Yelena I. Polyakova[1*], Heidemarie Kassens[2], Jörn Thiede[3], Alexander P. Lisitzin[4], Ivan E. Frolov[5], Leonid A. Timokhov[6], Henning A. Bauch[7], Igor A. Dmitrenko[8], Dorothea Bauch[9]
[1] Faculty of Geography, Lomonosov Moscow State University, e-mail: ye.polyakova@mail.ru
[2] Leibniz Institute of Marine Geosciences, Kiel University (IFM-GEOMAR), e-mail: hkassens@ifm-geomar.de
[3] German Academy of Sciences, Humanities and Literature/Faculty of Geography, St.-Petersburg State University, e-mail: Joern.Thiede@awi.de
[4] P.P.Shirshov Institute of Oceanology, RAS, lisitzin@ocean.ru
[5] Arctic and Antarctic Research Institute, e-mail: ifrolov@aari.nw.ru
[6] Arctic and Antarctic Research Institute, e-mail: ltim@aari.nw.ru
[7] Leibniz Institute of Marine Geosciences, Kiel University (IFM-GEOMAR)/German Academy of Sciences, Humanities and Literature, e-mail: hbauch@ifm-geomar.de
[8] Leibniz Institute of Marine Geosciences, Kiel University (IFM-GEOMAR), e-mail: idmitrenko@ifm-geomar.de
[9] Leibniz Institute of Marine Geosciences, Kiel University (IFM-GEOMAR), e-mail: dbauch@ifm-geomar.de
[*] **Corresponding author**

RUSSIAN-GERMAN COLLABORATION IN THE ARCTIC ENVIRONMENTAL RESEARCH

ABSTRACT

The overview of the 20-years joint Russian-German multidisciplinary researches in the Arctic are represented in this article. Data were obtained during numerous marine and terrestrial expeditions, all-year-round measurements and observations. On the basis of modern research methods including satellite observation, radiocarbon (AMS ^{14}C) dating of the Arctic sea sediments, isotope, biochemical and other methods, the new unique records were obtained. Special emphasis devoted to the latest data concerning modern sea-ice, ocean and sedimentation processes, evolution of the permafrost and paleoenvironments in the Laptev Sea System.

KEY WORDS: Arctic, Laptev Sea System, ocean and sea-ice processes, sedimentation, marine ecosystem, past environments, permafrost

INTRODUCTION

The Arctic comprises some of the most sensitive elements of the global environment, which are considered to respond rapidly to climate change. In this context the Laptev Sea and its Siberian hinterland are of particular interest. River discharge into the Laptev Sea constitutes a key source for the Arctic halocline´s freshwater budget, and the shallow Laptev Sea Shelf is a major ice production area, linking the Siberian shelves to the Arctic Ocean and the Nordic seas. The most vivid expression of the modern climate regime and its changes in real time in the Arctic is the rapidly shrinking Arctic sea ice cover, which during late summer 2007 was reduced to extend only across about two thirds of the Arctic Ocean [Overland et al., 2008] and which has substantially thinned over the past decades, leaving most of the Eurasian shelf seas ice-free during the summer. Much of this sea-ice

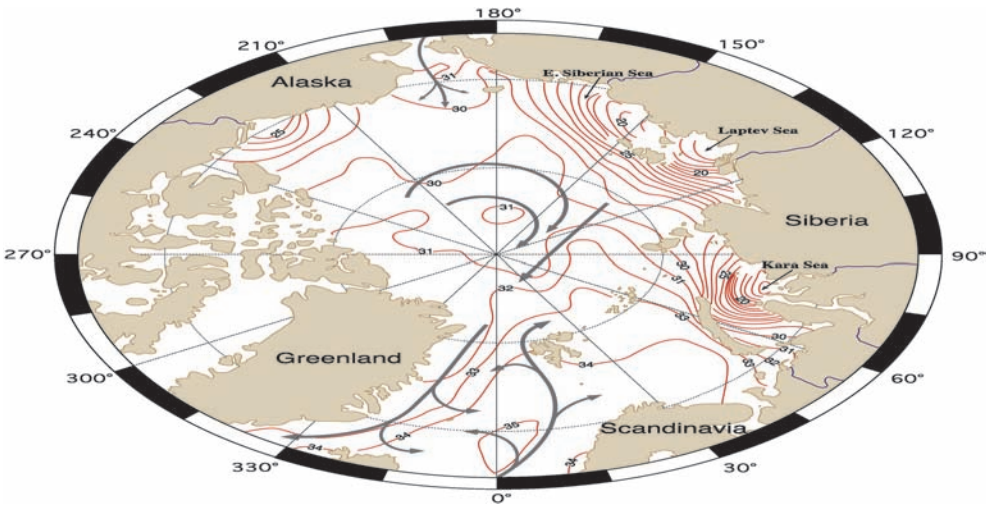

Fig. 1. Surface ocean circulation and average summer water salinity (1960s to 1980s) in the Arctic Ocean, its shelf seas, and in the adjacent Nordic Seas [after Bauch, H., et al. 2000]

is formed in the Eurasian shelf seas during the winter and then enters the Beaufort Gyre of the Transpolar Drift (Fig. 1), and if it survives the seasonal changes over the years, it will finally be exported through Fram Strait to the Norwegian-Greenland Sea. The rapidly shrinking ice cover will result in major changes of the albedo in the future and hence of the radiation balance over the Arctic Ocean. We suspect that it will not only represent a response to but that the shrinking ice cover itself will contribute further climate changes.

However, our knowledge of the processes driving the Arctic system today and in the past is still very limited, thus making it difficult to predict future climate scenarios. The Polar region countries belong to one of the most weakly investigated regions of our planet. Moreover, these regions are almost uninhabited although the large natural resources are amassed here. Collaborative work of Russian and German marine and polar research institutions as a result of the new opportunities which opened up as a consequence of political developments started almost 20 years ago. The scientists involved in this collaboration have joined forces to carry out numerous joint expeditions and they pursue the philosophy of an interdisciplinary "systems" approach rather than allowing the individual disciplines to work isolated by themselves. The joint work during expeditions on research vessels at seas and in stations as well as field camps in the adjacent coastal area have not only produced an intimate partnership between Russian and German scientists, but it has also supported the definition and refinement of the „systems approach".

HISTORY OF COLLABORATION AND THE MAJOR PROJECTS

History of Collaboration

The Russian-German cooperation in the field of arctic research began in 1991 when the State Research Center – Arctic and Antarctic Research Institute (AARI, Russia) and the GEOMAR Research Center for Marine Geosciences (GEOMAR, Germany) organized a joint expedition for studying sea ice in the Laptev Sea. In May 1993, together with other Russian and German research institutions, AARI and GEOMAR held a scientific conference on the problems of the geosystem of the Laptev Sea. The Russian and German scientists were in agreement that the Laptev Sea region, comprising the Laptev Sea and the adjacent Siberian seas –

the East Siberian Sea and the Kara Sea, the Taymyr/Severnaya Zemlya area, the New Siberian Islands and the bordering hinterland, is a unique natural complex without parallel anywhere on Earth.

At the beginning, the program was carried out on a bilateral basis between AARI and GEOMAR. On February 10, 1995, it was included into the Agreement between the Ministries of Science of Russia and Germany on Cooperation in the field of Marine and Polar Research as the project "Ecological-climatic Laptev Sea System". Coordinators from the Russian side were AARI of the Roshydromet and VNIIOkeangeologia and from the German side the Alfred Wegener Institute for Polar and Marine Research (AWI) and GEOMAR.

A bilateral Russian-German multidisciplinary research project to investigate the "Siberian River Run-off" (SIRRO), specifically of the West-Siberian rivers Ob and Yenisei was established in 1997. The research institutes involved in this project were from the Russian side the Vernadsky Institute of Geochemistry and Analytical Chemistry (GEOKHI), the Arctic and Antarctic Research Institute (AARI), the Shirshov Institute of Oceanology (IORAS), the Murmansk Marine Biological Institute (MMBI), and from the German side the Alfred Wegener Institute for Polar and Marine Research (AWI), Research Center for Marine Geoscinces (GEOMAR), and the Institute of Oceanography (IFM).

The ideology of the Russian-German arctic research was to involve highly skilled specialists. Leading scientists from Russia and Germany participated in the field works, data analysis, modeling, the synthesis of empiric data and the composition of scientific papers. A large number of young scientists and students took part not only in the field investigations, but also in the analysis of the data and preparation of the scientific results. Thus, for 20 years the joint research has yielded substantiated and highly interesting results. A new step in the development of the cooperation was the establishment of the Russian-German Otto Schmidt Laboratory for Polar and Marine Research at AARI, AWI and GEOMAR in 1999, and the Russian-German Master Program in Applied Polar and Marine Sciences (POMOR), which was established in 2002 at the State University of St. Petersburg and a consortium of northern German universities led by Bremen University; this Master-course has received the necessary European accreditation.

For the years 2007–2009 the 4th International Polar Year (IPY) has been mounted and has gained substantial support both from the scientific institutions involved as well as from the administrative and political authorities. The importance and impact of the IPY has lately been marked by a proposal of the personal deputy of the Russian presidency to IPY, Dr. Artur Chilingarov, to extend the duration of the ongoing IPY to a whole decade. Moreover, the 2011 was declared as the German-Russian Science Year due to bilateral intergovernmental consultations reaffirmed strategic partnership in education, research and innovation.

The Russian-German cooperation is an example of mutually beneficial, progressive, and trustful cooperation in the field of polar and marine research in the Arctic, a cooperation that is characterized by the fact that the partners are mutually complementary in their technological and financial possibilities as well as in the potential of their scientists for solving the fundamental problems of the contemporary environmental changes and of the paleoclimate in the severe conditions of these remote regions of the Arctic and in modeling the changes in this region under the impact of natural and anthropogenic factors.

Major Research Projects

In this article we aim to give overview of the 20-years joint Russian and German investigations of the extreme environmental system of the Laptev Sea. The Laptev Sea and its Siberian hinterland are of particular

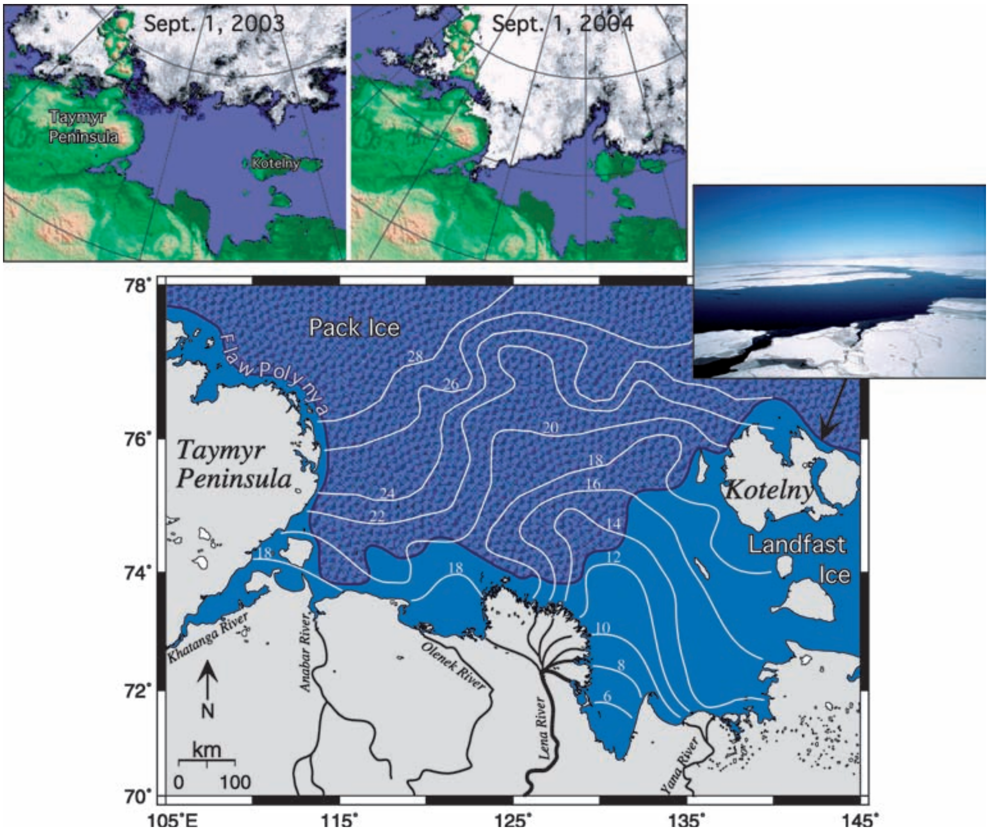

Fig. 2. Major features of the Laptev Sea for various seasons [after Bauch, H. and Kassens, 2005]. The average position of the flaw polynya separates the pack ice from the landfast ice [after Dmitrenko et al., 1998].

The two microwave images (top left) reveal quite quite contrasting distribution of sea-ice concentration. The open sea areas, in particular in summer 2004, correlate well with the average summer surface salinity (white isolines; adopted from Bauch, H. and Polyakova, [2003]) and the landfast ice distribution in winter, both underscoring the strong influence of the Lena river water on the physical conditions in the Laptev Sea. Photograph top right shows the flaw polynya in spring 1999

interest because of their distance both from the Atlantic and Pacific Oceans. River discharge into the Laptev Sea constitutes a key source for the Arctic freshwater input, and it generates a shallow brackish layer on top of the Arctic Ocean halocline (Fig. 2). The shallow Laptev Sea shelf is a major area of sea-ice production that links the Siberian shelves of the Arctic Ocean with the Nordic seas. During the Last Glacial Maximum, most of these shelves were above sea level and developed thick permafrost sequences; today they are submarine, after having experienced the postglacial late Pleistocene and Holocene transgression. The history of the submarine permafrost and its modern state of decay are largely unknown.

The major comprehensive research program combining the efforts of several projects addressed both oceanic and terrestrial processes, and their consequences for marine and terrestrial biota, landscape evolution as well as land-ocean interactions [Kassens et al., 1999, 2007, 2009]. The primary scientific goal of the multidisciplinary program was to decipher past climate variations and their impact on contemporary environmental changes. Extensive studies of the atmosphere, sea ice, water column, and sea-floor on the Laptev Sea Shelf, as well as of the vegetation, soil development, carbon cycle, permafrost behavior and lake hydrology, and sedimentation on Taymyr Peninsula, Severnaya Zemlya Archipelago, and New Siberian Archipelago were performed during the past 20 years under a framework of joint research activities. They included land and marine expeditions during spring (melting), summer (ice free) and autumn (freezing) seasons. The close bilateral cooperation between many institutions in Russia and Germany (>40 institutions) succeeded in drawing a picture of important processes shaping the marine and terrestrial environment in northern Central Siberia in Late Quaternary time. This is important because it allows to be able to judge rates and extremes of potential future environmental changes.

Scientific investigations within the scope of the bilateral projects were planned as part of a system approach. They comprise marine and terrestrial investigations, and a suite of modeling experiments and theoretical considerations, which were carried out within the scope of the Russian-German research projects: "Laptev Sea System" (1993–1999), supervisors – J.Thiede, H.Kassens, L.A.Timokhov, V.L.Ivanov; "Laptev Sea System 2000" (2000–2002),), supervisors – J.Thiede, H.Kassens, H.-W.Hubberten, L.A.Timokhov, D.Yu. Bolshiyanov; Laptev Sea System: dynamics and history of permafrost (2003–2006) supervisors – H.Kassens, H.-W.Hubberten, L.A.Timokhov, D.Yu. Bol`shiyanov; "Global change in the Eurasian Arctic shelf Seas: frontal zones and polynyas of the Laptev Sea (2007–2009), supervisors – H.Kassens, L.A.Timokhov.

The terrestrial investigations were also carried out within the scope of the Russian-German research projects: "Late Quaternary Environmental Evolution of Central Taymyr" (1993–1997) and the "Experimental Station at the Samoilovskii Island (Lena Delta)" (2006–2009), supervisors – H.-W.Hubberten, D.Yu. Bol`shiyanov. During the annual marine and terrestrial expeditions to the Laptev Sea region the comprehensive unique data were obtained for the following multidisciplinary investigations.

German-Russian Otto Schmidt Laboratory for Polar and Marine Research

Established at the State Research Center of the Russian Federation the Arctic and Antarctic Research Institute in Saint Petersburg eleven years ago, the German-Russian Otto-Schmidt-Laboratory for Polar and Marine Research is the central interface and base for research projects in the field of marine and polar research that are carried out jointly by the Russian Ministry of Education and Science and the German Ministry of Education and Research (Fig. 3).

Named after Russian polar researcher Otto Yulievich Schmidt (1891–1956), the Otto-Schmidt-Laboratory (OSL) has developed into a modern research laboratory for the fields of meteorology, oceanography, marine chemistry, biology and geosciences. It is equipped with standard laboratory and measuring devices, a computer center and the electronic library with access to more then 10,000 scientific journals. The main goal of the Otto Schmidt Laboratory is training of young scientists in the scope of a fellowship program. The current fellowship program "Changing Environments" is scientifically motivated by the rapidity and extent of the climate change in the Arctic. The program pairs master students, graduated research assistants, and postdoctoral fellows with experienced mentors and challenges them to participate in ongoing research projects. Since 1999, 280 scientists from 280 research institutions of the Russian Federation have successfully taken part in the OSL fellowship programs.

The Otto Schmidt Laboratory is funded by the German Ministry of Education and Research, the Ministry of Education and Science of the Russian Federation, the Arctic and Antarctic Research Institute, the Alfred Wegener Institute and the Leibniz Institute of Marine Sciences at the University of Kiel IFM-GEOMAR. Further information at: www.otto-schmidt-laboratory.de.

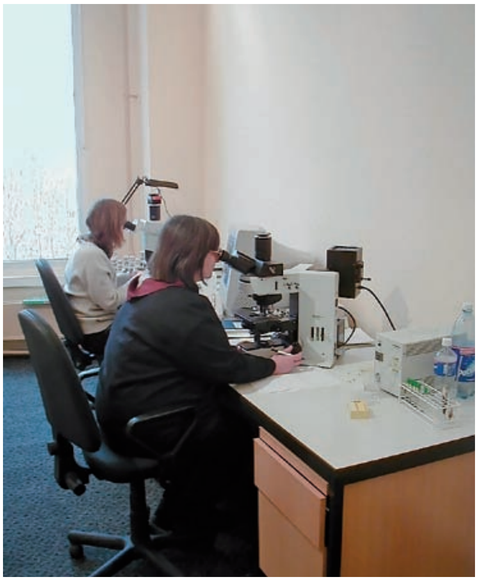

Fig. 3. The German-Russian Otto-Schmidt-Laboratory for Polar and Marine Research (AARI)

Among the former grantees of the OSL 3 have finished their second doctoral dissertation, 18 their Ph.D., 5 an M.Sc., and 17 are currently doing their Ph.D. In 2001, S. Berezovskaya was awarded the grant of the President of the Russian Federation for being the best graduate of the year. The grant comprised funding for a whole year of further qualification in Germany. In 2003, A. Stepanova was awarded the gold medal of the St. Petersburg State University for the best diploma thesis. In 2008, T.S. Klyuvitkina was awarded the research grant of the President of the Russian Federation (no. MK-827.2008.5) for supporting young Russian scientists for her project "Evolution of sea-ice hydrology and sedimentation in the seas of the eastern part of the Russian Arctic (Laptev, East Siberian, Chukchi seas) under global climate change and sea-level changes".

Russian-German Cooperation in Education: Master Program in Applied Polar and Marine Sciences (POMOR)

In order to encourage students to participate in Arctic research, the Russian-German Master Program in Applied Polar and Marine Sciences (POMOR) was established in 2002. POMOR is a joint initiative of the Saint Petersburg State University, the University of Hamburg, the Leibniz Institute of Marine Sciences (IFM-GEOMAR), the Alfred Wegener Institute for Polar and Marine Research (AWI), the Baltic Sea Research Institute Warnemuende (IOW) and the Universities of Bremen, Kiel, Potsdam and Rostock.

POMOR imparts knowledge of the polar and marine environmental systems from coastal to deep-sea regions. Moreover, applied aspects of oceanography, marine geosciences and marine biology are covered by the six modules:

1. Ocean basins, sediments and climate change.

2. High seas and coastal waters oceanography.

3. Polar and marine ecosystems: structure, functioning and vulnerability.

4. Natural resources.

5. Coastal zones: processes and environmental management.

6. Periglacial environment.

Courses (in English) and practical training are held at the State University of Saint Petersburg in close cooperation with the Otto Schmidt Laboratory for Polar and Marine Research. The students also spend one semester at the University of Hamburg or one of the German partner universities (University of Bremen, Christian Albrecht University of Kiel and University of Potsdam). After two years of study, the students are awarded two Master Degrees: one Master of Science in Applied Polar and Marine Sciences from the State University of Saint Petersburg and one from the University of Hamburg, Germany.

Since 2002, 62 students have graduated from POMOR, four of them have already got a PhD Degree. 22 students are studying now and will defence their Master theses in 2011. The combination of theoretical courses with simultaneous immersion into the profession are the keystone to successful education of highly skilled scientists, which is important in both national and international terms.

SYNTHESIS OF RESULTS OF RUSSIAN-GERMAN RESEARCH

The Siberian shelf can be regarded as an integrator of recent Arctic climatic changes that have occurred over the Eurasian Arctic and surrounding land. These include the reduction in sea-ice extent and thickness, warming of atmosphere, and increase in river discharge. Overall, these changes result in a profound modification of the local oceanic freshwater cycle. As a main source of the freshwater of the Arctic Ocean, the Siberian shelf is also critically important for feeding the halocline layer that buffers the cold, fresh surface layer from the warmer, saltier Atlantic water beneath. Therefore, in current article we aim to place high emphasis on the results of the marine researches carried out in the scope of the program "Laptev Sea System".

Modern Ocean and Sea-ice Processes

The current hydrography of the Laptev Sea water masses and the extent of its sea-ice cover are controlled by the interaction of the open Arctic Ocean water masses and the influx of freshwater from a number of major river systems.

Riverine Discharge

Freshwater input through river discharge is an important component of the freshwater balance of the Laptev Sea and the Arctic Ocean. The many rivers draining onto the Laptev Sea shelf comprise about 25% of the total annual riverine input into the Arctic Ocean. The main portions (> 70%) of freshwater are transported annually through the Lena River, the second largest river in northern Eurasia in terms of water discharge [Gordeev, 2000].

In the frame of the first Laptev Sea System Project (1993–1999), a multidisciplinary working program was carried out at almost 500 stations in the Laptev Sea and along the Siberian rivers draining into the Laptev Sea. Due to hydrographic surveys it was concluded that the distribution of river water from the river mouths northward is quite stable in this shallow sea, and the direction of their distribution is governed by the sea bottom relief (Western and Eastern Lena River paleovalleys, Anabar and Khatanga paleovalleys, etc.).

A time series of summer freshwater content anomalies (FWCA) over the Laptev and East Siberian shelves was constructed from historical hydrographic records for the period from 1920 to 2005 (Fig. 4).. Results from a multiple regression between FCWA and various atmospheric and oceanic indices show that the freshwater content on the shelves is mainly controlled by atmospheric vorticity on quasi-decadal timescales [Dmitrenko et al., 2008 a]. This FWCA represents approximately 35% of the freshwater inflow provided by river discharge and local sea-ice melt. However, the large interannual and spatial variability in the freshwater content of the shelves, as well as the spatial coverage of the hydrographic data, makes it difficult to detect the long-term tendency of fresh water storage

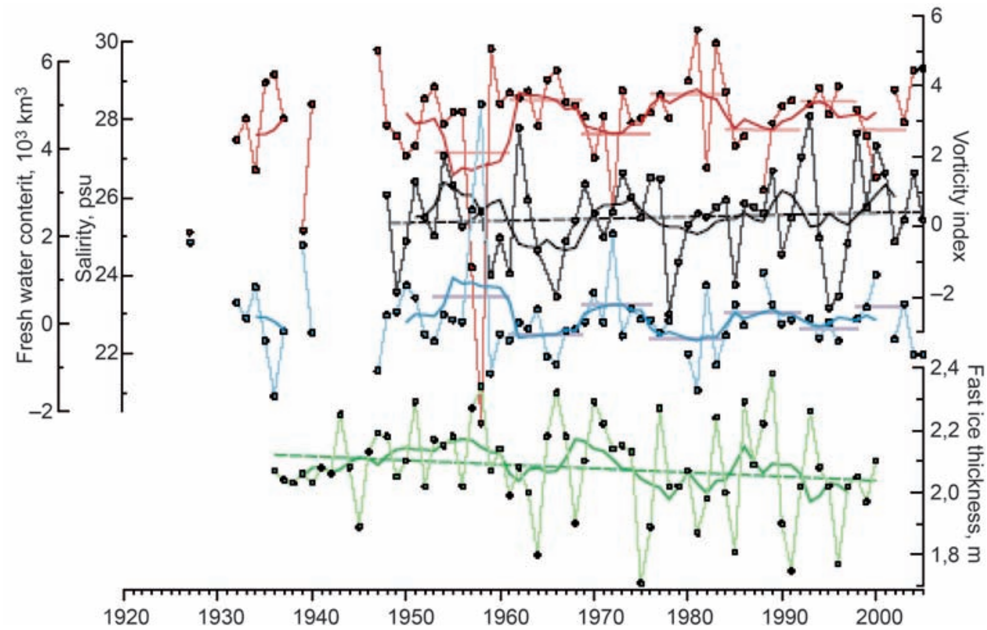

Fig. 4. The 7-year running mean of the Laptev Sea annual summer mean salinity *S* (red dots) and freshwater content anomaly (FWCA) (blue dots) shown by red and blue solid lines, respectively [after Dmitrenko et al., 2008 a]. Horizontal lines show quasidecadal 10-15 year mean salinity (pink), FWC (violet), and atmospheric vorticity (gray). The black line shows the 7-year running mean of the annual summer atmospheric vorticity (gray dots. The 7-year running mean of the May fast ice thickness (green dots) at station Sannikova (Laptev Sea) is shown by a green line. The linear trends are shown by bold dashed line

associated with climate change [Dmitrenko et al., 2008 a].

Stable oxygen isotope measurements ($\delta^{18}O$) were used to investigate the effect of sea-ice formation and concurrent release of cold saltier waters (brine) to the water column. River water in the Arctic is highly depleted in $\delta^{18}O$ relative to marine waters and the effect of sea-ice melting or formation on the water column can be separated from river source since sea-ice processes strongly influence salinity whereas the $\delta^{18}O$ signal remains nearly unaltered.

The $\delta^{18}O$ investigations in the joint Russian-German cooperation show that as a result of sea-ice formation brine-enriched bottom waters are produced on the Laptev Sea shelf and the southern Kara Sea shelf [Bauch, D. et al., 2005; 2009]. Brine-enriched bottom waters are found in the eastern St. Anna Trough and exported here to the Arctic Ocean halocline [Bauch, D., et al., 2005]. In the Laptev Sea this brine-enriched bottom water has been found to be exported in the eastern Laptev Sea to the Arctic Ocean halocline [Bauch, D. et al., 2009]. The impact of winter sea-ice formation may vary significantly interannually and a change in the vertical distribution of this impact was observed in the eastern Laptev Sea in summer 2007 [Bauch, D. et al., 2010]. The factors responsible for this qualitative difference are not understood and it is an open question whether they are related to climate change and reduced summer sea-ice cover. Inter annual differences in the impact of winter polynya activity depend on preconditioning and thereby the atmospheric forcing from precedent summers, which may be rather local [Bauch, D., et al., 2011]. Laptev Sea bottom water is exported northward in the eastern Laptev Sea [Bauch, D., et al., 2009] and our studies suggest that changes in summer wind forcing may have a considerable impact on Laptev Sea bottom water.

Laptev Sea Polynya and Sea-ice Production

Large, persistent areas of open water and young ice off the land-fast ice are referred to as flaw polynyas. The system of flaw polynyas on the Russian Arctic shelf, known as the Great Siberian Polynya, is an important component of the Arctic climate system. Extensive stretches of open water up to 200 km wide combined with extremely low air temperatures induce intensive ice formation and local increases in salinity of the water column during winter and early spring. The Great Siberian Polynya is a possible source of both saline shelf waters for the Arctic Ocean and Transpolar Drift ice.

In the Siberian Arctic seas, flaw polynyas are most distinct in the Laptev Sea (Fig. 2). One of the aims of the bilateral Russian-German project "Laptev Sea System – Global change in Eurasian Arctic shelf Seas: frontal zones and polynyas of the Laptev Sea" was to assess the spatial patterns and variability of ice growth in the Laptev Sea, including its linkage to atmospheric and oceanic processes as well as its importance for sediment transport through the entrainment of particulate matter.

Extensive data sets on the Laptev Sea sea-ice conditions have been collected during a number of Russian-German expeditions into the area. The understanding of the physics underlying the relevant oceanographic processes has been substantially improved, not least due to advances in measurement techniques, including the application of satellite remote sensing. Newly available data sets now provide an opportunity to evaluate the impact of the flaw polynyas on the hydrography of the Laptev Sea in more detail and to higher degree of accuracy. For instance, the impact of the coastal polynya on surface salinity, along with variable river runoff and atmospheric forcing, was analyzed and ice production rates were estimated based on the polynya hydrography. Ice production was obtained from the salinity distribution, which reflects the amount of brine rejection in the polynya. The rate of salinity adjustment in response to ice formation was evaluated statistically from time series of winter salinity observations. These results evidence that, for instance, in the eastern Laptev Sea polynya, the mean salinity increase of the surface layer can reach up to 4 units, corresponding to an ice production of 3 to 4 m [Dmitrenko et al., 2001, 2005, 2009]. Therefore, it was confirmed that the Laptev Sea polynya is an important ice source for the Transpolar Drift system.

It was also revealed that the winter sea-ice production anomalies in the Laptev Sea are linked to the wind-driven circulation anomalies in the Laptev Sea region and in general corresponds to the Arctic Oscillation [Dmitrenko et al, 2009]. The increased wind-driven advection of ice away from the Laptev Sea coast when the Arctic Oscillation (AO) is positive implies enhanced coastal polynya production and brine release into the shelf water. When the AO is negative, the ice production and seasonal salinity amplitude tends to weaken [Dmitrenko et al., 2001, 2005, 2009].

During the joint Russian-German 1999 expedition winter hydrographical parameters were measured with an ADCP. Moreover, a two-layer system of the water column in the polynya, north of the Lena Delta in spring 1999, was observed on the bases of CTD profiling, and therefore, it was shown that the Laptev Sea waters are stratified throughout the year. It was also revealed that the strong stratification limits the exchange of oxygen and phosphate between the bottom and surface waters. Remineralization of organic matter near/at the seafloor results in a depletion of oxygen and enrichment in phosphate [Dmitrenko et al., 2005].

The stable-isotope ice-core data from the fast ice area in the southeastern Laptev Sea, adjacent to the Lena Delta, demonstrated that river water contributes roughly two thirds to total landfast ice mass and may also exert an influence on the ice mass balance due to its impact on the surface water freezing point and thermal ice properties [Eicken et al., 2005]. For instance, in 1999, roughly one quarter of total river discharge was locked up in the southeastern Laptev Sea landfast ice, and possibly as much as another 10–20% may have been entrained into the landfast ice of the western East Siberian Sea. The entrainment of river water into the landfast ice cover is also of importance from the perspective of cross-shelf freshwater transfer and large-scale mixing processes.

The existence of the vast shelf areas (Kara, Laptev and East-Siberian Seas) covered with fast ice during the winter period considerably hampers navigation. The average interannual position of the fast ice edge depends upon the bottom relief, being restricted to the 25–30 m isobaths. However, its annual variations against the average position are available. Based on field, remote-sensing, and hydrological survey (1979–1998) data, and statistical analysis it is shown that the flood river runoff affects fast-ice extension during the next winter. The observed correlation between ice extension and flood river runoff is the result of thermodynamic processes induced by penetration of river water, and confirms the supposition about the negative influence of river discharge on ice formation in the coastal regions of the Arctic seas [Dmitrenko et al., 2008 a].

Atlantic Water Advection

The Arctic is responding more rapidly to global warming that most other areas on our planet. Northward-flowing Atlantic Water (AW) is the major means of heat advection toward the Arctic and strongly affects the sea ice distribution. Records of its natural variability are critical for the understanding of feedback mechanisms and the future of the Arctic climate system. Detection and documentation of the current anomalous state of the Arctic Ocean is possible only thanks to concerted international observational efforts. This AW is carried into and through the Arctic Ocean by the pan-Arctic boundary current, which moves cyclonically along the basin´s margin (Fig. 5). The speed of along-slope warming propagation was estimated using the distinctive pattern of this warming event. According to these estimates, it took ~5 years for the warming to reach the Laptev Sea slope from the Fram Strait region [Dmitrenko et al., 2008 b]. This was revealed on the basis of repeated oceanographic investigations (vertical profiles of temperature and salinity). For example, several AW warm impulses that penetrated the Arctic Ocean were observed in the Fram Strait in 1999–2000. The AW temperature record from the long-term monitoring site in the northern Laptev Sea shows several events of rapid AW temperature increase totaling 0.8 C in February-August 2004 (Dmitrenko et al., 2008). The anomalous mean velocity of 2.4 – 2.5$\pm$0.2 cm/s was obtained on the basis of travel time required between the northern Laptev Sea and two anomaly fronts delineated over the Eurasian flank of the Lomonosov Ridge.

The AW is restricted to the continental slope near the 100 m isobaths, and its sporadic appearance on the shelf is governed by atmospheric circulation and reversal up-welling currents. On the basis of records from 1932 to 2008, field observations carried out in April–May 2008, and 2002–2009 cross-slope measurements, the climatology of bottom hydrography of the Laptev Sea demonstrates a warming that extends offshore from the 30–50 m depth contour. For April-May 2008 on-shelf near-bottom warm and saline water intrusions up to the 20 m isobath were observed [Dmitrenko et al., 2010].

Processes of Modern Sedimentation

Like the wind-forced dynamics of the ice regime, sediment transport is also strongly affected by different regimes of atmospheric circulation and ice cover. New data show that this effect starts as soon as the Laptev Sea flaw polynya opens up during winter

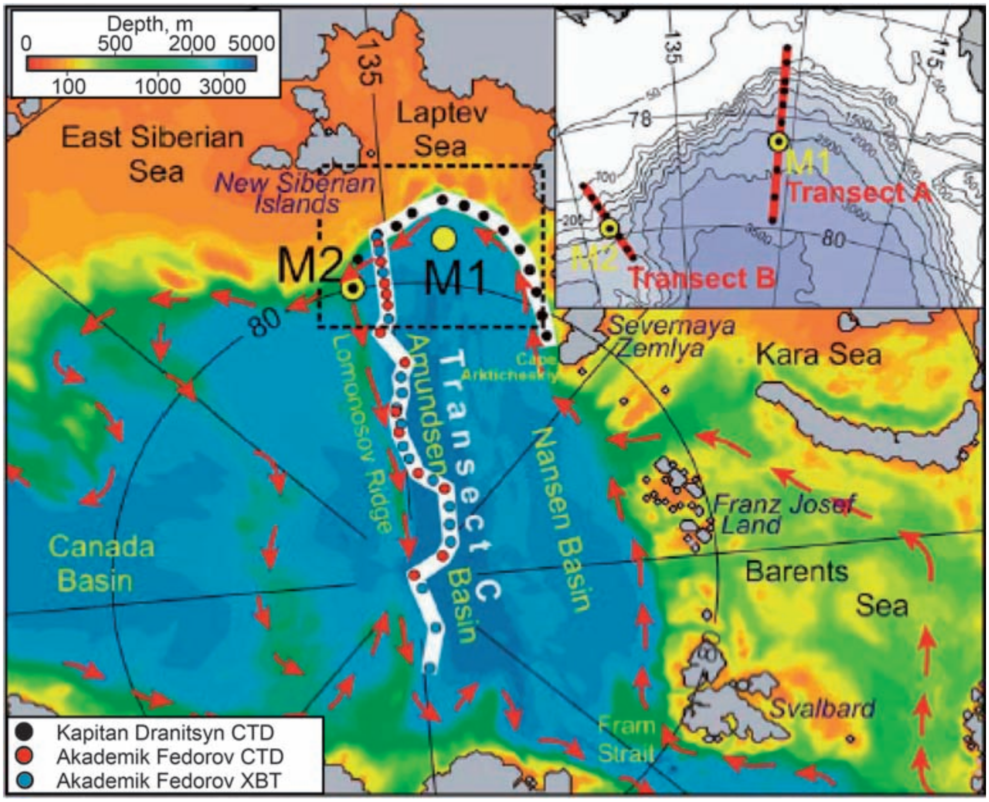

Fig. 5. A map of the Arctic Ocean with inset showing an enlarged view of the northern Laptev Sea region (dashed square).

Red arrows trace the AW pathways. Yellow circles mark the mooring position [Dmitrenko et al., 2008]. White line shows along-margin CTD/XBT Transect C occupied in August-September 2005. Inset shows CTD cross-margin transects A and B (red lines) carried out in 2002–2005. Bathymetry is adapted from the International Bathymetric Chart of the Arctic Ocean (IBCAO), 2001 version

[Dmitrenko et al., 2001, 2005]. Long-term measurements with bottom-moored instruments provide strong evidence that modern shelf sediment transport is mainly wind-forced and connected to the N-S-running submarine valleys on the shelf of the eastern Laptev Sea (Fig. 6) [Wegner et al., 2003, 2005]. In these valleys, suspended sediments are transported in a distinct bottom nepheloid layer, a layer of increased suspended matter concentration up to 12 m thick, which is strongly influenced by the prevailing atmospheric circulation and the ice cover [Dmitrenko et al., 2001; Wegner et al., 2003]. Calculations of the net horizontal sediment flux during the ice-free period have revealed that the main transport within the bottom nepheloid layer in the submarine valleys is directed towards the inner shelf [Wegner et al., 2003]. With respect to the sediment export from the eastern Laptev Sea shelf into the deep Arctic Ocean [Wegner et al., 2005] inferred that during the ice-free period, most of the material derived from riverine input is trapped within a quasi-estuarine circulation system on the inner and mid-shelf regions. This pattern of sediment transport might also explain the low sediment accumulation rates on the outer shelf and the slope of the Laptev Sea since the end of the Holocene transgression [Bauch et al., 2001; Stein et al., 2003, 2004]. If the net sediment transport in the bottom nepheloid layer is directed toward the central and inner shelf, and if we further take into account that large areas

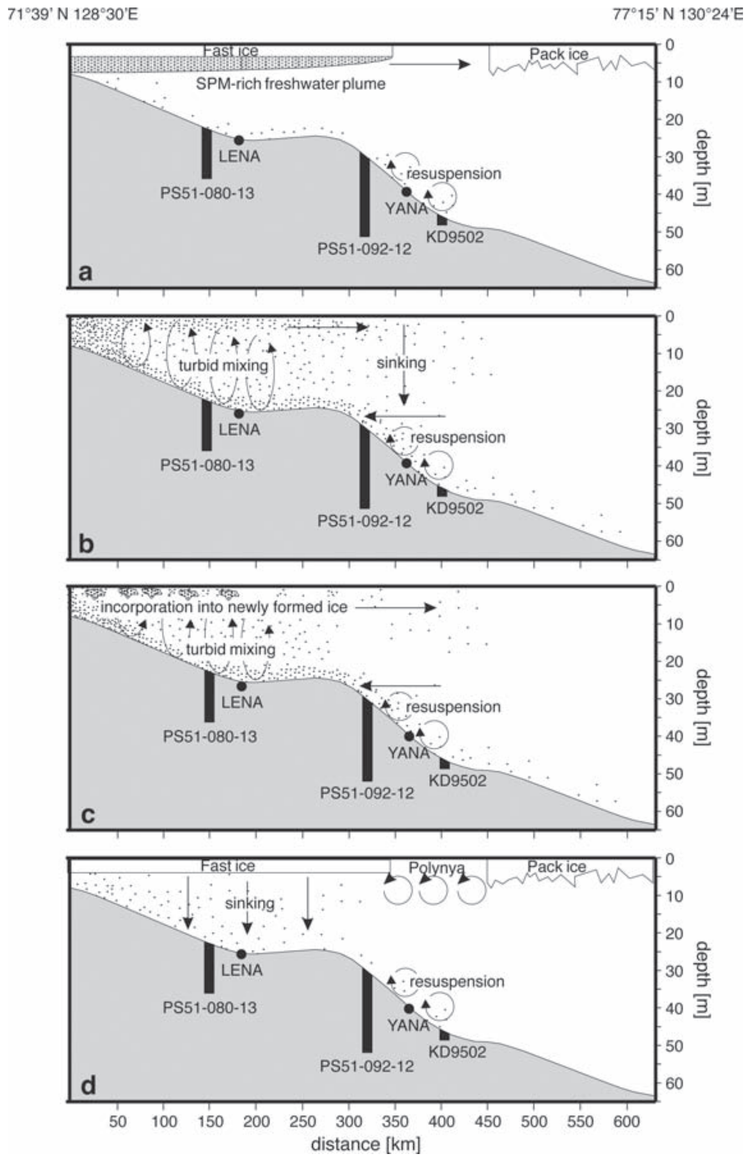

Fig. 6. Schematic overview of sediment transport dynamics on an NS-transect along the Eastern Lena Valley during the river-ice breakup (after Wegner et al., 2005):

(a) the ice-free period, (b) and beneath the fast ice, (c) under the fast ice conditions; (d) with the arrows indicating the general transport direction of SPM and the length of the Black boxes indicating the modern sedimentation rates (PS51-080-13: 28 cm 10-3 : years-1; PS51-092-12: 41 cm 10-3 : years-1; [Bauch, D., et al., 2001])

of the Laptev Sea are covered by relict sediments and lag deposits with no present-day sediment deposition, we can draw the conclusion that the sediment input into the Laptev Sea is not balanced by sediment deposition on the shelf and long-range export through the water column to the Arctic basins. This discrepancy in sediment budgets may be explained by an eastward sediment transport to the East Siberian Sea that follows the Siberian Coastal Current and a long-range transport of sediments by sea ice [Wegner et al., 2005].

Evidence has accumulated over the past two decades that demonstrates that the entrainment of sediments into the sea ice is a common phenomenon on the shallow Siberian shelves [Eicken et al., 2005]. It has been shown that even under calm weather conditions, the freezeup during October seems to be an important time period for sediment transport by sea ice from the shallow shelf areas of the Laptev Sea towards the Arctic basin [Kassens et al., 1999]. By combining field measurements, remote sensing, and numerical modeling, Eicken et al. [2005] were able to identify the shallow shelf near the New Siberian Islands as a key site for ice entrainment and a basin-wide dispersal of sediments by sea ice. They documented a total ice-bound sediment export of 18.5 million tons for one entrainment event in 1994–1995. Another possible mechanism for the formation of sediment-laden sea ice is the resuspension of fine-grained bottom sediments in the polynya area and the subsequent entrainment of these sediments into only newly formed ice [Kassens et al., 1999, 2009; Darby, 2003; Dmitrenko et al., 2009]. Recent studies have shown that the Laptev Sea is one of the major source areas for sea ice in the Transpolar Drift System and a center of sediment entrainment by ice [Darby, 2003; Dmitrenko et al., 2009]. However, the general idea that suspension freezing during sea-ice formation in the winter polynya is the dominant sediment entrainment process in the Laptev Sea is in conflict with the field observations of Dmitrenko et al., [2001], who has shown that even during winter, the strong density stratification of the water column, especially in the eastern Laptev Sea, prevents convection from penetrating down to the seafloor. Thus, resuspension of fine-grained bottom sediments accompanied by suspension freezing beneath the polynya is unlikely to occur in the eastern Laptev Sea. This supports the hypothesis that the fall freeze-up (October) might also be an important and as yet underestimated period for the formation and export of sediment-laden sea ice.

The incorporation of sediments into newly formed ice is not only important for the transport of sediments, Arctic sea ice also plays a crucial role for the large-scale transport and cycling of trace elements [Kassens et al., 1999, 2007]. Within the framework of an interdisciplinary field study of freeze-up processes in the Laptev Sea, Hölemann et al. [1999] observed that the concentrations of dissolved Mn, Fe, Cd, and Pb in newly formed sediment-laden ice were up to 40 times higher than the measured dissolved concentrations were in seawater and fresh water in the region of ice formation. Another key element of the modern environment of the Laptev Sea and the transport processes between this marginal sea and the Arctic Basin is the spring freshet of the Lena River [Kassens et al., 1999, 2007]. It was established that during the high discharge period in May and June, ~30% of annual runoff and 60% of suspended sediments are discharged onto the still ice-covered shelf. In the course of the freshet, riverine dissolved and particulate substances are transported in a freshwater layer beneath the fast ice of the Laptev Sea. These river-to-sea transport processes show strong interannual variations because the dynamics of the spring flood and the extension of the fast ice in spring are controlled by short-term atmospheric processes.

Results of atmospheric aerosols and insoluble particles in snow in different areas of the Arctic in 1994–2007 have shown, that the background concentration of insoluble particles >0.45 μm in the Arctic snow varies from 0.2 to 3 mg/l, which is considerably higher than suspended matter concentration in under-ice water. Sedimentary matter in fresh snow is represented mainly by mineral and biogenic particles (spores, pollens, fibers, diatoms) of pelitic and aleuritic size; soot and anthropogenic combustion spheres are less abundant. Studing the lithology and geochemistry of the snow cover (natural collector of both dissolved and particulate aeolian matter) helps to reveal new aspects of interaction of aerosols with different natural objects in the Arctic. Arctic aerosols exert secondary influence on the Arctic environment via snow and ice (depositing spheres), which increases the importance of aeolian transport of matter for Arctic ecosystems. Balance estimations show that input of aerosols to the Arctic sedimentary matter beyond the marginal filters of rivers is close to the riverine discharge input. In general, the input of aerosols to Arctic sedimentation is about 10% [Shevchenko et al., 2009; Shevchenko & Lisitzin, 2004].

Marine Ecosystem

Biological studies focused on the abundance and community structure of phytoplankton, zooplankton, and benthos as well as benthic life in relation to environmental changes [Kassens et al., 1999, 2007]. It was revealed that river runoff has a pronounced influence on the distribution, activity, and community structure of the phytoplankton and zooplankton in the whole shelf region [Tushling et al., 2000; Abramova & Tushling, 2005; Stepanova et al., 2003; Bauch & Polyakova, 2003]. Triggered by the Lena River discharge, this influence varies during the seasons and shows the highest impact on the ecosystem in spring and early summer, when outflow rates are high. The strong seasonal and interannual variability not only affects the phytoplankton distribution [Abramova & Tushling, 2005] but also leaves a mark on the spatial distribution of benthic communities [Stepanova et al., 2003] as well as their geochemical signature [Müller-Lupp et al., 2004; Bauch et al., 2004].

In the Laptev Sea the overall phytoplankton biomass during the summer period given by carbon content of the different taxa wasrelatively low compared to other Arctic shelf regions, despite a maximum of chlorophyll a, revealing the influence of the Lena River runoff. In newly forming sea ice, pigment concentrations varied considerably. However, total algal biomass within the new and young ice was relatively high and within the range of the water column standing stock in autumn [Tushling et al., 2000].

Zooplankton in the southern and eastern regions of the Laptev Sea contributed as much as 27% of total biomass. Three distinct faunal provinces were identified by multivariate analysis in the central, the northern, and the southeastern parts of the Laptev Sea. It was supported by the major environmental factor regulating the distribution and structure of macrobenthic communities [Kassens, et al., 1999].

Past Marine Environments

The dramatic changes in the paleoceanography and climate of the Arctic periphery affected all aspects of the Arctic Ocean system during the Quaternary, including hydrography, sedimentation, and biota. The latest major revolution of arctic environments occurred during the long transition from the peak of the last glaciation some 20 ka ago well into Holocene times. Besides the disappearance of large ice sheets in many parts of the circum-Arctic region, the associated climatic warming, the rising sea level, and atmospheric changes affected environmental conditions dramatically in the central Arctic Ocean and its marginal regions. During this transition, the shallow continental shelf became widely flooded, causing the circum-Arctic environment to change from a dominantly terrestrial-fluvial to a marine environment with a strong fluvial influence over the vast width of the Siberian shelves. Time-transgressive changes in sedimentation together with geochemical and micropaleontological proxy data give clear evidence of the southwardly transgressing sea on the shallow shelves until about 5–6 ka.

Parts of the north Siberian margin, notably in the Kara and Laptev seas, are now probably the most comprehensively studied seafloor along the Arctic margins, due to multidisciplinary investigations mainly in the framework of Russian-German joint projects over the past 20 years [Bauch et al., 2001; Stein et al., 2003, 2004; Kassens et al., 1999, 2007, 2009]. Because most of the shelf areas east of Taymyr Peninsula were subaerially exposed and not covered by glacier ice during the last glacial maximum, the postglacial sea

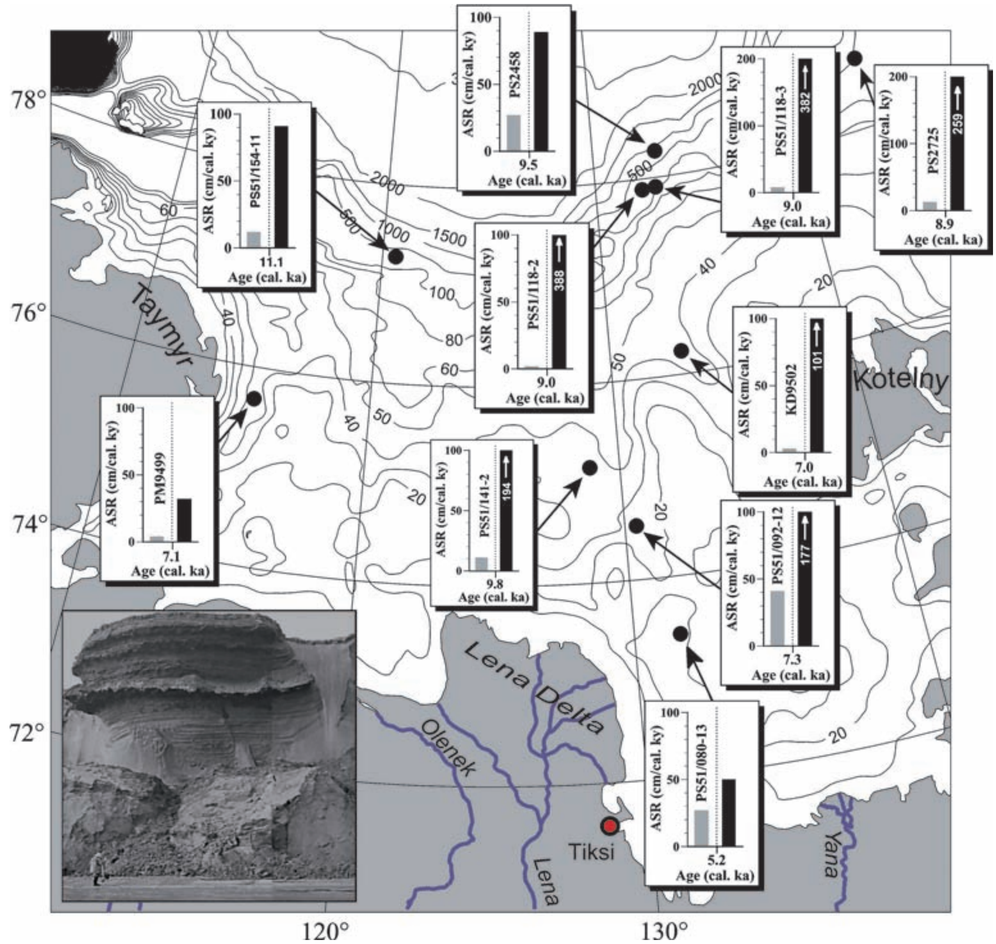

Fig. 7. Major breaks in average sedimentation rates (ASR) as revealed by sediment cores from different water depths of the Laptev Sea [after Bauch, H. et al., 2001]

level rise caused massive input of sediment by eroding a formerly periglacial permafrost landscape (Ice Complex) and transforming it into a shallow shelf sea. Radiocarbon-dated sediment cores from various water depths across the shelf and slope provide insight into the history of vast Siberian shelves since the last glaciation (Fig. 7) [Bauch, H., et al., 2001; Bauch, H. & Polyakova, 2003; Polyakova et al., 2005; Taldenkova et al., 2010].

To establish the detailed chronology of the Holocene transgression in Arctic Siberia, a total of 14 sediment cores from the Laptev Sea continental slope and shelf were studied covering the water depth range between 983 and 21 m. The age models of the cores were derived from >120 radiocarbon AMS ^{14}C datings, which covered the past 15.4 ka [Bauch, H., et al., 2001]. The inundation history was reconstructed mainly on the basis of major changes in average sedimentation rates (ASR), but also other sedimentological parameters were incorporated (Fig. 8). A diachronous reduction in ASR from the outer to the inner shelf region is recognized, which was related to the southward migration of the coastline as the primary sediment source. It was estimated that the flooding of the 50-, 43-, and 31-m isobaths was completed by approximately 11.1, 9.8, and 8.9 cal. ka, and that Holocene sea-level highstand was approached near 5 cal. ka. Between theses time intervals, sea level in the Laptev Sea rose by 5.4, 13.3, and 7.9 mm/year, respectively [Bauch, H., et al., 2001].

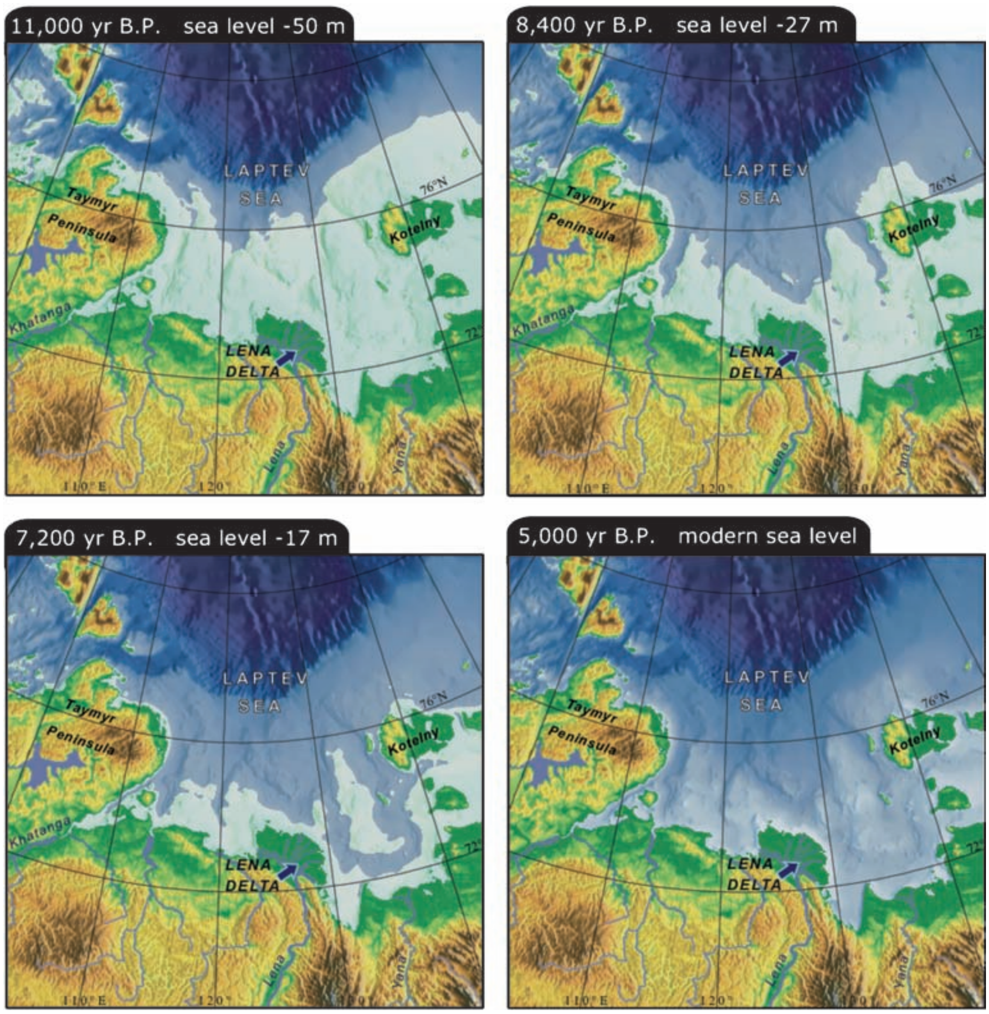

Fig. 8. Time-slice reconstruction for the Laptev Sea shelf showing the retreat of the coastline [after Bauch, H. and Kassens, 2005]; note the south-north running paleovalleys on the shelf incised by the rivers during times of low sea level

Micropaleontological, sedimentological, and geochemical studies of sediment cores allow reconstructing not only the postglacial inundation history, but also concomitant paleoceanography and climate-driven environmental change. Based on modern analogues which are applied to evaluate crucial ecological preferences [Polyakova, 2003; Stepanova et al., 2003; Bauch, H., et al., 2004], various fossil groups, such as diatoms, aquatic palynomorphs, ostracods, foraminifers, and bivalves all provide ample evidence of the transformation phase of the Laptev Sea shelf from terrestrial to marine environments [Bauch, H., et al., 2001; Bauch, H. & Polyakova, 2001, 2003; Polyakova et al., 2005; Klyuvitkina & Bauch, H., 2006; Taldenkova et al., 2008, 2010].

For instance, diatom assemblages were employed to study temporal changes of Siberian river runoff on the Laptev Sea shelf. Using a correlation between freshwater diatoms (%) in the surface sediments and summer surface water salinity [Polyakova, 2003], paleosalinity conditions were reconstructed for the eastern Laptev Sea for the time since 11.3 calendar years [Bauch, H. & Polyakova, 2003; Polyakova et al., 2005]. Because sedimentation processes in the river-proximal shelf areas are mainly governed by the salinity gradients [Lisitzin, 1995, Stein et al., 2004], the depositional environments of riverine diatoms as a major component of river-loaded organic matter in the shelf zone were determined according to the mean interannual summer surface-water salinities. The revealed avalanche–like precipitation of both organic matter and riverine planktonic diatoms in the mixing zone of fresh- and marine waters under salinity <5‰ ("marginal filter" according Lisitzin, [1995]) provided an additional proxy for the investigation of the sedimentation processes on the Siberian shelves.

Moreover, detailed reconstructions of the Lena River runoff through the major riverine channels of the Lena Delta were performed for the last 6 cal. ka [Polyakova et al., 2006] on the basis of paleosalinity records from the adjacent shallow marine area. Using indicator species of dinocysts as the principle marine proxy, an influence of Atlantic water on the Laptev Sea shelf was inferred [Polyakova et al., 2005, 2006; Klyuvitkina and Bauch, H., 2006].

In addition, interpreting both planktonic and benthic fossil communities allow to make relevant assumptions on past water depths, the specific depositional setting as well as the variable influence of paleoriver discharge on the shelf salinity during the last 11,000 years (Fig. 9, [Bauch, H. & Polyakova, 2003; Mueller-Lupp et al., 2004]. Paleosalinity reconstructions based on diatoms and benthic foraminiferal $\delta^{18}O$ from the cores indicate that Holocene river input into the eastern Laptev Sea has been governed by dominantly cyclical behavior. While the diatom record primarily reflects the southward retreat of the coastline during the postglacial transgression between 9000 and 7000 yr ago, as well as variable sea-ice conditions during the Holocene, the foraminiferal data indicate changes in bottom-water salinity with a recurrence interval of 1000 yr over the past 8500 yr. Although global transgression in the Laptev Sea came to an end ~5000 yr ago, modern environmental conditions were established only during the later phase of the Holocene transgression, which reached the southern region of the Laptev Sea between 7000 and 5000 yr ago [Bauch. H. & Polyakova, 2003, Polyakova et al., 2005].

Bivalves, ostracods and foraminifers, studied in AMS ^{14}C-dated sediment cores from the shelf and the continental slope of the Laptev Sea aging back to 15.8 cal. ka with North Atlantic affinities, provide evidence on past inflows of Atlantic-derived waters, whereas freshwater inputs, downslope sediment movements and ice rafting are documented by the presence of euryhaline, brackish-water and freshwater ostracods and the planktic/benthic ratio [Taldenkova et al., 2008]. On the basis of continuous records of ice-rafted debris (IRD) in sediment cores from the western Laptev Sea outer shelf and continental slope provide evidence for iceberg production by the local ice caps on Severnaya Zemlya [Taldenkova et al., 2010].

In addition to water discharge, the Siberian rivers also deliver large amounts of suspended particulate material including organic carbon. Characteristics of organic carbon in marine sediments such as $\delta^{13}C$, C/N ratio as well as different types of biomarkers allow determination of the terrestrial or marine provenance of the organic fractions [Bauch, H., et al., 2001; Fahl & Stein, 1999; Stein et al., 2003, 2004]. Thus, the composition of the arctic shelf sediments helped to trace land-ocean pathways of organic matter and sediments.

The Laptev Sea represents the southern rim of the Eurasian Arctic Ocean basin in northern Russia, where there is a currently active spreading axis, the Gakkel Ridge, which is the divergent boundary between the North American and the Eurasian plates in the Arctic. The Gakkel Ridge, the world´s slowest spreading mid-ocean ridge, approaches the Laptev Sea shelf at a right angle and the tectonic structure. Multichannel seismic-reflection studies, carried out over the Laptev Sea shelf during the past two decades, have

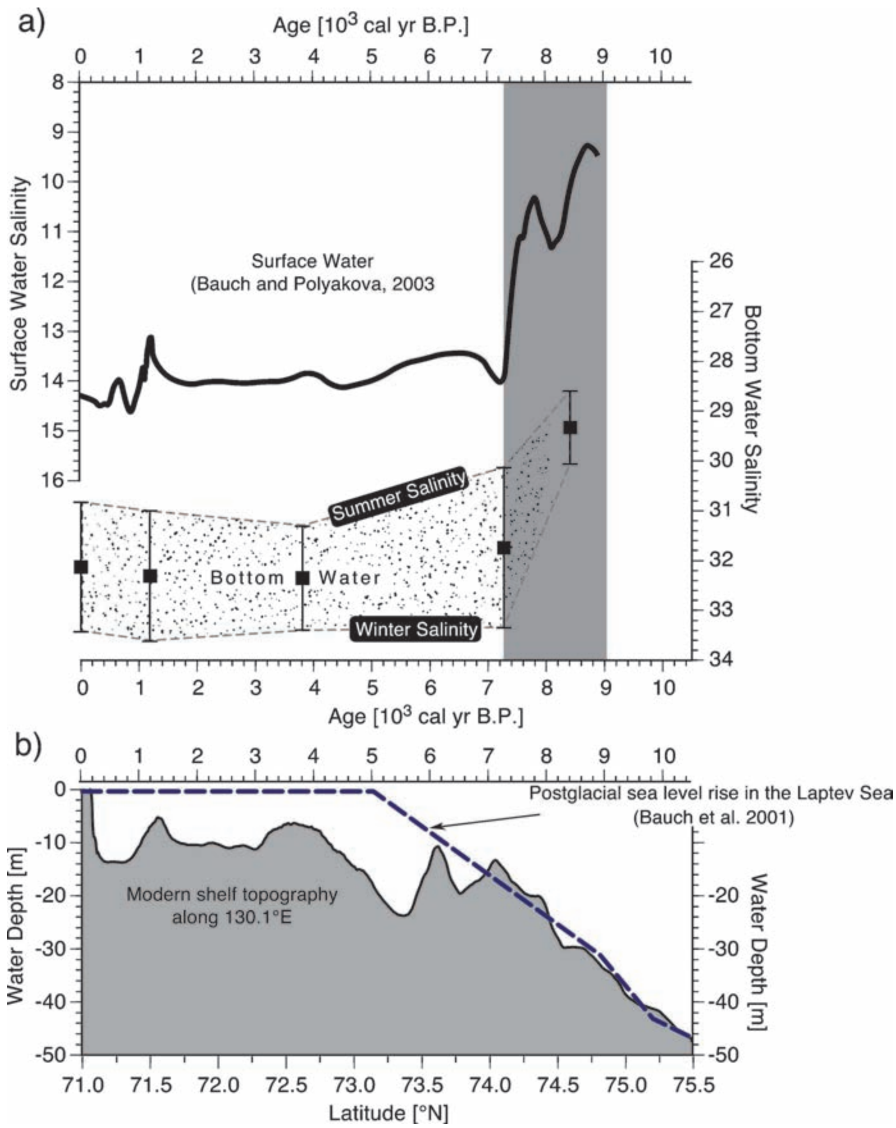

Fig. 9. Reconstructed surface and bottom water salinity in core PS51/92-12 for the past 9000 cal. yr.

a) Surface salinity reconstruction were obtained from Bauch and Polyakova [2003] and based on freshwater diatoms. Bottom water reconstructions after Mueller-Lupp et al., 2004. b) Profile of the modern shelf topography along 130,1°E and the reconstructed postglacial sea-level rise in the Laptev Sea from Bauch, H., et al. [2001]

revealed a vast rift system with a very slow spreading rate of 0.3 cm/yr [Drachev, 2000]. Its origin is related to the opening of the Eurasian Basin and the evolution of the Gakkel spreading center. The process started ~58 million yr ago and has remained active throughout the Cenozoic. The Laptev Sea shelf is one of a few places worldwide where a currently active mid-ocean-ridge system approaches a continental margin. The high tectonic activity of this region is resulting in fault formation and earthquakes along the major structural elements. Considering that ice-bonded and ice-bearing sediments with thickness of several hundred meters have been verified by seismic records, the Laptev

Sea is a sensitive area in terms of stability and global climate changes.

Evolution of permafrost

The permafrost in northern Eurasia is a very complex and special phenomenon which developed in response to very cold temperatures over the region during the Late Cenozoic. It can be up to 1500 m thick, covers approximately 25% of the land masses of the Earth and finds its most vivid expression in the formation of Ice Complexes in Northern Central Siberia, mostly to the East of the Eurasian ice sheets of the Quaternary Glacial Maxima. One of the most important contributions of the bilateral Russian-German studies in the region were the detection and description of the submarine continuation of the continental permafrost under the adjacent shelves which were dry land during the Last Glacial Maxima, the determination of timing, regional distribution of the onset of permafrost formation, the precision of paleoenvironmental changes during the Ice Complex formation, and its degradation under postglacial sea level rise and modern environmental processes.

Ice Complexes, extremely ice-rich permafrost deposits (Fig. 10) are widely distributed in the Arctic regions of northeast Siberia, and present excellent archives for the reconstruction Late Quaternary paleoenvironmental conditions in non-glacial areas (Fig. 11) [Siegert et al., 2009]. Since the Russian Polar Expedition in 1900–1903 to the New Siberian Islands, Taymyr Peninsula and Laptev Sea coast, led by E.V.Toll, who performed the first geological analysis of the permafrost ice, the genesis of Ice Complexes is one of the most debatable problems of the Quaternary geology in Northern Eurasia.

Intensive multidisciplinary studies (cryo-lithological and sedimentological, radiocarbon age determinations, paleobotanical and micropaleontological investigations, studies of mammal and insect fossils, and stable isotope analyses of ground ice) were performed by Russian and German scientists during 1998–2007 in the Laptev Sea coastal regions, the Lena Delta and the New Siberian Islands (Fig. 11). Of particular interest in these studies were the coastal exposures of the Bykovsky Peninsula southeast of the Lena Delta the

Fig. 10. Ice Complex from the Bolshoi Lyakhovskii Island [after Siegert et al., 2009]

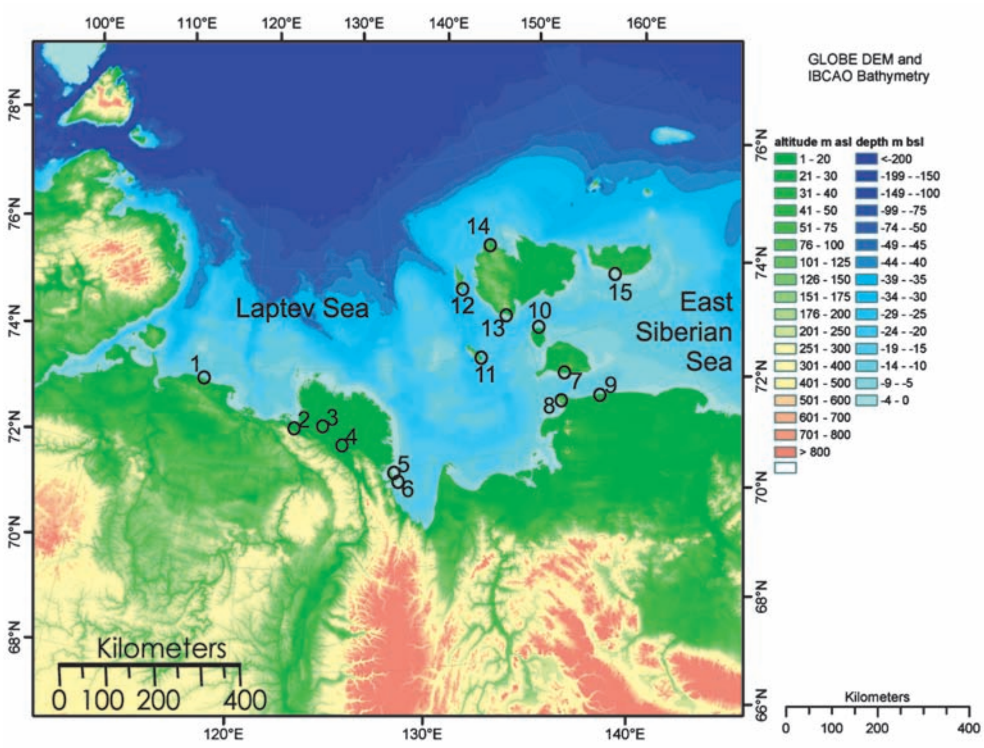

Fig. 11. Location of studied Ice Complexes in the coastal regions of the Laptev Sea (after Siegert et al., 2009):

1 – Mamontovy Klyk Cape, 2 – Ebe Sisi Island, 3 – Khardang Island, 4 – Kurungnakh Island, 5 – Bykovskii Peninsula, 6 – Muostakh Island, 7 – Bolshoi Lyakhovskii Island; 8 – Svyatoi Nos Cape, 9 – Oyagos Yar coast, 10 – Malyi Lyakhovskii Island, 11 – Stolbovoi Island, 12 – Belkovskii Island, 13 – Kotelnyi Island, 14 – Anisii Cape, 15 – Novaya Sibir Island

Cape Mamontov Klyk in the western Laptev Sea and the southern coast of the Bol'shoi Lyakhovsky Island from the New Siberian Archipelago, documenting the detailed environmental dynamics of the Arctic shelf lowland over the past 60 Ky [Schirrmeister et al., 2002, 2008; Siegert et al., 2009],.

The submarine continuation of the continental permafrost under the adjacent Laptev Sea shelf is still poorly understood, due mainly to scarce direct observations. Thermal modelling and geophysical data suggest that large areas of the shallow Eastern Siberian shelf are underlain by relic offshore submarine permafrost from the coastline down to a water depth of about 100 meters. Recent results suggest that ice-bearing continuous permafrost with thickness of 400–600 meters can be expected in the coastal offshore zone, whereas the coastal onshore permafrost should be 700–1000 meter thick [Romanovskii et al., 2005, 2009].

Evidences from an offshore Russian-German drilling program in the Laptev Sea in 2000 confirmed the existence of ice-bearing submarine sediments in the eastern part of the shelf at 33 m water depth. Total sediment recovery was approximately 17 m [Kassens et al., 2007]. According to AMS ^{14}C dating and diatom assemblage records the frozen sediments were formed under terrestrial environments (possibly flooded river plain) and shallow-water marine conditions influenced by the extensive riverine discharge during the end of the Last Glacial Maximum, between 15.6 and 17.5 yrs BP.

In April 2005 a coastal and offshore drilling program entitled COAST took place near the Cape Mamontov Klyk in the western

Laptev Sea [Rachold et al., 2007]. The transect extended from onshore to 12 kilometers offshore up to 44.8 m below sea level (total sediment recovery >70, Fig. 11 and 12). The permafrost table was found in all boreholes, whereas the young sedimentary marine cover increased with distance from shore. On the basis of geocryological, thermal, and pore water/ice salinity data, oxygen and hydrogen isotope concentrations of the pore ice and infrared-optical stimulated luminescence (IR-OSL), the age of sediments evolution of subsea permafrost in the western Laptev Sea shelf during and after inundation of water by the postglacial sea level rise was determined [Rachold et al., 2007]. Subsea permafrost deposits retrieved from the boreholes showed the typical cryogenic structures (ice veins) of ice-bonded terrestrial permafrost, thus indicating that subsea permafrost was generally created by the flooding of terrestrial permafrost due to postglacial sea level rise. The low isotope ($\delta^{18}O$) values from this Siberian Ice Complex indicate that the ice was formed from winter precipitation during cold Pleistocene climate conditions [Meyer et al., 2002]. In addition, IR-OSL age determinations of 111,000 ± 7500 years for the lowermost unfrozen sediments (Fig. 12), which contain marine pore water with salinities reaching 30‰, indicate that these marine sediments could be of Eemian age (Marine Isotope Stage 5e).

Particular emphasis in Russian-German collaborative cryolithologic researches has been placed on the processes of degradation of submarine permafrost [Romanovskii et al., 2005, 2009; Rekant et al., 2009: Rachold et al., 2007]. Submarine permafrost and permafrost-related gas hydrates are believed to be storing significant sink of methane. The eastern Siberian shelf is underlain by relic offshore submarine permafrost in an environment that is favorable for the stability of gas hydrates [Romanovskii et al., 2005, 2009]. The dramatic changes in the Arctic environment in recent years may have far-reaching significances for methane release from the Arctic continental margins, if warming of the coastal waters continues, and the submarine permafrost becomes

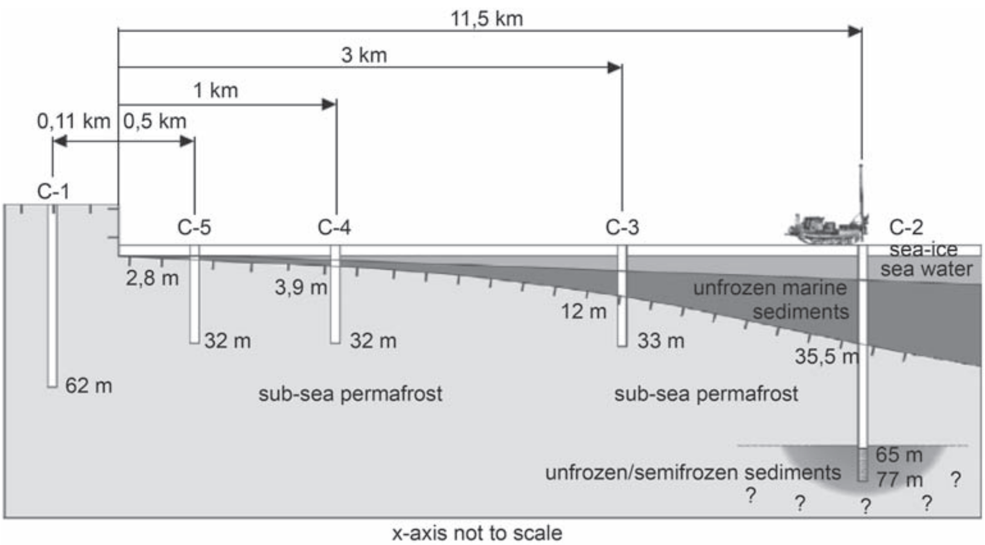

Fig. 12. The coastal transition zone from terrestrial to subsea permafrost near Mamontovy Klyk in the western Laptev Sea [after Junker et al., 2008].

The permafrost table was found in all offshore boreholes, whereas the young sedimentary marine cover increased with distance from shore. A special feature was found in borehole C2 where unfrozen marine sediments of Eemian age were found below the subsea permafrost [Rachold et al., 2007] thermodynamically unstable. Up to now, there is no evidence that such emissions have yet increased because of global warming. However, numerous speculations regarding the submarine permafrost degradation and liberation of methane have been proposed recently, with emphasis on possible implications for further climate change.

The analysis of summer hydrographic data (1920–2009) revealed a dramatic warming of the bottom water layer over the eastern Siberian shelf coastal zone (<10 m depth), since the mid-1980s, by 2.1°C. Modeling shows, however, that the observed increase in temperature does not lead to a destabilization of methane bearing subsea permafrost and to an increase in methane emission [Dmitrenko et al., unpublished data].

The Arctic coastal region is the transition zone between onshore and offshore permafrost. Coasts composed of unconsolidated but perennially frozen sediments (Ice Complex) are widespread in the Arctic. Several thousand kilometers of these coasts retreat because of erosion at long-term rates that typically range from 2 to 6 m/y but can reach as much as 18 m/y. The sediment input into the Laptev Sea by coastal erosion was determined on the basis of long-term monitoring of coastal dynamics on key sites, field measurements of the shorelines on key sites, comparison of shorelines on topographic maps from different depths, satellite images, and aerial photographs. It was established that the Laptev Sea coast on average delivers approximately 58.4×10^6 t · a^{-1} sediments by coastal erosion, which is less than half of riverine sediment discharge into this sea [Rachold et al., 2000; Are, 2008]. Among other processes, frazil ice is an especially powerful agent of coastal erosion, and the sediment transport by frazil ice is mostly responsible for the surprisingly high rates of coastal retreat in the Arctic [Are et al., 2008].

When considering these yearly rates, one must remember that erosion in the Arctic is restricted to three relatively calm summer months of open coastal waters. The predicted global warming will increase the extent and duration of open water and, therefore, erosion rates. Coastal retreat is important for man-made structures such as pipeline crossings and for the supply of sediments, nutrients, and organic carbon to the sea. Forecasting coastal retreat is one of the main problems of coastal dynamics, and predictive mathematical models are widely used to solve that problem.

CONCLUSION

After first contacts in 1989 with institutions in Moscow and St. Petersburg and based on previous exchanges the bilateral Russian-German cooperation has developed into successful platform for scientific work and exchange. We have been able to organize and successfully carry out large in number marine expeditions and terrestrial campaigns, thanks for stable Russian infrastructure and financial support from public sources on both sides. During the expedition and the later exchanges between the institutes involved many young scientists have been guided by senior scientists of the other country and thus they have been confronted with different scientific cultures and approaches. This has not deterred them, but helped to build confidence in the partnership, but also in their own strengths.

The Ms-courses POMOR, the establishment of the Otto-Schmidt-laboratory in St. Petersburg and the Samoylov field Station in the Lena Delta as well as the cooperative agreements between the relevant Russian and German institutions are immediate expressions of the joint interest in this cooperation and they have provided for continuity and reliability in the partnership. The scientific results have found substantial public interest both in Russian, Germany and many other countries because the dynamics of environmental change in the area of investigation are not only of local importance, but are relevant to understand global change. We hope we have-though these joint activities-laid the seeds for growth and further progress in the bilateral Russian-German cooperation in polar and marine sciences. ■

REFERENCES

1. Abramova, E.N., and Tushling K. (2005). A 12-year study of the seasonal and interannual dynamics of mesozooplankton in the Laptev Sea: Significance of salinity regime and life cycle pattern. Global and Planetary Change, Special Issue, 48, 1–3, 141–164.

2. Are, F., Reimnitz, E., Grigoriev, M., Hubberten, H.-W., and Rachold, V. (2008) The influence of cryogenic processes on the Erosional Arctic Shoreface. Journal of Coastal Research, 24 (1), 110–121.

3. Bauch, D., Dmitrenko, I.A., Wegner, C., Hölemann, J., Kirillov, S.A., Timokhov, L.A., and Kassens, H. (2009) Exchange of Laptev Sea and Arctic Ocean halocline waters in response to atmospheric forcing, Journal of Geophysical Research, 114, C05008, doi:10.1029/2008JC005062.

4. Bauch, D., Erlenkeuser, H., and Andersen, N. (2005) Water mass processes on Arctic shelves as revealed from δ ^{18}O of H_2O. Global and Planetary Change, 48, 165–174.

5. Bauch, D., Gröger, M., Dmitrenko, I., Hölemann, J., Kirillov, S., Mackensen, A., Taldenkova, E., and Andersen, N. (2011) Atmospheric controlled freshwater release at the Laptev Sea continental margin. Polar Research, 30: 5858.9.DOI:10.3402/polar.v.30i0.5858.

6. Bauch, D., Hölemann, J., Willmes, S., Gröger, M., Novikhin, A., Nikulina, A., Kassens, H., and Timokhov, L. (2010) Changes in distribution of brine waters on the Laptev Sea shelf in 2007. Journal of Geophysical Research, 115, C11008, doi: 10.1029/2010JC006249, 2010.

7. Bauch, H.A., Erlenkeuser, H., Bauch, D., Mueller-Lupp, T., and Taldenkova, E. (2004) Stable oxygen and carbon isotopes in modern benthic foraminifera from the Laptev Sea shelf: implications for reconstructing proglacial and profluvial environments in the Arctic. Marine Micropaleontology, 2004, 51 (3–4), 285–300.

8. Bauch, H.A., and Kassens, H. (2005) Arctic Siberian shelf environments – an introduction. Global and Planetary Change, 48 (1–3), 1–9.

9. Bauch, H.A., Mueller-Lupp, T., Taldenkova, E., Spielhagen, R.F., Kassens, H., Groots, P.M., Thiede, J., Heinemeier, J., and Petryashov, V.V. (2001) Chronology of the Holocene transgression at the North Siberian margin. Global and Planetary Change, 31, 125–139, doi: 10.1016/S091-8181(01)00116-3.

10. Bauch, H.A., and Polyakova, Ye.I. (2003) Diatom-inferred salinity records from the Arctic Siberian margin: implications for fluvial runoff patterns during the Holocene. Paleoceanography, 2003, 18 (2), 501–510.

11. Darby, D.A. (2003) Sources of sediment found in sea ice from the western Arctic Ocean, new insights into processes of entrainment and drift patterns. Journal of Geophysical Research, 108, C8, 32–57, doi: 10.1029/2002JC001350.

12. Dmitrenko, I., Hölemann, J.A., Tyshko, K., Churun, V., Kirillov, S., and Kassens H. (2001) The Laptev Sea flaw polynya: Effect on the mesoscale hydrography. Annals of Glaciology, 33, 373–376.

13. Dmitrenko I.A., Kirillov S.A., Tremblay L.B. (2008 a). The long-term and interannual variability of summer fresh water storage over the eastern Siberian Shelf. Implication for climatic change. Journal of Geophysical Research, doi:10.1029/2007JC004304

14. Dmitrenko, I.A., Kirillov, S., Tremblay, L.B., and Bauch, D. (2009) Sea-ice production over the Laptev Sea shelf inferred from historical summer-to-winter hydrographic observations of 1960s – 1990s. Geophysical Research Letters, 36, L13605, doi:10.1029/2009GL038775.

15. Dmitrenko, I.A., Tyshko, K.N., Kirillov, S.A., Eiken, H., Hölemann, J.A., and Kassens, H. (2005) Impact of flaw polynyas on the hydrography of the Laptev Sea: Global and Planetary Change, Special Issue, 48, 1–3, 9–27, doi: 10.1016/j.gloplacha.2004.12.016.

16. Dmitrenko, I.A., Polyakov, I.V., Kirillov, S.A., Timokhov, L.A., Frolov, I.E., Sokolov, V.T., Simmons, H.L., Ivanov, V.V., and Walsh, D. (2008 b). Toward a warm Arctic Ocean: Spreading of the early 21st century Atlantic Water warm anomaly along the Eurasian Basin margins. Journal of Geophysical Research, 113, CO50223, doi:10.1029'2007JC004158.

17. Drachev S.S., Kaul N., Beliaev V.N. (2003) Eurasia spreading basin to Laptev Shelf transition: structural pattern and heat flow. Geophysical Journal International, 152, 688–698.

18. Eicken, H., Dmitrenko, I., Tyshko, K., Darovskikh, A., Dierking, W., Blahak, U., Groves, J., and Kassens H. (2005). Zonation of the Laptev Sea landfast ice cover and its importance in a frozen estuary. Global and Planetary Change, 48, 55–83.

19. Gordeev V.V. (2000). River input of water, sediment, major ions, nutrients and trace metals from Russian territory to the Arctic Ocean. In: Lewis, E. L., Jones, E. P., Lemke, P., Prowse, T. D., and Wadhams, P. (eds.) The Freshwater Budget of the Arctic Ocean. NATO Sci. Ser. 2. Environmental Security, V. 70. Kluwer Academic Publisher, Dordrecht, 297–322.

20. Hölemann J.A., Schirmacher M., and Prange A. (2005). Seasonal variability of trace metals in the Lena River and the south-eastern Laptev Sea: impact of the spring freshet // Global and Planetary Change, 48, 112–125.

21. Junker, R., Grigoriev, M.N., and Kaul, N. (2008). Non-contact infrared temperature measurements in dry permafrost boreholes. Journal of Geophysical Reseach, 111, B04102, doi: 10,1029/2007JB004946.

22. Kassens, H.-M., Bauch, H.A., Dmitrenko, I.A., Eiken, H., Hubberten, H.-W., Melles, M., Thiede, J., and Timokhov, L.A. (Eds.) (1999). Land-ocean systems in the Siberian Arctic: dynamics and history. Berlin: Springer, 712 p.

23. Kassens, H., Lisitzin, A.P., Thiede, J., Polyakova, Ye.I., Timokhov, L.A., Frolov, I.E. (eds.) (2009). System of the Laptev Sea and the Adjacent Arctic Seas: Modern and Past Environments. Moscow: Moscow University Press, 608 pp.(in Russian).

24. Kassens, H., Thiede, J., Bauch, H.A., Hoelemann, J.A., Dmitrenko, I., Pivovarov, S., Priamikov, S., Timokhov, L., and Wegner C. (2007). The Laptev Sea system since the last glacial. The Geological Society of America. In: Harff, J., Hay, W.W., and Tetzlaff D.M. (eds.) "Coastline Changes: Interrelation of Climate and Geological Processes: Geological Society of America. Special Paper, 426, 89–96.

25. Klyuvitkina T.S., and Bauch H.A. (2006) Hydrological changes in the Laptev Sea during the Holocene inferred from the studies of aquatic palynomorphs. Oceanology, 2006, 46, 6, 859–868.

26. Lisitzin, A.P. (1995). Marginal filter in the oceans. Oceanology, English Translation, 34 (5), 671–682.

27. Meyer H., Dereviagin A.Yu., Siegert C., Schirrmeister, L., and Hubberten, H.-W. (2002) Paleoclimate reconstruction on Big Lyakhovsky Island, North Siberia – Hydrogen and oxygen isotopes in ice wedges. Permafrost and Periglacial Processes, 13, 91–105.

28. Mueller-Lupp T., Bauch H.A., and Erlenkeuser H. (2004). Holocene hydrographical change of the eastern Laptev Sea (Siberian Arctic) recorded in $\delta^{18}O$ profiles of bivalve shells. Quaternary Research, 61 (1), 32–41.

29. Overland, J., Turner, J., Francis, J., Gillett, N., Marschal, G., and Tjernström (2008). The Arctic and Antarctic: Two faces of climate change. EOS, Transactions American Geophysical Union, 89, 19, 177–178.

30. Polyakova Ye.I. (2003). Diatom assemblages in the surface sediments of the Kara Sea (Siberian Arctic) and their relationship to oceanological conditions. In: Stein, R., Fahl, K., Fütterer, K., Galimov, E.M., and Stepanets, O.V. (eds.) "Siberian River Run-off in the Kara Sea: Characterization, Quantification, Variability, and Environmental Significance", Proceedings in Marine Sciences, Amsterdam: Elsevier, 375–400.

31. Polyakova Ye.I., Bauch H.A., and Klyuvitkina T.S. (2005). Early to Middle Holocene changes in Laptev Sea water masses deduced from diatom and aquatic palynomorph assemblages. Global and Planetary Change, 48, 208–222.

32. Polyakova Ye.I., Klyuvitkina T.S., Novichkova E.A., H.Bauch, and H.Kassens (2006). High-resolution reconstruction of Lena River discharge during the Late Holocene inferred from microalgae assemblages. Polarforschung, 75, 2–3, 83–90.

33. Rachold V., Bolshiyanov D., Grigoriev M., Hubberten, H.-W., Junker, R., Kunitskii, V.V., and Merker, F. (2007). Nearshore Arctic subsea permafrost in transition. EOS, 88, 13, 149–156.

34. Rachold V., Grigoriev M.N., Are F.E., S.Solomon, E.Reimnitz, H.Kassens, and Antonow, M. (2000). Coastal erosion vs riverine sediment discharge in the Arctic shelf seas. International Journal of Earth Sciences, 89 (3), 450–460.

35. Rekant, P.V., Tumskoi, V.E., Gusev, E.A., Schwenk, T., Spiess, F., Chercashev, G.A., and Kassens, H. (2009). Distribution and peculiarity of bedding of the sub-sea permafrost near Semenovskoe and Vasilievskoe shoals (Laptev Sea) revealed by high-resolution seismic profiling. In: Kassens, H., Lisitzin, A.P., Thiede, J., Polyakova, Ye.I., Timokhov, L.A., and Frolov, I.E. (eds.) System of the Laptev Sea and the Adjacent Arctic Seas: Modern and Past Environments. Moscow: Moscow University Press, 332–348 (in Russian).

36. Romanovskii, N.N., Eliseeva, A.A., Gavrilov, A.V., Tipenko, G.S., and Hubberten, H.-W. (2009). Offshore permafrost and gas hydrate stability zone on the shelf of the East Siberian Seas. In: Kassens, H., Lisitzin, A.P., Thiede, J., Polyakova, Ye.I., Timokhov, L.A., and Frolov, I.E. (eds.) (2009). System of the Laptev Sea and the Adjacent Arctic Seas: Modern and Past Environments. Moscow: Moscow University Press, 292–319 (in Russian).

37. Romanovskii, N.N., Hubberten, H.-W., Gavrilov, A.V., Eliseeva, A.A. and Tipenko, G.S. (2005). Offshore permafrost and gas hydrate stability zone on the shelf of the East Siberian Seas. Geo-Marine Letters, 25, 167–182.

38. Siegert, C., Kunitsky, V.V., and Schirrmeister, L. (2009). Ice Complex deposits – a data archive for the reconstruction of climate and ecology at the Laptev Sea coast during the Late Pleistocene. In: Kassens, H., Lisitzin, A.P., Thiede, J., Polyakova, Ye.I., Timokhov, L.A., and Frolov, I.E. (eds.) (2009). System of the Laptev Sea and the Adjacent Arctic Seas: Modern and Past Environments. Moscow: Moscow University Press, 292–319 (in Russian).

39. Schirmeister, L., Siegert, C., Kuznetsova, T., Kuzmina, S., Andreev, A., Kienast, F., Mezer, H., and Bobrov, A. (2002). Paleoenvironmental and paleoclimatic records from permafrost deposits in the Arctic region of Northern Siberia. Quaternary International, 89, 97–118.

40. Schirmeister, L., Gross, G., Kunitsky, V., Magens, D., Meyer, H., Derevyagin, A., Kuznetsova, T., Andreev, A., Babiy, O., Kiena F., Grigoriev, M., Overduin, P. P., and Preusser, F. (2008). Periglacial landscape evolution and environmental changes of Arctic lowland areas for the last 60 000 years (western Laptev Sea coast, Cape Mamontov Klyk). Polar Research, 27, 249–272.

41. Shevchenko V.P., and Lisitzin A.P. (2003). Aeolian input. In: Stein R., and Macdonald R.W. (eds.) The Arctic Ocean Organic Carbon Cycle: Present and Past. Berlin-Heidelberg-New York: Springer, 53–54.

42. Shevchenko, V.P., Vinogradova, A.A., Lisitzin, A.P., Novigatsky, A.N., and Goryunova, N.V. (2009). Atmospheric aerosols as the source of the sedimentary matter and pollution in the Arctic. In: Kassens, H., Lisitzin, A.P., Thiede, J., Polyakova, Ye.I., Timokhov, L.A., and Frolov, I.E. (eds.) (2009). System of the Laptev Sea and the Adjacent Arctic Seas: Modern and Past Environments. Moscow: Moscow University Press, 292–319 (in Russian).

43. Stein R., Dittmers, K., Fahl, K., Kraus, M., Matthiessen, J., Niessen, F., Pirrung, M., Polyakova, Ye., Schoster, F., Steinke, T., and Fütterer, D.K. (2004). Arctic (palaeo) river discharge and environmental change: evidence from the Holocene Kara Sea sedimentary record. Quaternary Science Reviews, 23, 1485–1511.

44. Stein R., Fahl, K., Fütterer, D.K., Galimov, E.M., and Stepanets, O. (eds.) (2003). Siberian River Run-off in the Kara Sea: Characterisation, Quantification, Variability and Environmental Significance. Proceedings in Marine Sciences, v.6. Amsterdam: Elsevier, 484 p.

45. Stepanova, A., Taldenkova, E., and Bauch, H.A. (2003). Recent Ostracoda from the Laptev Sea (Arctic Siberia): Species assemblages and some environmental relationships. Marine Micropaleontology, 48, 23–48, doi:10.1016/S0377-8398(02)00136-6.

46. Taldenkova E., Bauch, H.A., Stepanova, A., Strezh, A., Dem'yankov, S., and Ovsepyan, Ya. (2008). Postglacial to Holocene history of the Laptev Sea continental margin: Palaeoenvironmental implications of benthic assemblages. Quaternary International, 183, 40–60.

47. Taldenkova, E., Bauch, H.A., Gottschalk, J., S.Nikolaev, Rostovtseva, Yu., Pogodina, I., Ovsepyan, Ya., and Kandiano, E. (2010). History of ice-rafting and water mass evolution at the northern Siberian continental margin (Laptev Sea) during Late Glacial and Holocene times. Quaternary Science Reviews, 29, 3919–3935.

48. Tushling, K., .Juterzenka, K., Okolodkov, Yu.B., and Anoshkin, A. (2000). Comparison and distribution of the pelagic and sympagic algal assemblages in the Laptev Sea during autumnal freeze-up. Journal of Plankton Research, 22, 5, 843–864.

49. Wegner, C., Hölemann, J.A., Dmitrenko, I., Krillov, S., Tuschling, K., Abramova, K., and Kassens H. (2003). Suspended particle matter on the Laptev Sea shelf (Siberian Arctic) during ice-free conditions. Estuarine, Coastal and Shelf Science, 57, 55–64.

50. Wegner, C., Hölemann, J.A., Dmitrenko, I., Kirillov, and Kassens, H. (2005). Seasonal variations in Arctic sediment dynamics – evidence from 1–year records in the Laptev Sea (Siberian Arctic). Global and Planetary Change, 48 (1–3), 126–140.

51. Zakharov, V.F. (1996). Sea Ice in the Climatic System. St.-Petersburg: Gidrometizdat, 213 pp (in Russian).

Yelena I. Polyakova – paleogeogapher, micropalaeontologist, marine geologist, Leading Researcher at the Faculty of Geography of the Lomonosov Moscow State University. She received her Ph.D. degree (geography) in 1980 and Doctor of Science degree (Late Cenozoic palaeogeography of the Eurasian Arctic seas) in 1992. For many years she leaded numerous Russian and international multidisciplinary projects on the research of the Arctic seas and the adjacent hinterland of the Eurasian Arctic. She takes an active part in the Russian-German Arctic programs and the training of young specialists – micropalaeontologist.

Heidemarie Kassens – Doctor of Science, marine geologists, palaeoeceanographer. Since 1992 carries out investigations in the Siberian Arctic, leaded 13 Russian-German expeditions to the Arctic Ocean and a high number of the joint scientific research projects. She is Director of the Russian-German Otto Schmidt Laboratory of Polar and Marine Research (AARI, St.-Petersburg) since 1999, and she is the leader of the Program "Laptev Sea System" and the Master Program (POMOR) in the St.-Petersburg University (since 2002). She made an important contribution to Russian-German collaboration in Arctic research and the training of young specialists.

Jörn Thiede – Doctor of Science (marine geology), palaeooceanographer, professor, the Foreign Member of Russian Academy of Science and the Member of a number of European Academies of Science. He directed the largest scientific centers of Germany: Center for Marine Geosciences (GEOMAR) and Alfred Wegener Institute of Polar and Marine Researches (AWI). Since 1994 he is coordinator of Russian-German scientific collaboration in Arctic and Antarctic, initiated joint Polar and marine research and numerous scientific research projects, leaded expeditions to the Polar regions. He contributed to the foundation of the Russian-German Otto Schmidt Laboratory of Polar and Marine Research (AARI, St.-Petersburg) and the Master Program (POMOR) in the St.-Petersburg University.

Alexander P. Lisitzin – the leading Russian marine geologist, professor, Academician of the Russian Academy of Science, head of the department at the P.P.Shirshov Institute of Oceanology, RAS. He is Laureate of the Russian Government Premiums (1971, 1977) and the International Premium by F. Shepard (1968). He elaborated new lines in science concerning the dispersed sediment matter and the formation of the bottom sediments in the World Ocean under the interaction of the external and inner spheres of the Earth. He leaded more than 25 expeditions to all parts of the World Ocean and the first investigations of hydrotherms with the use of inhabited submarines, carries out investigations in Arctic and Antarctic.

Ivan E. Frolov – Doctor of Science (geography), professor, Director of the Arctic and Antarctic Research Institute (AARI, St.-Petersburg, Russia) since 1992, climatologist. He participated and headed more than 30 scientific expeditions to the Arctic and Antarctic. In 2000 he initiated and organized Arctic expeditions on the drift-ice research stations "North Pole – 32". He is Laureate of the Russian Government Premium of 2002, and was awarded the Order of the Labour Red Banner in 1987.

Leonid A. Timokhov – Doctor of Science (physics and mathematics), professor, oceanographist, climatologist, Chief Researcher of the Arctic and Antarctic Research Institute (AARI, St.-Petersburg, Russia). During many years he carried out unique multidisciplinary research in Arctic. He directed the Russian-German Otto Schmidt Laboratory of Polar and Marine Research (St.-Petersburg) since its foundation and leaded the Russian-German Arctic Research Programs "Laptev Sea System". He made an important contribution to Russian-German collaboration in the field of Polar research.

Henning A. Bauch is a senior research scientist with the Academy of Mainz (Germany) based at GEOMAR (Kiel). He is a trained geologist-paleontologist who received his PhD from the University of Kiel. His general research interests focus on the reconstruction of various Quaternary paleoenvironments, primarily within the field of paleoceanography and paleoclimatology. Over the years he has participated in ship cruises and land-based expeditions to the Arctic and sub-Arctic. His particular regions of interest are the subpolar and polar North Atlantic, the Arctic and the North Eurasian continental margin.

Igor A. Dmitrenko after studying physical oceanography in St. Petersburg State University worked at the Arctic and Antarctic Research Institute in St. Petersburg, Russia, and received his PhD in 1994 on the mesoscale turbulence in the Arctic Ocean. Since 2002 as a physical oceanographer he was working for the International Arctic Research Center at the University of Alaska Fairbanks in Alaska, USA. The main aspects of his research covered the variability of subsurface warm Atlantic water input along the continental slope of the Siberian Arctic. Since late 2007 he has joined Leibniz Institute of Marine Sciences, University of Kiel, Germany. His research is focused on the role of atmospheric and sea-ice forcing in shelf environment, shelf-basin interaction and the redistribution of river run-off water over the Arctic Siberian shelf.

Dorothea Bauch is a specialist in isotope geochemistry at IFM-GEOMAR, Kiel, Germany. After studying physics at the Universities of Göttingen and Heidelberg, Germany, she worked at Lamont Doherty Earth Observatory, USA, and received her PhD in 1994. She worked on the interpretation of planktic foraminiferal isotope data based on plankton tow and sediment data. Her current research focuses on comprehensive studies of the Arctic Ocean halocline and its formation in the Siberian shelf regions applying isotope oceanographic methods.