrium polyphosphate, then boiled for 60 minutes in 30% solution of hydrogen peroxide. During the next 5-6 days samples are washed in distilled water to remove pelite and remains of natrium polyphosphate. Samples are then treated with 10% solution of chloric acid to remove carbonates. Finally, samples are washed again and a portion of the material is mounted under a cover glass and examined under the microscope with a magnitude more than 1200x.

As a rule, 200 to 600 individual diatom frustules were counted in each slide. Species percentages were calculated. The results of this study were entered in the computer data bank and were subject to a preliminary statistical analysis.

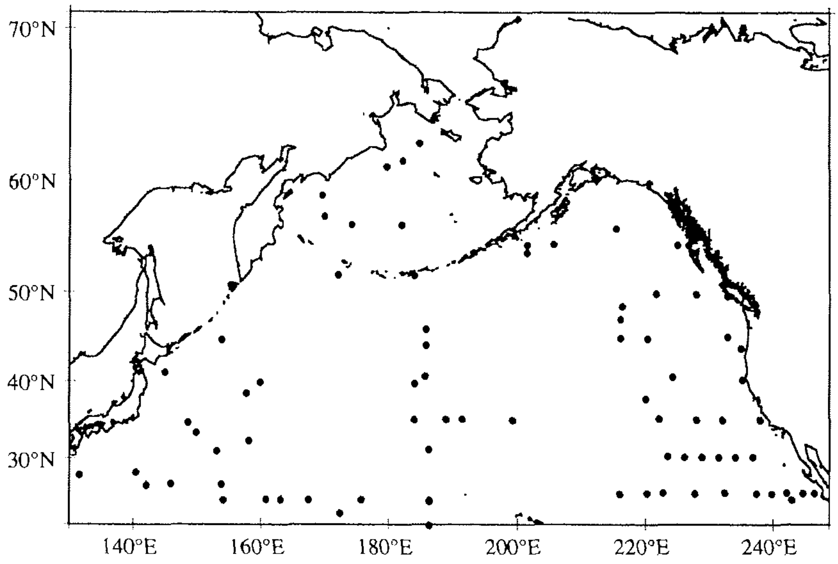

Fig. 1: Location map of sediment surface samples used in this study

Results and discussion

Diatoms in the surface sediments of the North Pacific

In total, 80 samples of surface sediments from the northern part of the Pacific Ocean were examined. The preservation of the diatoms is generally good and their abundance in most surface sediment samples is high. In most samples, an abundant diatom flora with a diverse taxonomic structure has been found. These samples are concentrated in the area of siliceous sediments north of 23°N in the western part and north of 30°N in the eastern part of the Pacific. In total, 114 diatom species were identified. Most species are autochtonous.

The analysis of the species concentration and the relationship to the average annual SST has revealed to the following regularities. The temperature range of 6-8°C is marked by the maximum content of following species (peak values):
Neodenticula seminae - 71.2%
Thalassiosira trifulta - 23.1 %
Rhizosolenia hebetata - 11.3 %
Thalassiosira antarctica - 10.8 %
Nitzschia grunovii - 3.8 %
Actinocyclus divisus - 3.6 %

Coscinodiscus pseudoincertus - 2.5 %
Thalassiosira ignota - 2.5 %
Th. kryophila - 2.4 %
Th. nordenskioldii - 1.5 %.

The temperature range of 9-12°C is marked by the maximum content of the following species (peak values):
Coscinodiscus marginatus - 32.5 %
Thalassiosira eccentrica - 15.3 %
Biddulphia aurita - 13.2%
Thalassiosira gravida - 10.0 %
Actinocyclus curvatulus - 6.4 %
Azpeitia tabularis - 4.9 %
Bacterosira fragilis - 1.8 %.

The temperature range of 13-19°C is marked by the maximum content of the following species (peak values):
Azpeitia crenulatus -20.6 %
Pseudoeunotia doliolus - 14.2 %
Rhizosolenia styliformis -6.1 %
Thalassiosira lineata - 5.4 %
Actinocyclus undulatus - 5.2%
Cyclotella triata - 2.5 %.

At the highest temperatures (from 21 up to 26°), only maxima of the subtropical and tropical species are developed (peak values):
Azpeitia nodulifer - 25.9 %
Nitzschia marina - 22.8 %
N. sicula -14.2 %
N. interrupta - 8.7 %,
Coscinodiscus radiatus - 7.4 %
Nitzschia bicapitata - 7.1 %
Thalassiosira leptopus - 5.71 %
Roperia tesselata - 5.9 %,
Coscinodiscus weilessii - 5.8 %
Hemidiscus cuneiformis -5.5 %
Rhizosolenia calcaravis - 5.4 %
Nitzschia longicollum -5.1 %
Rhizosolenia bergonii - 3.7 %
Azpeitia africanus - 3.7 %.

The relative abundance of 114 diatom species from each studied surface sediment samples from the North Pacific and the Bering Sea was analyzed to determine the following data for some selected climatostratigraphically important species:
1 - modern geographic distribution
2 - relation to surface water temperature and salinity
3 - detailed biogeographic records.

Some taxa with insignificant dissolution of valves in the water column (according to Tsoy and Wong, 1996) and with good preservation in the bottom sediments were selected: *Actinocyclus curvatulus, Azpeitia crenulatus, A. nodulifer, Coscinodiscus marginatus, Neodenticula seminae, Paralia sulcata,* *Pseudoeunotia doliolus, Rhizosolenia hebetata, Thalassiosira antarctica, Th. gravida, Th. oestrupii, Th. trifulta*, and *Thalassionema nitzschioides*. Distribution maps of these species were prepared (Figs. 2-14). The relationship between their abundance in the surface sediment and the surface water temperature was established (Figs. 15-16). The percentage distributions of the major species show distinct biogeographic features which correspond fairly well oceanographic parameters.

The most abundant cool water species in the investigated area are *Thalassiosira antarctica* and *Thalassiosira gravida* (resting spores). These species occur together, their common distribution corresponds to the boreal continental shelf, where the abundance of frustules exceeds 28%, and the continental margin at 55°N (less than 5%). Further south, they are essentially absent in the North Pacific (Fig. 2). Their significant occurrence in sediments correlates with a sea surface temperature range of 5 to 10°C (Fig. 15, left).

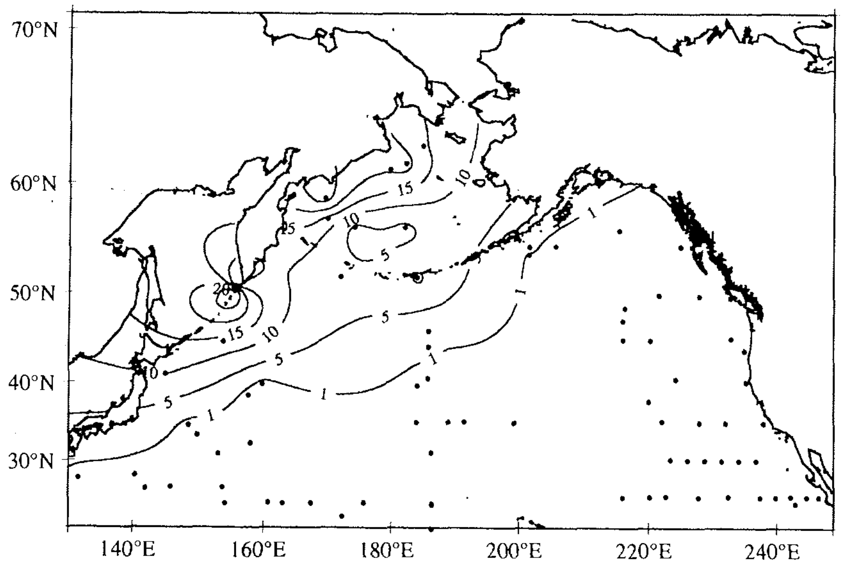

Fig. 2: Distribution of *Thalassiosira antarctica* and *Th. gravida* in North Pacific surface sediments

Neodenticula seminae (Figs. 3, 15, right) is the most abundant oceanic species exceeding more than 40% of the total diatom flora north of 50°N, especially along the Aleutian arc, in the area influenced by the Alaskan Gyre and the Alaskan Stream surface water. *Coscinodiscus marginatus* is the next most important cool oceanic species; its highest abundances (more than 20%) are centered in a latitudinal belt between 50 and 40°N, east of 180°E. Its distribution corresponds to the Subarctic Current (Fig. 4). *Actinocyclus curvatulus* has a similar distribution, with an abundance exceeding only 6-7 % (Fig. 5).

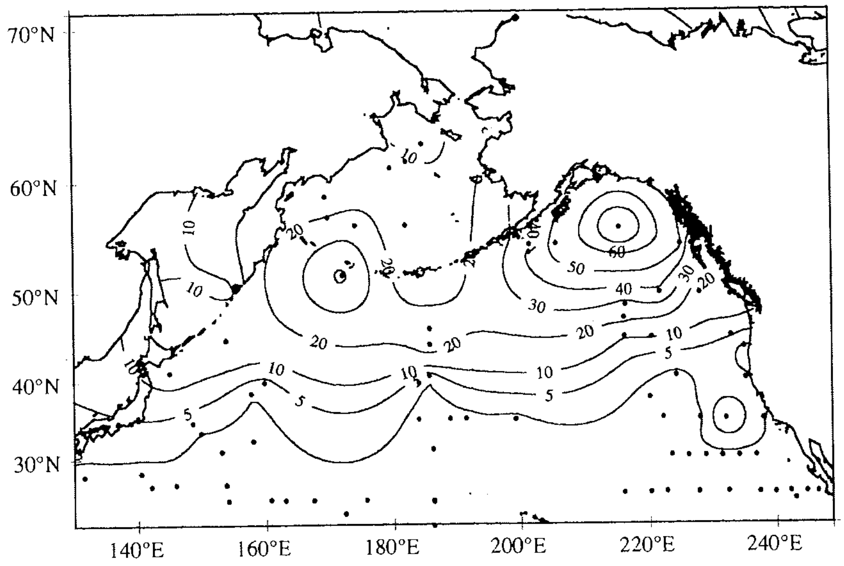

Fig. 3: Distribution of *Neodenticula seminae* in North Pacific surface sediments

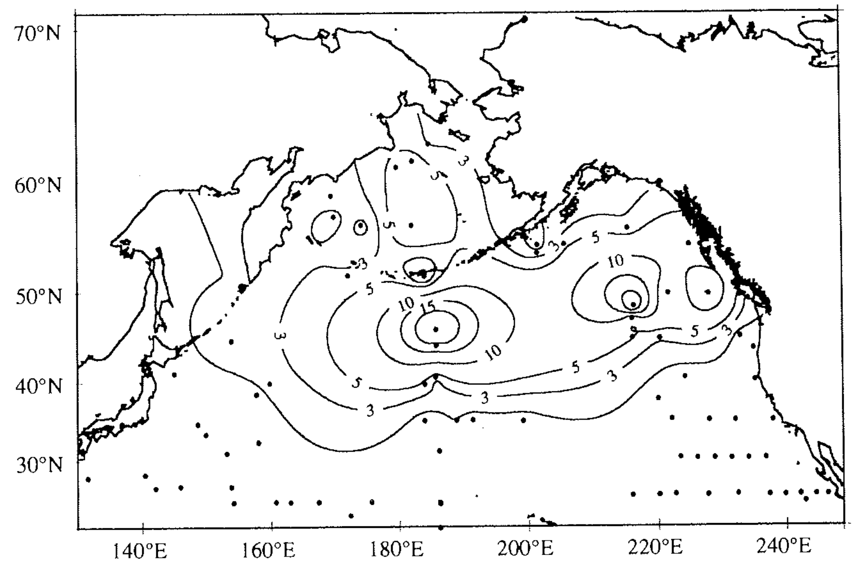

Fig. 4: Distribution of *Coscinodiscus marginatus* in North Pacific surface sediments

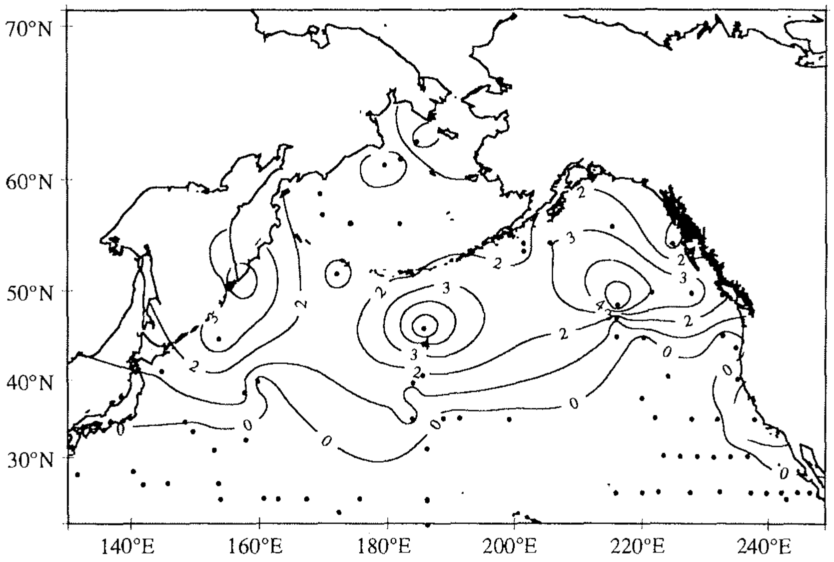

Fig. 5: Distribution of *Actinocyclus curvatulus* in North Pacific surface sediments

Rhizosolenia hebetata (Fig. 6) and *Thalassiosira trifulta* (Fig. 7) dominate the area of Bering and Okhotsk Gyres influence with abundance exceeding 25%. The mass presence of these species in sediments coincides with the temperature interval from +5 to +15°C (Fig. 16, left). *Thalassiosira trifulta* is a good indicator of influence nearness of sea basin.

Thalassiosira oestrupii (Fig. 8), *Azpeitia crenulatus* (Fig. 9) and *Pseudoeunotia doliolus* (Fig. 10) are the most important moderate warm water species, dominating in the area of the West Wind Drift Current influence with abundances exceeding 25, 15 and 15%, respectively. New data demonstrate that *Thalassiosira oestrupii* is more a moderate water species than it was thought earlier.

The important warm water species *Nitzschia marina* (Fig. 12) and *Azpeitia nodulifer* (Fig. 13) have their peak abundance (15-20%) in the area west of 160° E and south of 35°N. This area is characterized by warm surface water, connected to the influence of the Kuroshio Current.

Spores of the genus *Chaetoceros* (*Chaetoceros compressus*, *Ch. furcellatus, Ch. septentrionalis, Ch. subsecundus, Ch. raedicans*) are most common (more than 5%) in the western part of the studied region and may indicate a high phytoplankton productivity in the waters along the margins of the Pacific and the Bering Sea (Fig. 14). The benthic littoral species *Paralia* sulcata occurs only on the continental shelf, usually at water depths less than 100 m (Fig. 14). Both *Chaetoceros* spp. and *Paralia sulcata* do not have a close relationship between their highest abundance in the surface sediment and surface water temperature (Fig. 16, right).

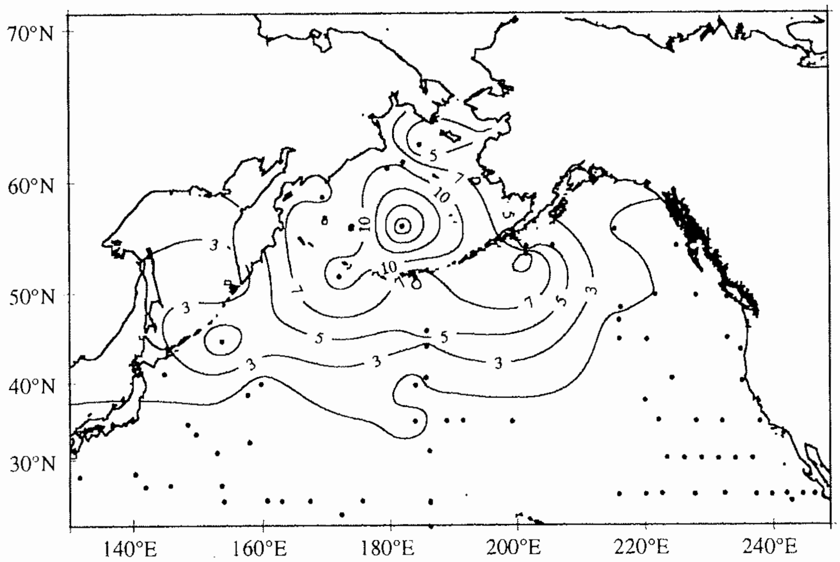

Fig. 6: Distribution of *Rhizosolenia hebetata* in North Pacific surface sediments

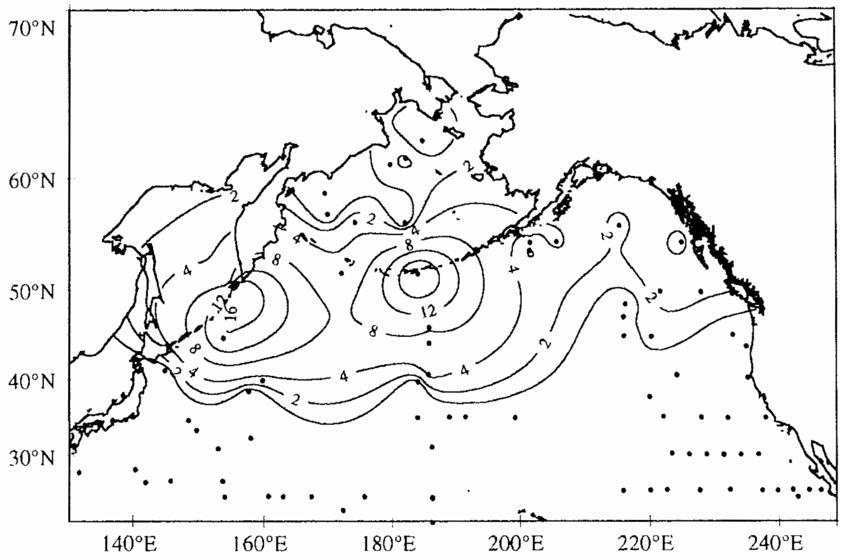

Fig. 7: Distribution of *Thalassiosira trifulta* in North Pacific surface sediments

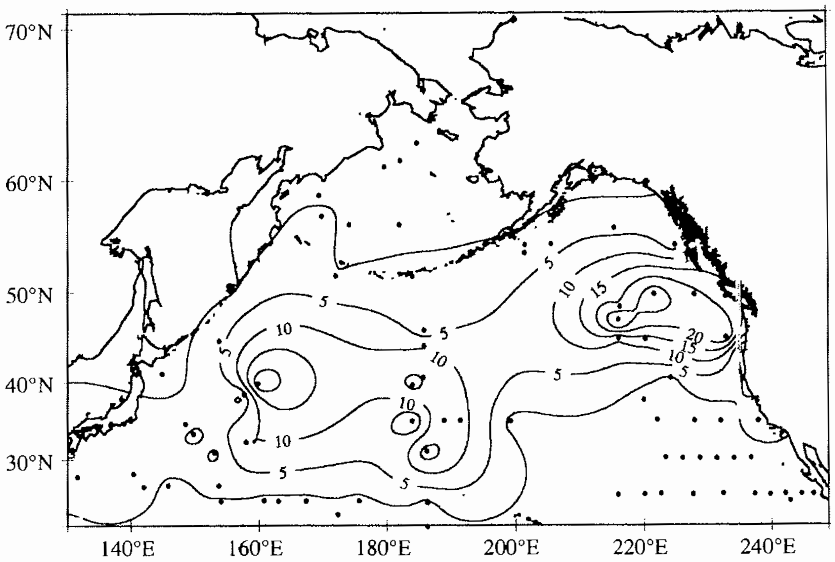

Fig. 8: Distribution of *Thalassiosira oestrupii* in North Pacific surface sediments

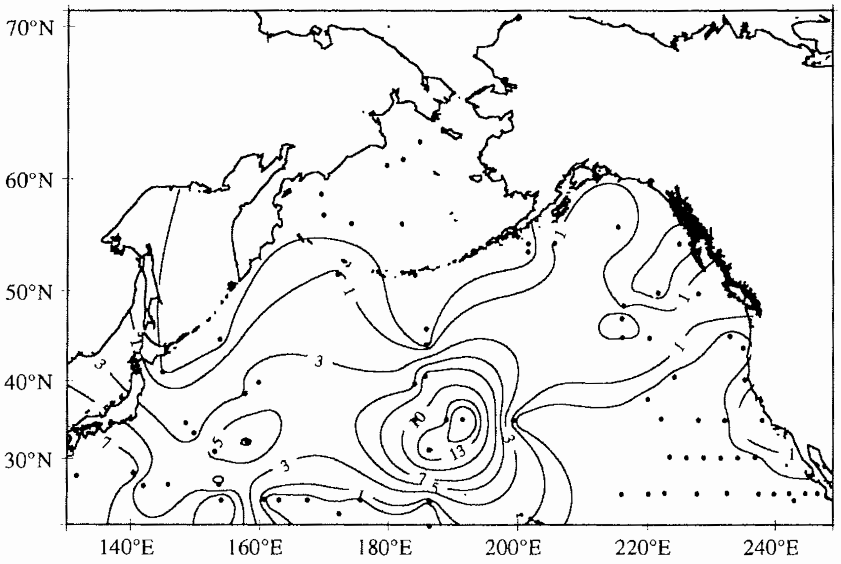

Fig. 9: Distribution of *Azpeitia crenatulus* in North Pacific surface sediments

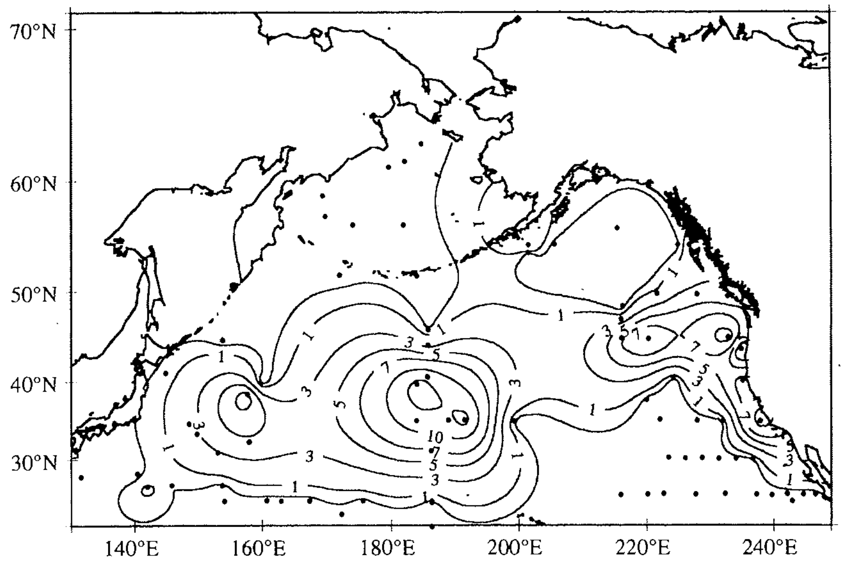

Fig. 10: Distribution of *Pseudoeunotia doliolus* in North Pacific surface sediments

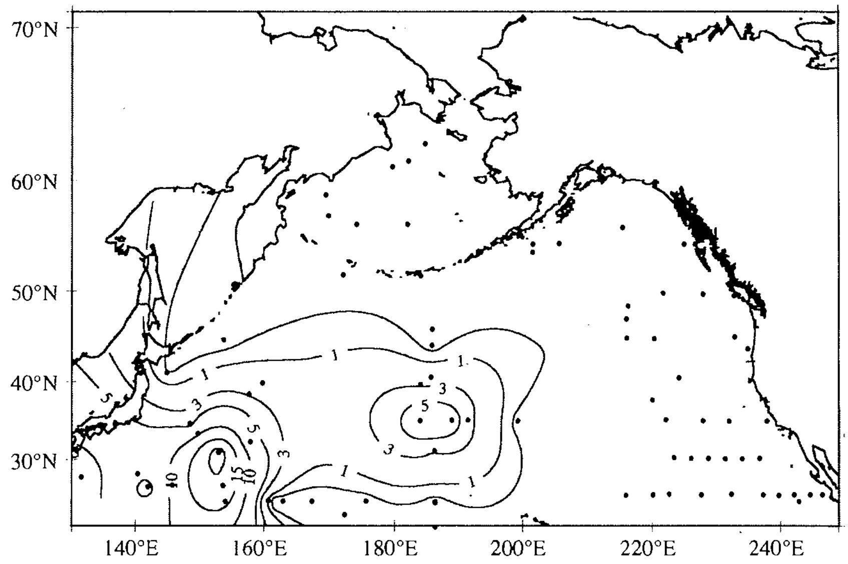

Fig. 11: Distribution of *Nitzschia marina* in North Pacific surface sediments

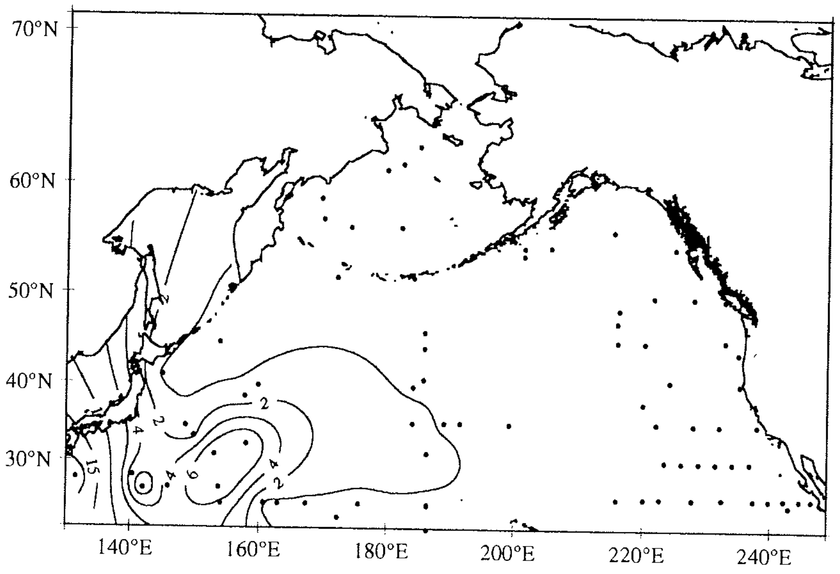

Fig. 12: Distribution of *Azpeitia nodulifer* in North Pacific surface sediments

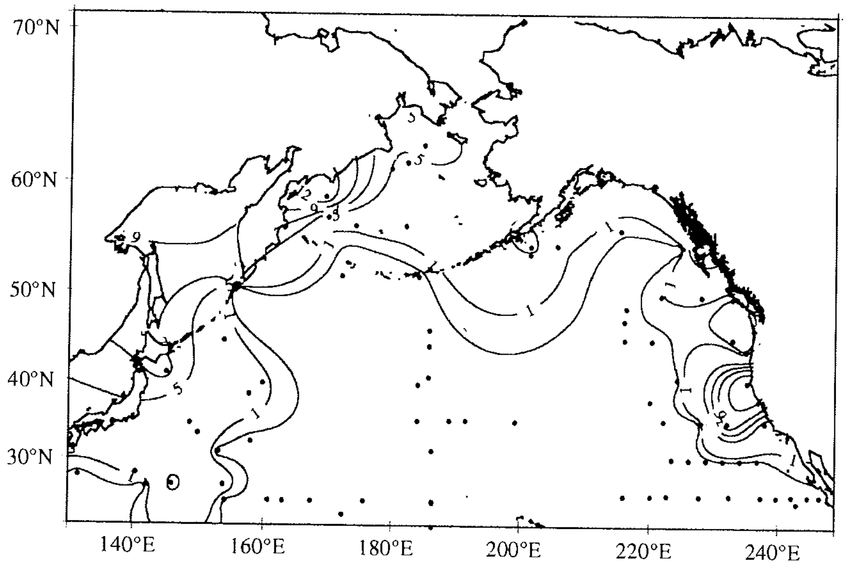

Fig. 13: Distribution of *Chaetoceros* sp. in North Pacific surface sediments

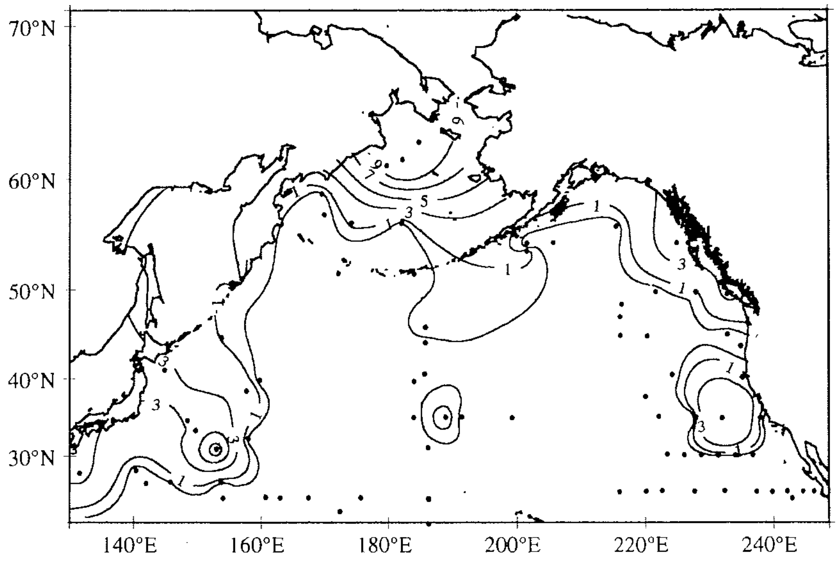

Fig. 14: Distribution of *Paralis sulcata* in North Pacific surface sediments

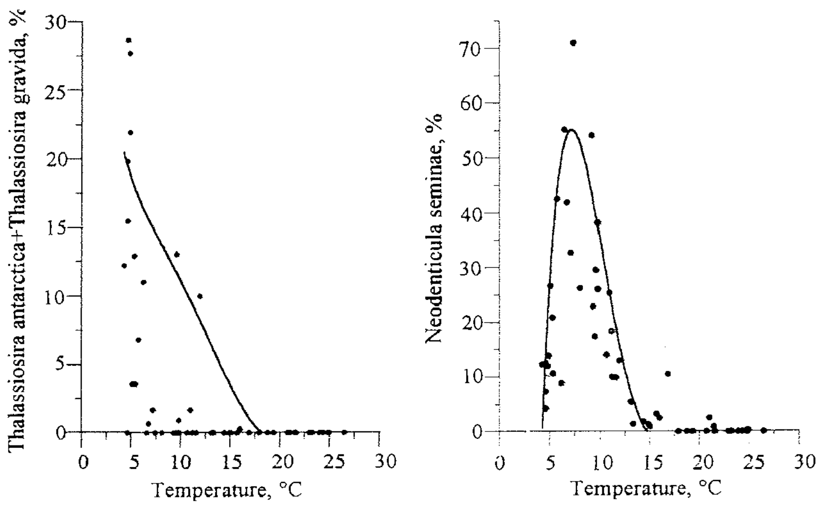

Fig. 15: Statistical relationship between the relative abundance of *Thalassiosira antarctica, Th. gravida* and *Neodenticula seminae*, and surface water temperature in the North Pacific.

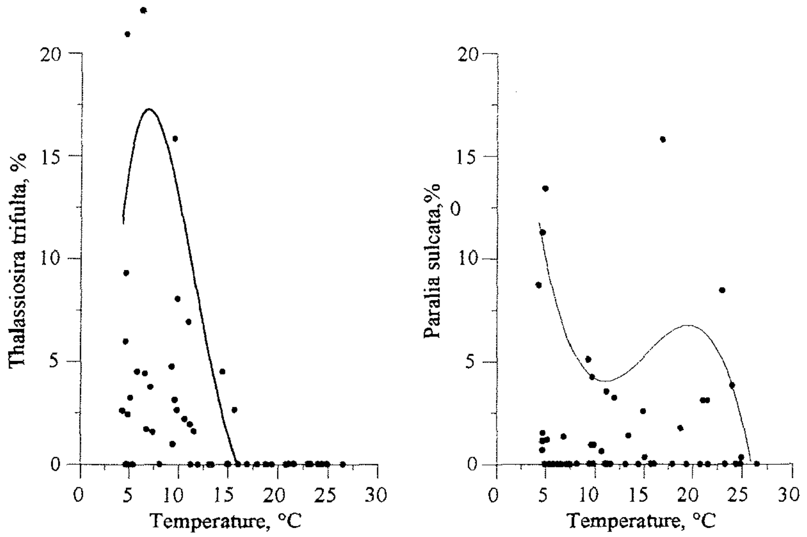

Fig. 16: Statistical relationship between the relative abundance of *Thalassiosira trifulta* and *Paralia sulcata* and surface water temperature in the North Pacific.

Diatoms in the recent and Holocene Bering Sea sediments

In the Bering Sea, diatoms were studied in 16 samples of surface sediments from different parts of the sea: The Kommandor Basin, the Shirshov Ridge, the Aleutian Basin, and the Navarin shelf. Using the published data (Sancetta, 1981), the subfossil diatom assemblages were divided into four groups.

In the southern deep-water parts of the Bering Sea, where water has a relatively high salinity (up to 34‰), the oceanic species *Neodenticula seminae, Rhizosolenia hebetata, Thalassiosira trifulta*, and *Actinocyclus curvatulus* prevail, forming the so-called "Bering Basin Assemblage" .

In the northern part of the Bering Sea, dominated by brackish shelf water at water depths of 50-100 meters and characterized by the longest annual presence of the sea ice cover (up to 6 months), the "Sea-Ice Assemblage" with dominating *Thalassiosira nordenskioldii, Biddulphia aurita, Bacterosira fragilis*, and *Nitzschia grunowii* is found.

The eastern part of the Bering Sea, with depths than 100 m and coastal brackish water, is characterized by species of the genera *Paralia, Melosira*, and *Navicula*, which dominate in the "Bering Shelf Assemblages".

In the western part of the Bering Sea, with strong seasonal changes of sea water temperature, strong winds, and high primary production, spores of the genera *Chaetoceros* and species *Thalassiosira antarctica, Th. gravida* , *Coscinodiscus marginatus, Thalassionema nitzschioides, Thalassiotrix longissima* and other, typical for the "Productivity Assemblage" complex, are prevailing.

Data on the recent diatom biogeography were used for a stratigraphy of Pleistocene and Holocene sediments. Five sediment cores were studied: Stn. 2548 from the Navarin shelf and stn. 2553 from the upper part of continental slope near Cape Navarin, stn. 2600 from the Aleutian Basin, stn. 2594 from the Shirshov Ridge, and stn. 2590 from the Komandor Basin. According to ratios of the above-mentioned taxonomic groups in the diatom assemblages, the sediments of each core were subdivided into transgressive and regressive units. Unfortunately, this study lacked direct time control data. However, according to Baldauf (1982) and Sancetta (1983), we can propose that the Pleistocene-Holocene boundary in the different parts of Bering Sea is characterized by the transition from a dominance of regressive diatom assemblages (including ice-related and litoral species) to a dominance of transgressive diatom assemblages with prevailing pelagic and "productivity" species. For instance, in core 2548 from the Navarin shelf, such transition occurs at a core depth of 300 cm (Fig. 17). Supposedly, the sediment interval of 0-300 cm represents the Holocene. Our earlier data (Levitan and Kazarina, 1982) and available published materials (Jouse, 1969; Sancetta, 1983) allow us to prepare a preliminary scheme of the Holocene sediments thicknesses in the Bering Sea (Fig. 18).

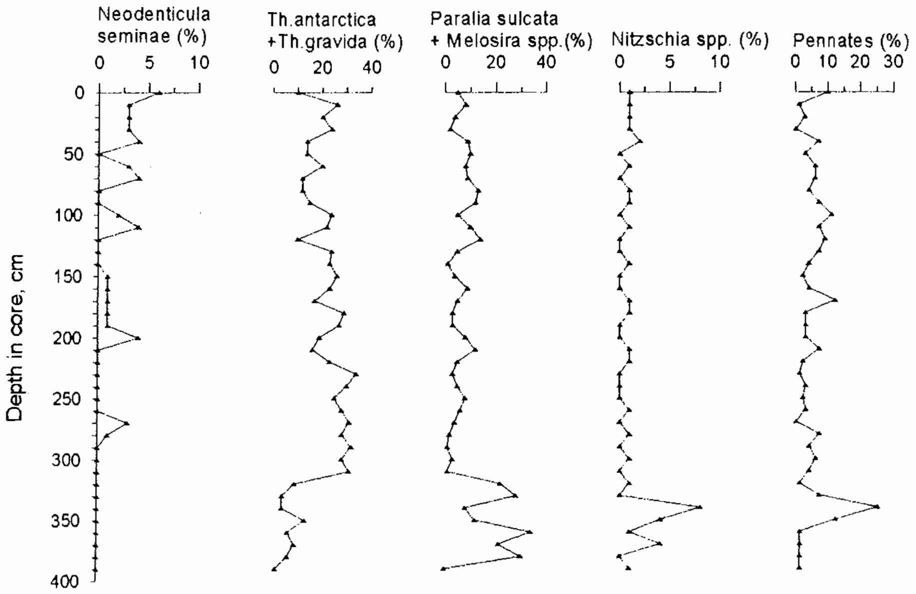

Fig. 17: Distribution of main diatom species in the sediment core 2548.

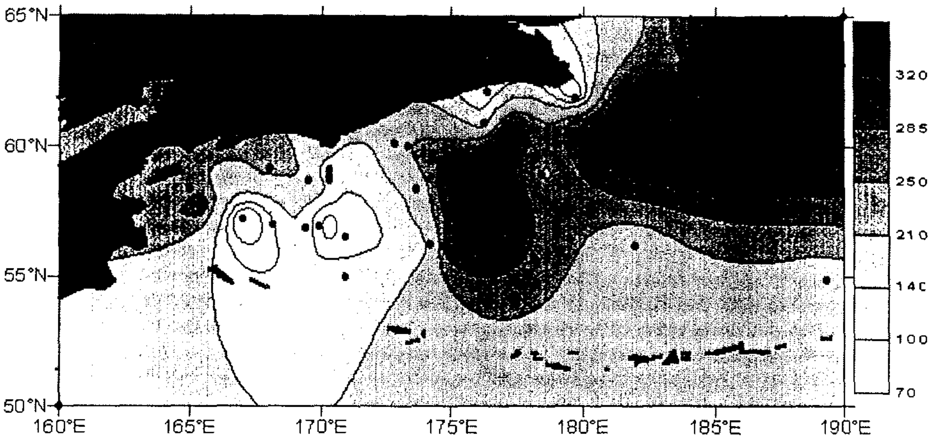

Fig. 18: Scheme of the Holocene sediments thickness in the Bering Sea.

Conclusions

(1) Diatoms in the surface sediments of the North Pacific and Bering Sea reflect the modern parameters of the overlying surface water: Temperature, salinity, currents, and bioproductivity. We have studied the correlation between features of the diatom species distribution and changes of each oceanographic parameter within these areas. Most oceanic species depend on the sea surface temperature. The next order of species from more cold water to more warm water ones is revealed: *C. marginatus, N. seminae, A. curvatulus, Th. oestrupii, Asp. crenulatus, Pseudoeunotia doliolus, Nitzschia marina*, and *Asp. nodulifer*. The neretic species *Th. antarctica, Th. gravida*, and *Chaetoceros* spp. are abundant in the nearshore productive regions. The sublitoral species *P. sulcata* and *Melosira* spp. live in regions of shallow depths and brackish water.

(2) Intervals have been revealed, when modern sea surface temperature exerted influence on the abundant occurrence of most diatom species identified in studied areas. Detailed data on the biogeography of the most dissolution-resistant and abundant species were obtained.

(3) Records of diatom assemblages from sediment cores of the Bering Sea allowed to define events of changes between transgressive and regressive stages in the history of this basin. According to criteria proposed by Baldauf (1982), Sancetta (1983) and others, the uppermost transgressive core interval is supposed to represent the Holocene. An initial map of the Holocene sediment thickness in the Bering Sea can be compiled.

Acknowledgments

We thank the German Bundesministerium für Bildung und Forschung (BMBF) for financial support within the "German-Russian Cooperation" program (grants 03F10GUS and 03F19GUS).

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ON THE PRESERVATION OF SEA-ICE DIATOM FRUSTULES DURING CLEANING IN HYDROGEN PEROXIDE AND ALCOHOL

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Abstract

The main goal of the investigation is to compare the preservation techniques of sea-ice diatom frustules during cleaning in hydrogen peroxide and alcohol. From cleaning in hydrogen peroxide, the most destroyed frustules were found to belong to 7 diatom species: *Berkeleya rutilans* (Trent.) Grun., *Corethron criophylum* Castr., *Cylindrotheca closterium* (Ehr.) Reim. et Lewin, *Entomoneis kjellmanii* Cl., *E. kufferathii* Manguin, *Proboscia alata* (Bright.) Sund., and *Rhizosolenia styliformis* Bright. The repeated washing of the diatom samples in alcohol did not significantly affect the diatom frustules. To make impartial assessment of the species composition of sea-ice diatom assemblages, the cleaning of diatom frustules in alcohol is recommended.

Introduction

The systematics of diatom algae is based on the morphological features of frustule and valve. To obtain optimum clarity of these structures, the cleaning of diatom cells from the organic material is necessary. At present, there are several methods of "cold" and "hot" cleaning (Kolbe, 1916; Kozlova, 1964; Hendey, 1938; Hustedt, 1958; Swift, 1967; Hasle and Fryxell, 1970). The removal of the organic material is a result of the reaction between the cell organic components and concentrated acids (sulphic or nitric), strong oxidizers ($KMnO_4$ or $K_2Cr_2O_7$), hydrogen peroxide, or alcohol. These reagents have a negative effect on weakly silicified frustules of some diatom species resulting in partial or full dissolution (or destruction) of frustules. The goal of the investigation is to compare how the cleaning of sea-ice diatom cells in hydrogen peroxide and alcohol affects the preservation of the frustules and to find out the species with the strongest destroyed cells.

Materials and Methods

Sea-ice diatoms and phytoplankton samples were collected by Dr. Vladimir A. Nikolaev (Komarov Botanical Institute, St. Petersburg, Russia) on board of R.V. "Academic Fedorov" in the Indian and Pacific sectors of the Southern Ocean in 1987-1988.

The samples of sea-ice phytoplankton were taken with bathometer and plankton net. Smaller pieces of drifting ice were taken directly from the water surface. Ice cores were taken using an ice corer.

The diatom samples were fixed with 40% neutral formaldehyd solution for a final formaldehyd concentration of 2-4%. A part of the sample was transferred to a test tube and washed from fixative by 3 times washing in distillated water. In order to avoid a loss of diatom cells with poured water out of the test-tube, several water drops were analyzed under a light microscope.

For cleaning of the diatom cells in hydrogen peroxide, 5-10 ml 30% hydrogen peroxide was added to the fixative-free sample, transferred to a fireproof test-tube and heated to 100°C. For cleaning of the diatom cells in alcohol, 96% alcohol was added to the fixative-free sample, and the test-tube was intensely shaken. When there was a lot of organic matter in the sample, the sample was washed with alcohol. When all organic matter was oxidized, the sample was washed from alcohol with distilled water. The time required to oxidize all organic material was usually 1-2 weeks, in a few cases up to one month. To control the oxidizing process, several drops of water containing diatoms were observed under a light microscope. Further procedures for preparation of permanent microscopic slides of the diatoms followed standard methods (Hasle and Fryxell, 1970; Anonymous, 1974).

Identification, microphotography and calculation of the diatom abundance in the samples were carried out under a light microscope NU-2. An accelerating voltage of 10-35 kV was used to study the diatoms under the scanning electron microscope JSM-35. A total of 65 samples was investigated.

Results

Comparison between samples cleaned in hydrogen peroxide and alcohol, and uncleaned ones have shown that the frustules of different diatom species were destroyed to different degrees. Upon cleaning in hydrogen peroxide, the most destroyed frustules were found to belong to 7 diatom species: *Berkeleya rutilans* (Trent.) Grun., *Corethron criophylum* Castr., *Cylindrotheca closterium* (Ehr.) Reim. et Lewin, *Entomoneis kjellmanii* Cl., *E. kufferathii* Manguin, *Proboscia alata* (Bright.) Sund., and *Rhizosolenia styliformis* Bright. (Table 1).

The number of *Cylindrotheca closterium* cells (Plate 1: 1 a) in the samples cleaned in hydrogen peroxide is at 58-82% less than in uncleaned ones (Table 1). The parts of the preserved frustules of this species appear as barely discernible valve outlines (Plate 1: 1 b).

The frustules of *Berkeleya rutilans* (Plate 1: 2 a) were less destroyed. The marginal valve areas were found to be dissolved, but the more silicified parts (valve endings and axial rib) were usually not destroyed

(Plate 1: 2b).The number of *B. rutilans* cells in the samples cleaned in hydrogen peroxide is by 16-18% less than in uncleaned ones (Tab. 1).
The weakly silicified frustules of the planktic diatom *Corethron criophilum* (Plate 1, 3a) were also destroyed after cleaning in hydrogen peroxide (Plate 1, 3b). The number of disintegrated frustules may reach 100% (Tab. 1).
After cleaning in hydrogen peroxide, the girdle areas of frustules of the two centric diatom species *Proboscia alata* (Pl. 1, 4a) and *Rhizosolenia styliformis* (Plate 2, 1a) were greatly disintegrated (Plate 1, 4b; Plate 2, 1b). The number of disintegrated frustules is 79-87% (Tab. 1).
The effect of boiling hydrogen peroxide on frustules of two pennate diatom species *Entomoneis kjellmanii* (Plate 2, 2 a) and *E. kufferathii* (Plate 2, 3a) was less significant. The destroyed frustules made up 5-8% (Tab. 1; Plate 2, 2b, 3b).
Upon repeated washing in 96% alcohol, sometimes, insignificant destruction of frustules was found only for two species - *Berkeleya rutilans* and *Corethron criophilum* (Tab. 1).

Table 1: Destruction rates of diatom frustules after application of different cleaning methods

SPECIES	RATIO OF DESTROYED FRUSTULES TO TOTAL NUMBER OF FRUSTULES OF THE SPECIES (%)		
	Uncleaned samples	Samples cleaned in hydrogen peroxide	Samples cleaned in alcohol
Cylindrotheca closterium	100	58-82	<1
Berkeleya rutilans	100	16-18	3-5
Corethron criophylum	100	90-100	5-10
Proboscia alata	100	79-85	<1
Rhizosolenia styliformis	100	80-87	<1
Entomoneis kjellmanii	100	5-8	<1
Entomoneis kufferathii	100	5-8	<1

The cleaning in alcohol did not markedly affect the frustules of the other species investigated (Tab. 1).

The frustules insignificantly destroyed upon cleaning in hydrogen peroxide belong to *Asteromphalus hookeri* Ehr., *Coscinodiscus bouvet* Karst., *C. centralis* Ehr., *Pseudonitzschia lineola* (Cl.) Hasle, *P. turgidula* (Hust.) Hasle, *P. turgiduloides* (Hasle) Hasle and *Synedra reinboldii* V.H..

The very long frustules of *Synedra reinboldii* were destroyed breaking off at the central part or near the endings. Sometimes, the insignificant destruction of marginal frustule areas was observed for the large marine centric diatoms *Coscinodiscus bouvet* and *C. centralis.* In rare cases, the destruction of valve endings was found in the pennate diatoms *Pseudonitzschia lineola*, *P. turgidula*, and *P. turgiduloides.*

After cleaning in alcohol, the destruction of diatom frustules of these species was not observed.

The well-preserved frustules upon cleaning both in hydrogen peroxide and alcohol belong to *Actinociclus actinochilus* (Ehr.) Simonsen, *Asteromphalus parvulus* Karst., *Chaetoceros bulbosum* (Ehr.) Heiden et Kolbe, *Coscinodiscus oculus-iridis* Ehr., *Eucampia antarctica* Castr., *Fragilariopsis curta* (V.H.) Hust., *F. cylindrus* (Grun.) Krieger, *F. kerguelensis* (O.M.) Hust., *F. obliquecostata* (V.H.) Heiden et Kolbe, *F. rhombica* (O.M.) Hust., *F. ritscherii* Hust., *Thalassiosira gracilis* (Karst.) Hust., *Thalassiosira gracilis var expecta* (V.L.) Fryxell et Hasle, *T. ritscherii* (Hust.) Hasle and *T. tumida* (Janisch) Hasle.

Conclusions

(1) Comparison of the preservation of diatom cells upon cleaning in 30% hydrogen peroxide and 96% alcohol give evidence for the disintegration and, sometimes, full dissolution of weakly silicified frustules.

(2) After boiling in hydrogen peroxide, the strongest destroyed frustules belong to seven sea-ice diatom species having very fine valves - *Berkeleya rutilans*, *Corethron criophylum*, *Cylindrotheca closterium*, *Entomoneis kjellmanii*, *E. kufferathii*, *Proboscia alata* and *Rhizosolenia styliformis.* More silicified species were usually better preserved .

(3) The repeated washing in alcohol did not markedly affect the frustules of the species investigated. Therefore, in spite of the boiling in 30% hydrogen peroxide, the cleaning in alcohol is recommended for the cleaning of the diatom cells from organic material, to preserve the original species composition of sea-ice diatoms, especially if some have weakly silicified frustules.

Acknowledgements

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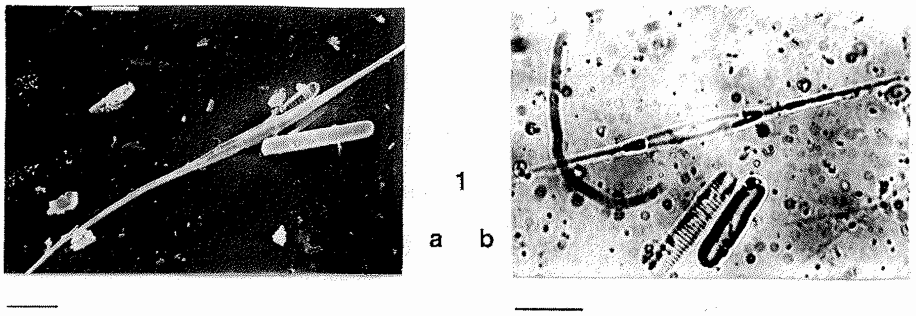
Plate 1

1 *Cylindrotheca closterium* (scale bar: 10 µm)
a – cleaning in alcohol, SEM
b – cleaning in hydrogen peroxide, LM

2 *Berkeleya rutilans* (scale bar: 10 µm)
a - cleaning in alcohol, SEM
b – cleaning in hydrogen peroxide, LM

3 *Corethron criophilum* (scale bar: 100 µm)
a - cleaning in alcohol, SEM
b – cleaning in hydrogen peroxide, SEM

4 *Proboscia alata* (scale bar: 10 µm)
a - cleaning in alcohol, SEM
b – cleaning in hydrogen peroxide, LM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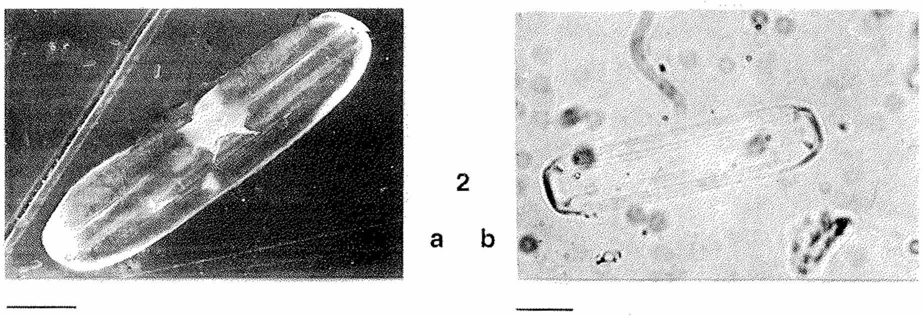
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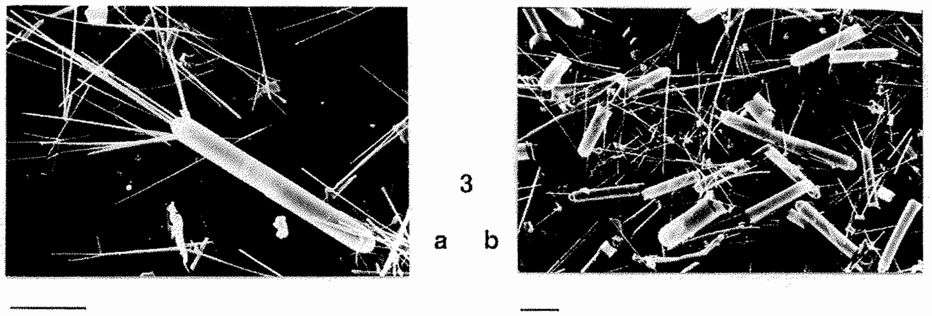
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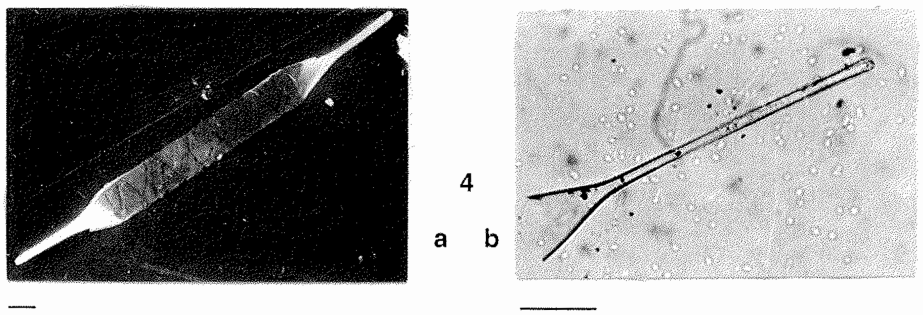
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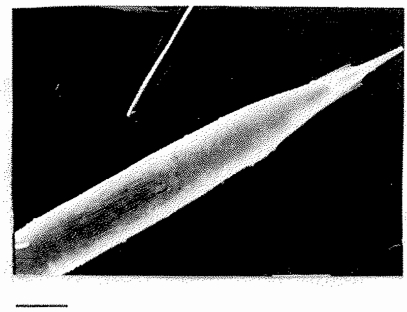
Plate 2.

1 *Rhizosolenia styliformis* (scale bar: 10 µm)
a – cleaning in alcohol, SEM
b – cleaning in hydrogen peroxide, LM

2 *Entomoneis kjelmanii* (scale bar: 10 µm)
a - cleaning in alcohol, SEM
b – cleaning in hydrogen peroxide, LM

3 *Entomoneis kufferathii* (scale bar: 10 µm)
a - cleaning in alcohol, SEM
b – cleaning in hydrogen peroxide, LM



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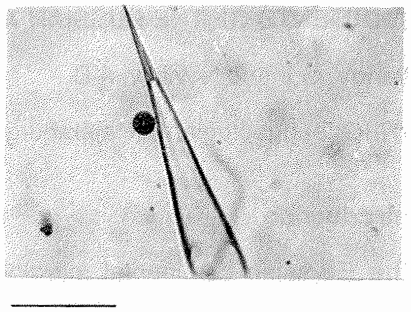

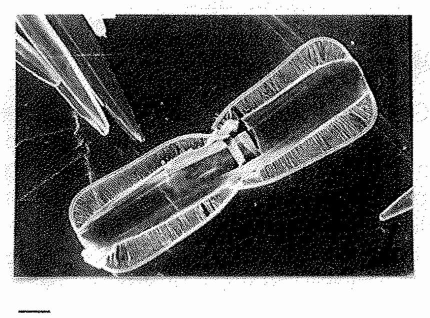

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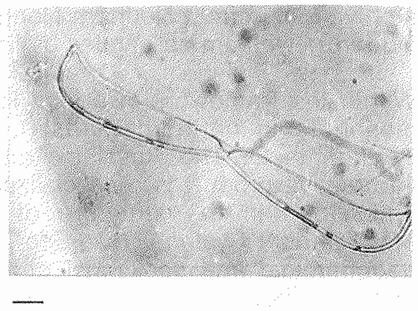

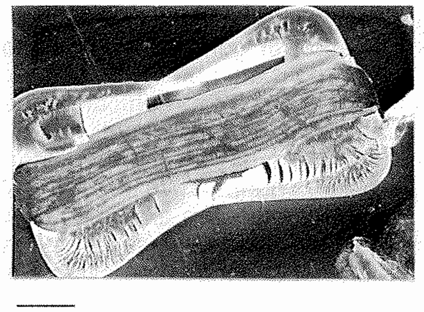

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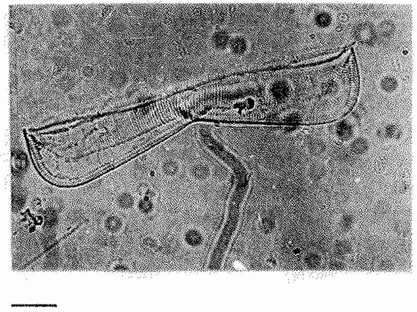

MICROPALEONTOLOGICAL DATA BASE "MICROFOSSILS IN BOTTOM SEDIMENTS OF THE RUSSIAN ARCTIC SHELF"

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Introduction

The Eurasian continental margin and adjacent marginal seas were almost inaccessible to Western scientists until the political opening of the Former Soviet Union. The excellent work by Russian scientists and their huge amount of sedimentological, geochemical, and paleontological data and samples archives, also from Northern North Atlantic and the North Pacific, were often hidden to western colleagues by lingual and political barriers.

Within the framework of a joint Russian-Germany project "Variability of the biosphere in northern Eurasia", a data base of "Microfossils In Bottom Sediments Of The Russian Arctic Shelf" was constructed. The resulting informative product is a specialized micropaleontological data base, which is embedded in the structure of a problem-oriented DBMS (Data Base Management System) "Geo-Eco", which allows to solve complex geological-geochemical and ecological problems in the investigation of Arctic seas. Materials from many scientific research cruises in the seas of the Russian Arctic served as a practical micropaleontological basis. Data for three main Arctic microfossils groups (diatoms, planktic and benthic foraminifers, ostracods) were systematized and generalized. The information for each group of fossils includes a systematic classification of genera and species names of the microfossils with a complete list of main attributes: Synonyms, author and year of description or re-identification; biogeographical range (arctic, arctoboreal, northboreal, bipolar, subtropical, tropical, southboreal, widespread); the relation to salinity (marine, brackish water, freshwater, euryhaline); habitat (littoral, panthalassic, neretic); quantitative microfossil composition for each of the samples. Numerical characteristics are given both in absolute values (number of specimens per slide) and by short codes (abundant, common, fair, rare, single). A hierarchical subordination of data is realized according to the following scheme: Investigated region (sea) - Object of study (section, well) - Lithological unit (sequence, layer) - Sample (macrodescription, complex of microfossils) - Unit analysis (quantitative and qualitative characteristics of each revealed fossil species).

Basic principles

Main attention was paid to the realization of two groups of main problems. The first one includes the following tasks:

- a treatment of a conceptual model for the preservation of initial stratigraphical-paleontological information based on data medium units;
- a determination of the hierarchical subordination of primary source data;
- a choice of a method for the representation of the different paleontological documentation;

- a connection of paleontological data with the results of other analytical investigations (lithological, geochemical, mineralogical and others).

The tasks of the first group are directly related to the list of the basic principles that must serve as the basis for the planned data base system. The function of the information system is impossible without their solution.

The second group of tasks is oriented for processing and summarizing of primary geological and paleontological data for the following solution of specific geological problems. The basic tasks of second group are given below:

- a determination of the range of typical tasks, solving by paleontological constructions, paleoenvironmental reconstructions;
- a description of sedimentary sequences and distinguishing of biostratigraphical units;
- areal mapping of micropaleontological parameters and the construction of multiple models of maps.

The tasks of the second group are indirectly outside the data base system. They are a category of appendices to the information system and can be used as the external application programs. In this case a basic conditions for the data base system are searching, selection and grouping data for various requests with the following compilation of output data sets in formats intended for their further processing.

Conceptual data model

An important prerequisite for the successful function of any information system is the exact reflection of the information image in it of the given application domain: objects and events that comprise it as well as properties and relationships. In this case an initial stage in the course of planning of this image is the development of a conceptual data model - a common information model of the application domain including problems of the classification, structurization, and semantic integrity (data validity and mutual consistency) of the primary information.

Initially the conceptual data model is compiled independently from limitations conditioned by a specific model (scheme) of the data (of one or another DBMS). After that the model is equipped with facilities of the database declaration.

The conceptual data model can be presented by the different storage structures of the data: hierarchical data model, network data model, relation data model. Conventionally the geological data bases are compiled according to the last (relation) scheme. Types of objects and connections of the application domain are given in the relation scheme as a set of data arrays linked between each other by external references (relation keys).

Figure 1 shows the principal scheme of the hierarchic subordination of information. Each conceptual layer of data organization characterizes a certain level of a detailed elaboration of information. The degree of this detailed elaboration increases while moving up to down from layer to layer. Hence each considered object on a current layer of data organization is an element of the set of attributes which characterize an object of a higher layer; at the same time this object is the set of attributes of subjected objects of the lower layer.

Availability of such a structure for hierarchic subordination of information conditions the nature of connections between objects (and its attributes) on different conceptual layers of data organization.

Two main vectors of direction of established connections - vertical and horizontal - should be differentiated. Both vectors are two-directed.

The vertical binding is provided by two types of dependence:
"One-to-Many" dependence - vertically from up to down,
"Many-to-One" dependence - vertically from down to up.
The horizontal binding between objects (or their attributes) on one hierarchic layer is manifested by a "One-to-One" dependence.

Data

A descriptive character of the geological and particular micropaleontological information is its peculiar feature. Often it is rather difficult to formalize by words the description of an object of investigation (sequence, lithologic layer or sample) that is habitual for a geologist. This fact presents certain difficulties with the storage of bulky descriptive blocks of data on data medium units. However, such "descriptive" approach in the geological practice is traditional, and we cannot ignore it. Hence the description of a studied object of any layer consists of two categories of data. The first category includes quantitative and qualitative parameters of an object expressed in the form of numerical and symbolic variables that have a fixed format. The second category includes the descriptive data presented in the form of a textual "field description" of an arbitrary length (undefined format). In this case the first category of data on one hand is the peculiar logical "squeezing" (sublimate) from the information field of the descriptive data that exactly reflects the nature of an object. On the other hand, the quantitative descriptions being the formalized data are the key words used for the selection and grouping information in the course of data retrieval on the database request.

Files system

The files system includes several different types of files:
Database files - include primary factographic data about various kinds of objects from the application domain, according to hierarchical layers of data organization (see fig.1). Data access (edit databases, input new data, search and create output data set) is carried out on the level of the ultimate user.
The following files are in the described system:

List of scientific cruises. File structure (available for updating fields):
- Index of the scientific cruise (scientific ship)

- Year of performance of work
- Index of the data source

List of survey stations. File structure (available for updating fields):
- Station index
- Latitude (degrees, minutes, seconds)
- Longitude (degrees, minutes, seconds)
- Water sea (meters)
- Bottom sampling
- Length of core (centimeters)
- Number of samples (per lithologic log)
- Author of collection (name of owner)
- Short description (note)
- Geological description (complete description of station)

List of selected sample unit. File structure (available for updating fields):
- Sample index
- Sampling interval (Up and Down relative to top of lithologic log, centimeters)
- Sample description

List of the microfossils. File description which contains the qualitative and quantitative characteristics of the microfossil complex at a specific station. The number of these files depends on the total quantity of analyzed stations. Information on each survey station is stored in a corresponding file description. A structure of each file is formed automatically, starting from the quantity of sample units selected and analyzed on the availability of microfossils. File structure (available for updating fields):
- Complex of microfossils (genera and species names)
- Main attributes (for each revealed fossil species)
- Numerical characteristics for each fossil species (by samples 1, 2, 3, ..., n)

Support files - include reference data to which the main executive program addresses during session. This group of files includes various catalogues, conceptional dictionaries and libraries. Each of these files includes information about a specific division of the application domain. In these files each concept of the application domain (semantic item) corresponds to a unique code (descriptor). Data access (edit and input new data) is carried out only on the level of the database administrator. The described system includes the following files:

List of the geographic regions in which scientific research works have been carried out.
For example:
- Barents Sea
- Kara Sea
- Laptev Sea
- East-Siberian Sea
- (etc.)

List of the geographic areas (inside a geographic region).
For example:
- Barents Sea: - North-Scandinavian rise

- Southern Barents basin
- Central Barents rise
- St. Anna Trough
- (etc.)

List of the types of bottom sampling.
For example:
- Gravity Corer
- Trawl
- Dredge
- Grab
- (etc.)

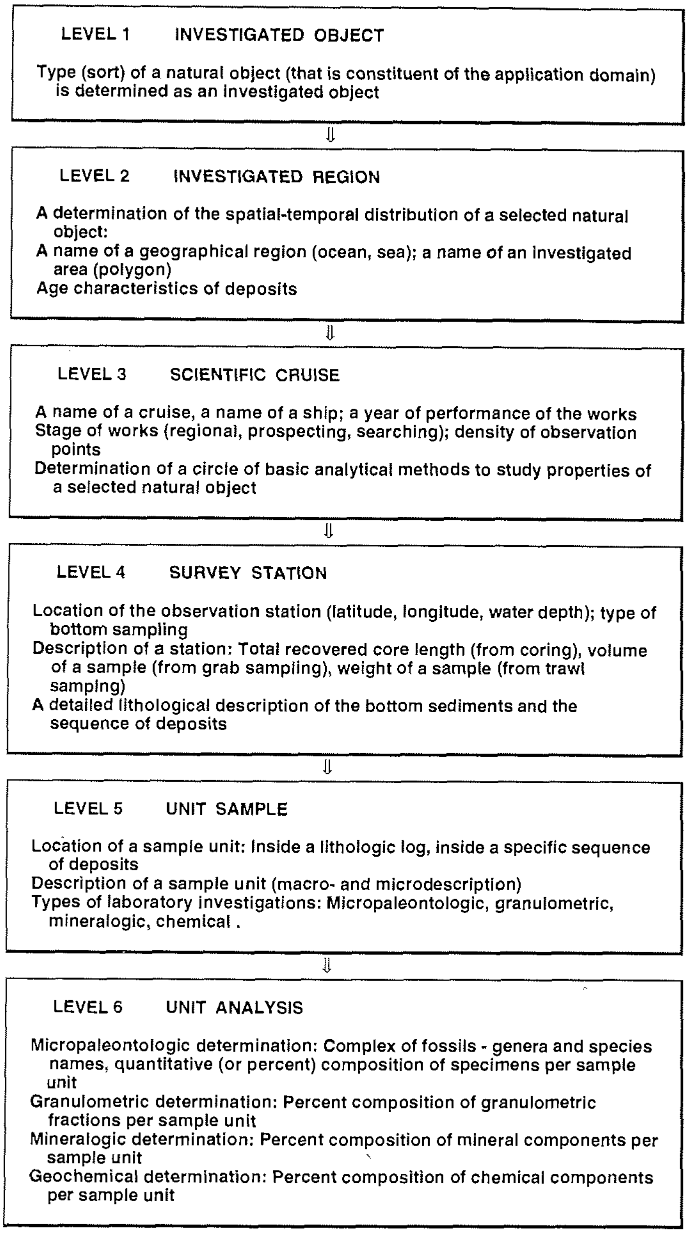
List of kind of bottom sediments is used to compile the descriptive characteristics of the bottom sediment type. A complete descriptive characteristic includes three components:
- material-genetic characteristics
- granulometric characteristics
- name of sediment (according to lithologic specification)

For example:
- Foraminiferal - Fine-Grained - Silt -
- Glauconitic - Medium-Grained - Sand -

List of analytic methods.
For example:
- Granulometric - (5-fractions)
  - (8-fractions)
  - (13-fractions)
- Mineralogic - (Light fraction)
  - (Heavy fraction)
- Chemical - (Spectral)
  - (Carbon analysis)
  - (Soda extraction)

Special support files - include main data for three Arctic microfossil groups: diatoms, planktic and benthic foraminifers, ostracods. Each of these files includes a systematic classification of genera and species names of microfossils (sorted in alphabetical order), which are typical for the region of the Arctic seas .

File structure (fields for each file):
- Genera and species name of microfossil
- Synonyms
- Author and year of description or re-identification
- Biogeographical range (arctic, arctoboreal, northboreal, bipolar, subtropical, tropical, southboreal, widespread)
- Relation to salinity (marine, brackish water, freshwater, euryhaline)
- Biotope (littoral, panthalassic, neretic)



LEVEL 1 INVESTIGATED OBJECT

Type (sort) of a natural object (that is constituent of the application domain) is determined as an investigated object

⇓

LEVEL 2 INVESTIGATED REGION

A determination of the spatial-temporal distribution of a selected natural object:
A name of a geographical region (ocean, sea); a name of an investigated area (polygon)
Age characteristics of deposits

⇓

LEVEL 3 SCIENTIFIC CRUISE

A name of a cruise, a name of a ship; a year of performance of the works
Stage of works (regional, prospecting, searching); density of observation points
Determination of a circle of basic analytical methods to study properties of a selected natural object

⇓

LEVEL 4 SURVEY STATION

Location of the observation station (latitude, longitude, water depth); type of bottom sampling
Description of a station: Total recovered core length (from coring), volume of a sample (from grab sampling), weight of a sample (from trawl sampIng)
A detailed lithological description of the bottom sediments and the sequence of deposits

⇓

LEVEL 5 UNIT SAMPLE

Location of a sample unit: Inside a lithologic log, inside a specific sequence of deposits
Description of a sample unit (macro- and microdescription)
Types of laboratory investigations: Micropaleontologic, granulometric, mineralogic, chemical .

⇓

LEVEL 6 UNIT ANALYSIS

Micropaleontologic determination: Complex of fossils - genera and species names, quantitative (or percent) composition of specimens per sample unit
Granulometric determination: Percent composition of granulometric fractions per sample unit
Mineralogic determination: Percent composition of mineral components per sample unit
Geochemical determination: Percent composition of chemical components per sample unit

Fig. 1: Principal scheme of hierarchic subordination of information. Information for a studied object on a specific layer is presented with data arrays (relations). Each array has its entity identifier - one or several columns of the table; their values clearly determine a copy of the studied object (binding) and in doing so the values of the rest of the columns of the tables. These (rest) columns are related to user's types of data.

Data access (edit and input of new data) is carried out on the level of the database administrator according to instructions obtained from the leading expert on the specific group of microfossils. Additional information on the new data in this group of files is provided in the case that scientific research works were carried out in other biogeographic zones, or other temporal periods for which the specific complexes of microfossils are typical.

Card file (bibliographical catalog) - includes information about the data source (full specification of the document). The information about all scientific cruises, which are stored in the different database files (group 1), by special identification codes linked to the appropriate library item from this card file.

File structure (available for updating fields):
- Title of the document
- Author (authors) of the document
- Year of issue
- Publisher
- Specification (scientific report, article, etc.)
- Abstract (documental data)

Data access (edit, input of new data, search and creation of an output data set) is carried out on the level of the final user. Input of a new item into a card file and creation of a new index of the data source is carried out before beginning the input of the factographic data array. A created new index of a data source will be automatically assigned to each data array from the current source regardless of in which database file the current data array was stored. The system has the regime of the bibliographical (documentary) retrieval in the card file. The user's retrieval request is formed of lexical units which are linked by the predicates ("and" or "or") in a logical expression. This can be a combination of the various conceptions (or their basic ethymologic forms) from the application domain. This makes it possible to reach more flexibility in the course of a request compared with a search of the appointed key words.

Data base management system

User Interface

The terminal session with the data bases is carried out in an interactive (dialog) mode. At any time of the work, the system displays an "active" window in which information from current part of the open data base is reflected. The multi-windows interface operates in such a way that each successively opened window is an outer reflection of each layer of the data organization.
According to the major conceptual scheme (see fig.1) layers of the data organization are successively connected elements of a common information space. In the regime of the visualization (view data mode) the system passes all hierarchic layers of data. It is impossible to miss any of them.

All data array (database files, support files) are linked by primary and secondary keys or indexes. These keys (indexes) are the major connecting elements of information on all layers of data organization - from the highest hierarchy layer to the lowest one.

The work of the system is organized through habit from common to private. Each step of moving vertically from up to down is accompanied by access to the appropriate data array(s). On a display a new window, which becomes "active", is opened. The more detailed information on a selected object from the previous layer is reflected in this current "active" window. Each step of the preview of information allows to chose a form of further presentation data for the user. This can be complete information for the chosen object ("show all" option), or a specific subdivision of the current data base ("show this" option). Access to the data through this last option is carried out on the basis of the indexing method by keys (primary and secondary) with the subsequent filtration of information from a current data array. For example, on the further layers the "Investigated Region" open window allows to obtain information for all scientific cruises which have been carried out in the selected region or only for one specific cruise. In a similar manner, the "active" window of the "Scientific Cruise" makes it possible to obtain access to information about all survey stations or only one station. Moving in the reverse direction - from down to up - is accompanied by a successive closing of each window of the data array. Hence the system gradually take off conditions established for the data filtration from different data arrays.

"Active" window

Scrolling the data array (vertically or horizontally) can be carried out in the data review window. Besides the basic information from a current data array, the system displays some reference data, the total number of selected objects (records of data base) on each considered layer and the order number of a current object (record) in a current list. The system provides several regimes of operations with data in the current active window:

View Data Mode - visualization of information from the current data array inside the active window;

Edit Data Mode - updating of the available fields in the current data array (see file structures and names of fields);

Input Data Mode - the records storage in corresponding data bases is carried out by the system only after the automatic data check of verification with a following setting of the primary and secondary keys;

Output Data Mode - the output of the information from current data base. The output data set is formed by request of the user. It can include both all the data from the current (open) data array and/or selected data which have been created under the user's condition. The output data set is formed both in form of different catalogues, tables and in form of data arrays for further processing with a special application software. Activation of additional regimes (edit, input and output) is carried out with the help of certain control buttons from the main (View Data Mode) regime of works with the data base.

Terminal session

The terminal session begins with the activation of the major executive window "*Main Menu*" (see Fig.2). This menu can be activated also by the special control button ("hot key") at any time during the session in the dialogue mode. The window "*Main menu*" gives access to the different types of data from the information support of the system. This can be the proper information data bases, various conceptional dictionaries and libraries as well as a card file (bibliographical catalog). Call of "*Main menu*" during the session does not allow to leave the current data base to receive the full bibliographical information about the data source or any other reference information from dictionaries and libraries.

Option *"View Map"* makes it possible to review (in a selected investigated region) the geographic map of this region as well as locations of the observational/sampling stations. A choice of the menu point "*Data Base*" opens a list of titles of data bases which enter in the system (see fig. 2). A next step after the selection of a data base is a selection to part this data base. In the data base *"Fossils"* there are three main groups of fossils: diatoms, ostracods and foraminifers.

Option *"View List"* allows to work with special support files: to review the common list of systematic classification for a specific group of microfossils, to update, and to add new names to this list. Similar manipulations with the systematic classification can also be carried out in the course of the work with an appropriate part of the conceptional library.

Option *"View Data"* makes it possible to access indirectly the user's data bases. Figures 3-6 show the successive scheme of selection and more detailed information on further steps of work with the group "*Diatoms*" (data base "*Fossils*"). In the given examples the "show this" option is used.

Acknowledgments

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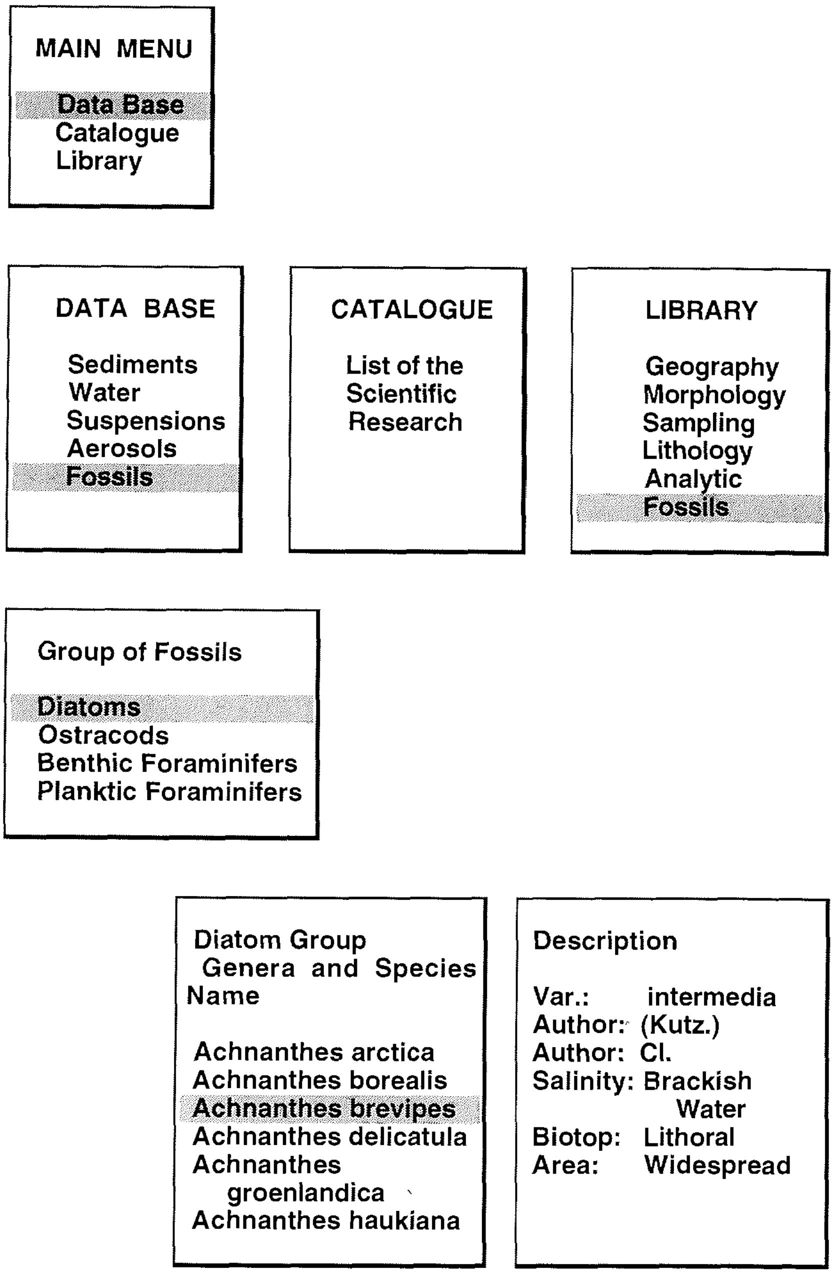
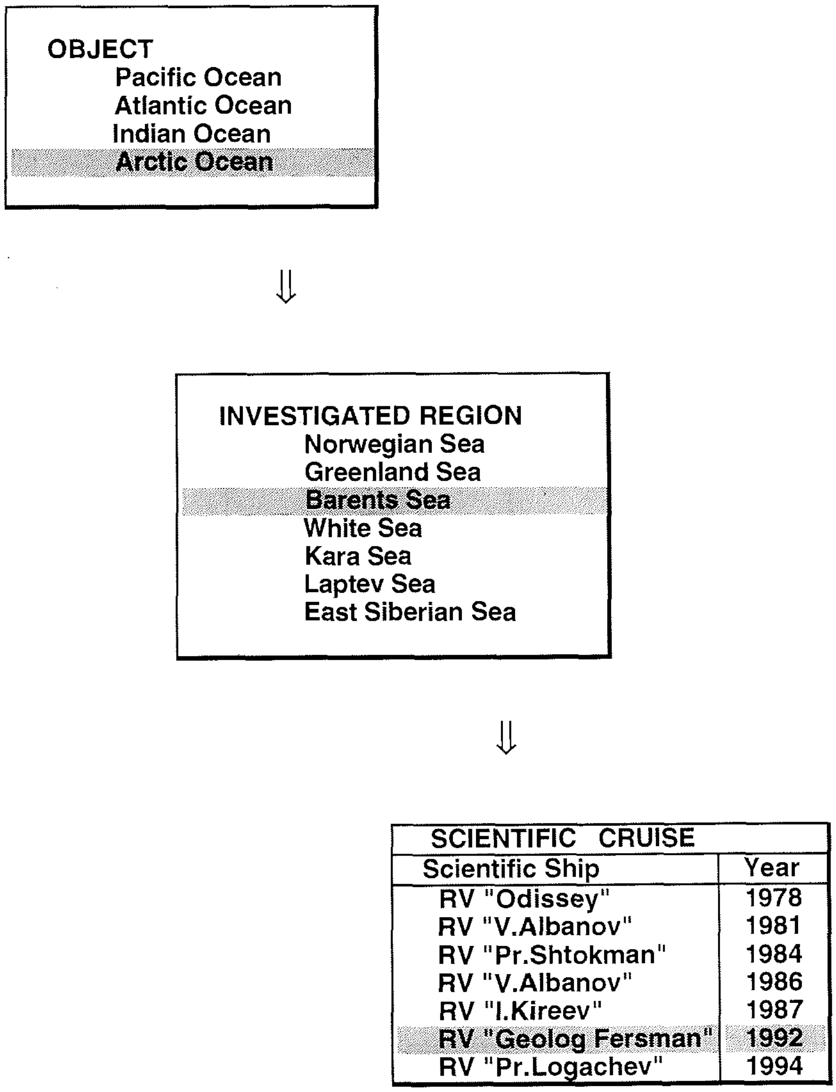


Var.: intermedia
Author: (Kutz.)
Author: Cl.
Salinity: Brackish Water
Biotop: Lithoral
Area: Widespread

Fig. 2: Current status of the system (hierarchical layer 1).



OBJECT
- Pacific Ocean
- Atlantic Ocean
- Indian Ocean
- Arctic Ocean

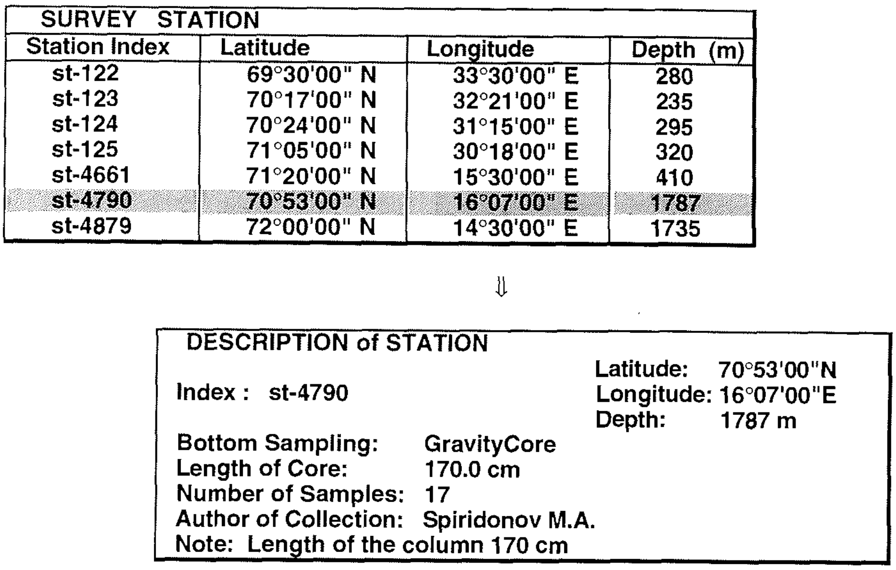
⇓

INVESTIGATED REGION
- Norwegian Sea
- Greenland Sea
- Barents Sea
- White Sea
- Kara Sea
- Laptev Sea
- East Siberian Sea

⇓

SCIENTIFIC CRUISE	
Scientific Ship	Year
RV "Odissey"	1978
RV "V.Albanov"	1981
RV "Pr.Shtokman"	1984
RV "V.Albanov"	1986
RV "I.Kireev"	1987
RV "Geolog Fersman"	1992
RV "Pr.Logachev"	1994

Fig. 3: Current status of the system (hierarchical layers: 2-3).



SURVEY STATION			
Station Index	Latitude	Longitude	Depth (m)
st-122	69°30'00" N	33°30'00" E	280
st-123	70°17'00" N	32°21'00" E	235
st-124	70°24'00" N	31°15'00" E	295
st-125	71°05'00" N	30°18'00" E	320
st-4661	71°20'00" N	15°30'00" E	410
st-4790	70°53'00" N	16°07'00" E	1787
st-4879	72°00'00" N	14°30'00" E	1735

⇓

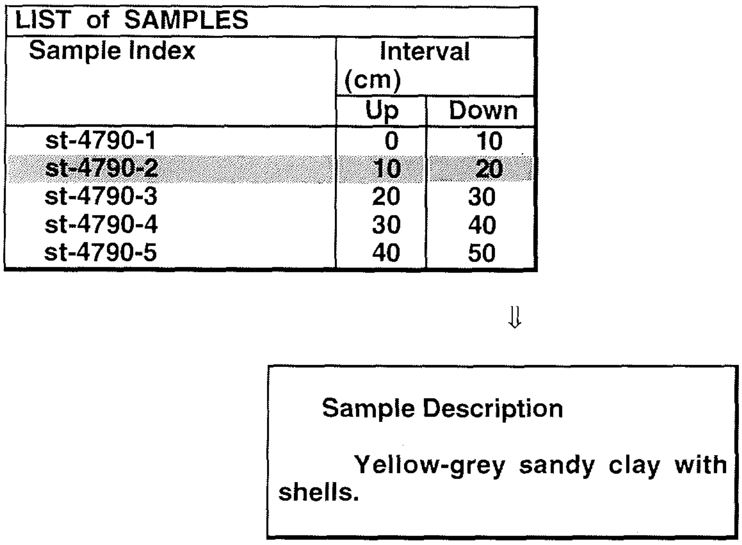
DESCRIPTION of STATION

Index : st-4790

Latitude: 70°53'00"N
Longitude: 16°07'00"E
Depth: 1787 m

Bottom Sampling: GravityCore
Length of Core: 170.0 cm
Number of Samples: 17
Author of Collection: Spiridonov M.A.
Note: Length of the column 170 cm

Fig. 4: Current status of the system (hierarchical layer 4).



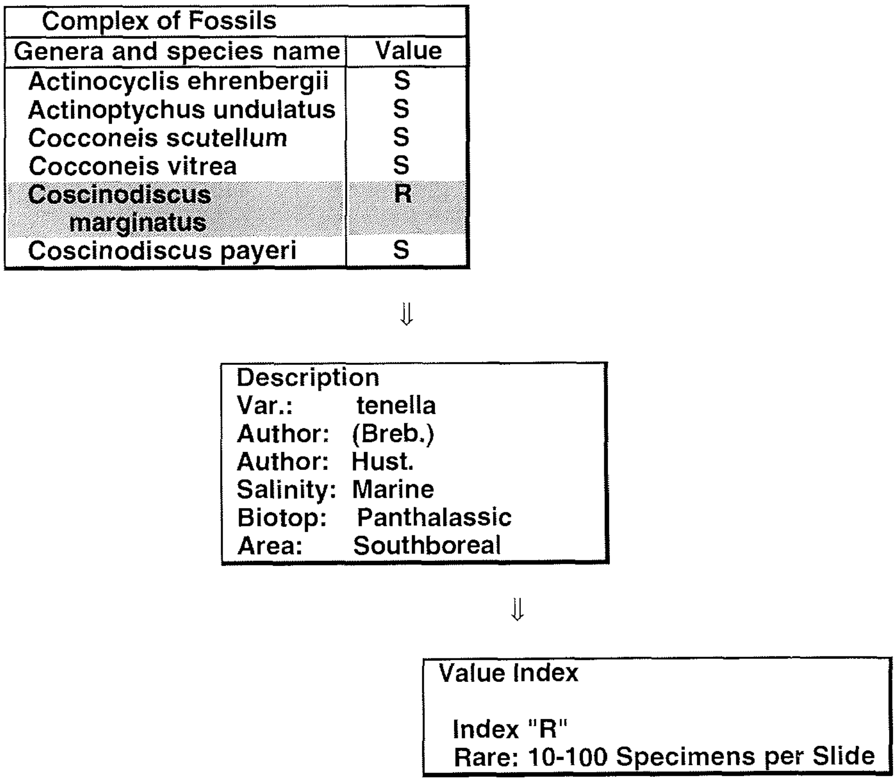
LIST of SAMPLES		
Sample Index	Interval (cm)	
	Up	Down
st-4790-1	0	10
st-4790-2	10	20
st-4790-3	20	30
st-4790-4	30	40
st-4790-5	40	50

⇓

Sample Description

Yellow-grey sandy clay with shells.

Fig. 5: Current status of the system (hierarchical layer 5)



Complex of Fossils	
Genera and species name	**Value**
Actinocyclis ehrenbergii	**S**
Actinoptychus undulatus	**S**
Cocconeis scutellum	**S**
Cocconeis vitrea	**S**
Coscinodiscus marginatus	**R**
Coscinodiscus payeri	**S**

⇓

Description
Var.: tenella
Author: (Breb.)
Author: Hust.
Salinity: Marine
Biotop: Panthalassic
Area: Southboreal

⇓

Value Index

Index "R"
Rare: 10-100 Specimens per Slide

Fig. 6. Current status of the system (hierarchical layer 6)

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