Arctic Paleo-River Discharge (APARD)

A new Research Programme of the Arctic Ocean Science Board (AOSB)

Edited by Ruediger Stein
with contributions of the participants of the
APARD-1 and APARD-2 Workshops

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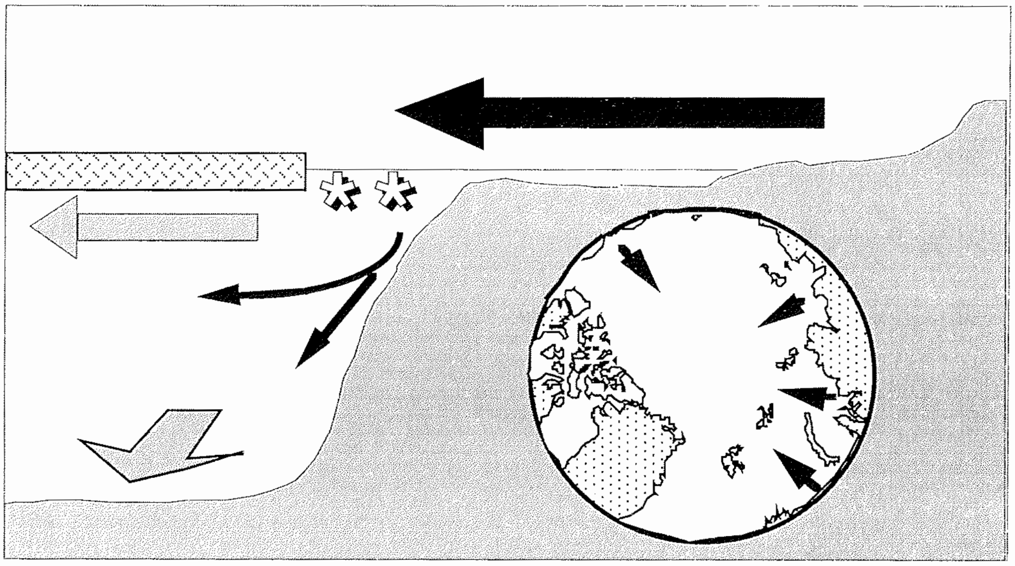

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1. Introduction

During the Arctic Ocean Science Board (AOSB) Meeting held in Helsinki, 17-19 April, 1996, it was recognized that freshwater input to and freshwater balance in the Arctic and its (paleo-) environmental significance have been identified as being of a high priority to many institutions active in Arctic oceanographical, chemical, biological, and geological research. Despite the importance of the Arctic Ocean river discharge on the global climate system and these international projects/programmes partly dealing with paleo-river discharge, there is no comprehensive multidisciplinary and international research programme on circum-Arctic river discharge and its change through time. Thus, it was decided to convene an international, multidisciplinary workshop on "Arctic Paleo-River Discharge (APARD)" at the Alfred Wegener Institute for Polar and Marine Research Bremerhaven, Germany, in the fall of 1996. The results of this APARD-1 Workshop were summarized in a draft which outlines the major scientific objectives and linkages to other international research programmemes dealing with Arctic river discharge. The APARD-1 draft was presented and discussed at the AOSB Meeting in Sopot/Poland, 25-28 February, 1997. The Board recommended that the next steps in APARD planning should be to prepare a scientific programme, based on the scientific objectives identified at the first workshop, and then encourage development of projects to implement the programme. Thus, a second APARD Workshop was held at the Institute of Arctic and Alpine Research (INSTAAR), Boulder, Colorado/USA, 09-12 November, 1997. At the AOSB Meeting in Oslo/Norway, 30 March to 01 April, 1998, the final APARD programme was presented and accepted as an official AOSB programme.

Based on the results of the APARD-1 and APARD-2 workshops, this publication presents the APARD science plan. The relationships of APARD to other research programmes dealing with Arctic paleo-river discharge (e.g., QUEEN, CAPE, GRAND, NAD) are outlined as well. As Appendix summaries of ongoing/planned proposed projects to implement the programme are listed. This APARD document may be a basis for planning and coordinating future research activities on Arctic paleo-river discharge.

In order to ensure the progress of the multidisciplinary circum-Arctic Paleo-River Discharge programme, an APARD Core Group was initiated. Major tasks of this group will be

* to inform the scientific community about ongoing and planned APARD related activities
* to encourage contacts, cooperation and exchange between research institutions involved in APARD related studies
* to stimulate joint multidisciplinary circum-Arctic data compilation and syntheses studies.

Members are:

APARD Core Group

Name	Institute	Expertise	Liason
R. Stein (Chairman)	AWI Bremerhaven (Germany)	Marine Geology Organic Geochemistry Paleoceanography	QUEEN
A. Duk-Rodkin	GSC Calgary (Canada)	Hydrology Paleogeomorphology	
H. Eicken	University of Alaska Fairbanks (USA)	Sea Ice Research	
A. Lisitzin	IORAS Moscow (Russia)	Marine Geology Geochemistry	LOIRA
P. Mudie	GSC Dartmouth (Canada)	Palynology Paleoceanography	CAPE
(Alternate: S. Solomon		Geomorphology)	
L. Polyak	Ohio State University (USA)	Micropaleontology Paleoceanography	GRAND
A. Sidorchuk	Moscow State University(Russia)	Hydrology Paleogeomorphology	
R. Spielhagen	GEOMAR Kiel (Germany)	Marine Geology Isotope Geochemistry Paleoceanography	QUEEN
J. Syvitski	INSTAAR Boulder (USA)	Marine Geology Modelling Paleoceanography	CAPE
J.-M. Weslawski	IOPAS Sopot (Poland)	Biology	

2. Scientific Background

The Arctic Ocean and its marginal seas are key areas for understanding the global climate system and its change through time (for overviews see ARCSS Workshop Steering Committee, 1990; NAD Science Committee, 1992; and further references therein). The present state of the Arctic Ocean itself and its influence on the global climate system strongly depend on the large river discharge which is equivalent to 10 % of the global runoff.

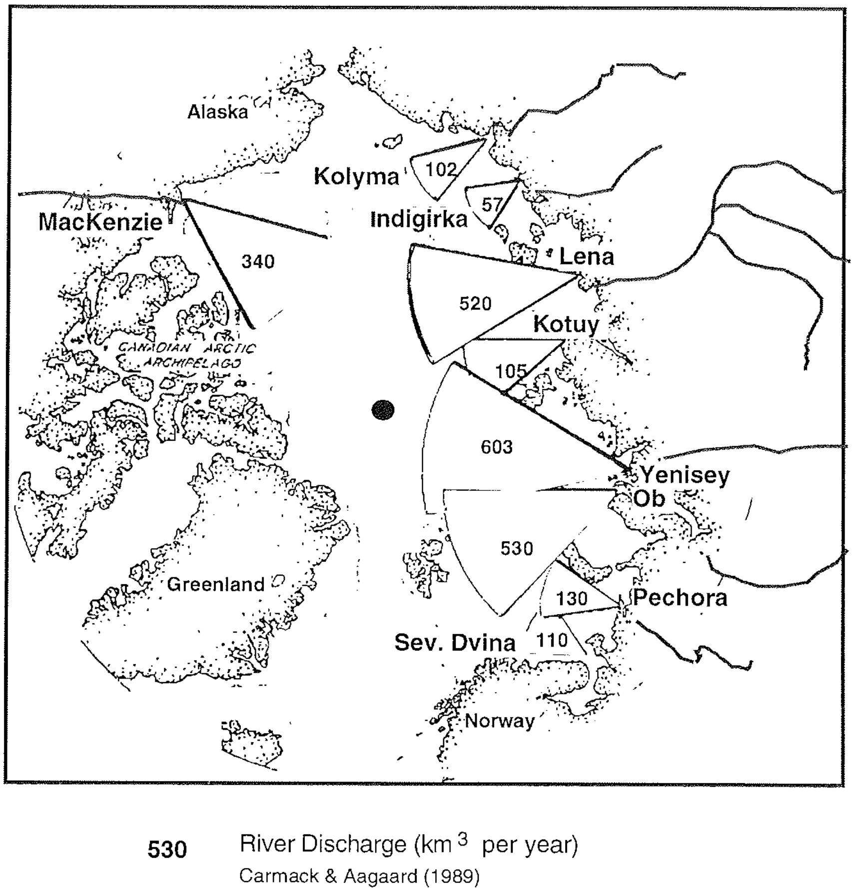


Fig. 1: Modern river discharge in the Arctic Ocean (Aaargaard and Carmack 1989).

The freshwater balance of the Arctic Ocean plays a key role in controlling sea-ice extent and intermediate/bottom water formation in the Northern Hemisphere, as well as Arctic Ocean surface-water conditions. Approximately half of freshwater in the Arctic is contributed by river discharge. Riverine water flux occurs across the broad circum-Arctic, mainly Eurasian continental shelves, which are also major sites for sea-ice formation in the eastern Arctic. The Mackenzie River is probably the main source of sea ice in the western Arctic (Dyke and Morris, 1990; Dyke et al., in press). The melting and freezing of sea ice result in distinct changes in the surface albedo, the energy balance, the temperature and salinity structure of the upper water masses, and the biological processes. Of particular importance are the Kara and Laptev seas receiving almost 2,000 km^3/yr. of river discharge (Fig. 1; Aagaard and Carmack, 1989), which constitutes more than 50% of the total Arctic continental run-off. The major part of this volume is provided by the Siberian rivers Ob, Yenisei, and Lena, which drain the huge catchment area east of the Ural Mountains. This territory receives relatively low precipitation of 100 to 600 mm/yr. Thus, a small change in regional precipitation or impoundment of drainages could significantly alter the delivery of freshwater to northern seas.

In the western Arctic, the Mackenzie River is very important in discharging 340 km^3/yr and contributing the largest annual load of suspended sediment (127 - 142 * 10^6 tons) to the Arctic Ocean (Pocklington, 1987; Macdonald et al., 1998). The Mackenzie River also has a very large drainage basin (1085 * 10^3 km^2, almost 20% of Canada´s land area) extending ca. 10° latitude south into low discharge regions presently experiencing droughts associated with global warming.

Maintenance of the Arctic freshwater balance is not the only impact of polar rivers. Their influence on the Arctic shelves extends from estuarine/deltaic sedimentation and biogeochemical processes to cross-shelf transport of nutrients, sediments, ice, and pollutants. Rivers are crucial for sustaining human population with spawning areas for fisheries, waterfowl and sea mammals, sources of driftwood and conduits for travel.

Dramatic changes in the hydrology of the Arctic occurred during the Quaternary, affecting sea-ice production, surface-water circulation, sediment and nutrient fluxes, and hemispheric thermohaline circulation. Arctic river discharge was probably repeatedly reduced during the glacial maxima reflecting colder and dryer climates of the Siberian lowlands. Potentially, some drainages were dammed by advancing glaciers, diverting discharge from the Arctic to the south. It is also known that, from 9.5 to 9.0 ka, the huge Canadian glacial Lake Agassiz water drained north into the Mackenzie River (Fisher and Smith, 1994). By contrast, the deglaciation events followed by a rise in sea level and degradation of permafrost, may have lead to a rapid increase in freshwater input to the Arctic seas, although there were also times (12 - 10 ka) when large lakes were impounded behind sills in the Mackenzie drainage system (Brooks, 1995). Fluctuations in paleo-river discharge were associated with geological records of circum-Arctic changes in oceanography, ice-cover, vegetation, biotic, and societal patterns.

3. Scientific Objectives

3.1. Modern riverine processes

3.1.1. Quantification and characterization of modern riverine input

* *Freshwater supply*

Some of the rivers discharging to the Arctic Ocean belong to the largest in the world. Today, the freshwater inflow by major rivers reaches a total of 3300 km^3/yr. Major contributors are the Yenisei (603 km^3/yr), the Ob (530 km^3/yr), the Lena (520 km^3/yr), and the MacKenzie (340 km^3/yr) (Fig. 1; Aagaard and Carmack, 1989; cf. Tab. 1). Their freshwater input is essential for the maintainance of the ca. 200 m thick low-salinity layer of the central Arctic Ocean and for the formation of sea ice on the Arctic shelves. While the outflow of Siberian rivers is reduced to a minimum and can be close to zero in the winter months, the outflow during river ice breakup in spring (May-July) reaches peak values (Fig. 2). All major Siberian rivers discharge 30-65% of the annual total output within one month (Treshnikov, 1985). In contrast, Arctic North American rivers can show a much weaker seasonality, because they are often fed by large headwater lakes (Fig. 3, Mackenzie River; Macdonald et al., 1995). Here, monthly means average 5-15% of the annual discharge; maximum values are reached in the summer (July/August) and minima during winter (Treshnikov, 1985). On the other hand, Colville River in northern Alaska discharged 58% of its total output of 1971 within 3 weeks in spring (Walker, 1973).

Table 1: Annual Arctic river discharge, total suspended matter (TSM), total organic matter (TOC), particulate organic matter (POC), and dissolved organic matter (DOC), (Gordeev et al., 1996)

River	Discharge ($km^3\ y^{-1}$)	TSM ($10^6\ t\ y^{-1}$)	TOC ($10^6\ t\ y^{-1}$)
Pechora	131	13.5	1.7
Ob	429	16.5	3.1 (POC = 0.3; DOC = 2.8)
Yenisey	620	5.9	4.6
Khatanga	85	1.7	0.5
Lena	525	17.6	5.3 (POC = 0.8; DOC = 4.5)
Indigirka	61	12.9	0.5
Kolyma	132	16.1	1.1
Mackenzie	249	142	3.4 (POC = 2.1; DOC = 1.3) (Macdonald et al., 1998)

The interannual variability of the winter outflow is generally low, but the summer discharge volume within certain months can differ by 100% from year to year. This applies both to the North American and Siberian rivers (Macdonald et al., 1995).

Off the river mouths, the river water mixes with shelf and ocean waters. On the outer Laptev Sea shelf, the river water component constitutes approx. 20% of the uppermost shelf waters (0-15 m) along the outflow track to the ocean, but only 6% of the waters at 50 m water depth (Stein, W., 1996). Values decrease further north and reach 15% and 4 % at the shelf break, respectively. On the narrow Beaufort Shelf off the Mackenzie River, mixing due to current activity is intense and occurs within 10 km of the delta. As a result, the river water component on the shelf has an irregular distribution, but can reach similar near-surface values as in the eastern Laptev Sea (Macdonald et al., 1995).

In addition to river discharge, glaciers and ice caps are important contributors to the fresh water inflow in Arctic Ocean (Fig. 4). Glaciers cover about $2*10^6$ km^2 of land surface in the high latitude Arctic. All these glaciers produce annually about 500 km^3 of meltwater from the glacier surface and additional to it may be 50% by iceberg calving. Sum of these gives about 30% of annual Arctic river runoff. Due to the negative mass balance for the period of glacier mass balance study in this area the sum of additional glacier meltwater inflow is as much as 600 km^3 (20 km^3/yr) for the period of 1961-1990 (Dyurgerov and Meier, 1997).

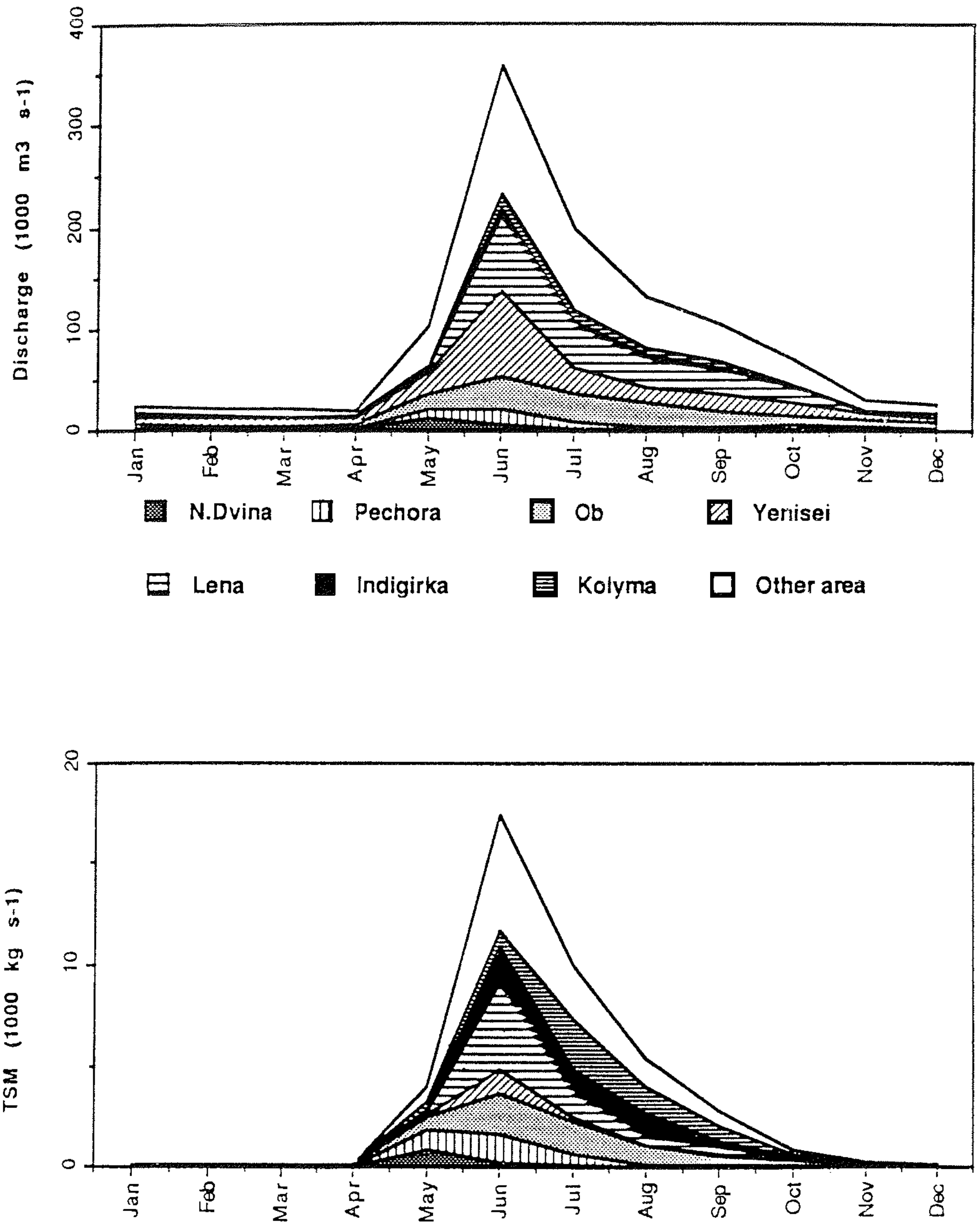


Fig. 2: Annual variability of Siberian river discharge and supply of suspended matter (Gordeev et al., 1996).

This does not include possible additional (against the steady-state condition) water supply from several other sources: 1) imbalance of Greenland Ice Sheet, 2) iceberg calving. The paleo-aspect of glacier runoff and iceberg production is still in its infancy and needs special attention. The extremely rough estimation of annual meltwater production at initial stage of ancient ice cover decay may give around 10-15*10^3 km^3 in an average year (for the glaciated area of 30*10^6 km^2).

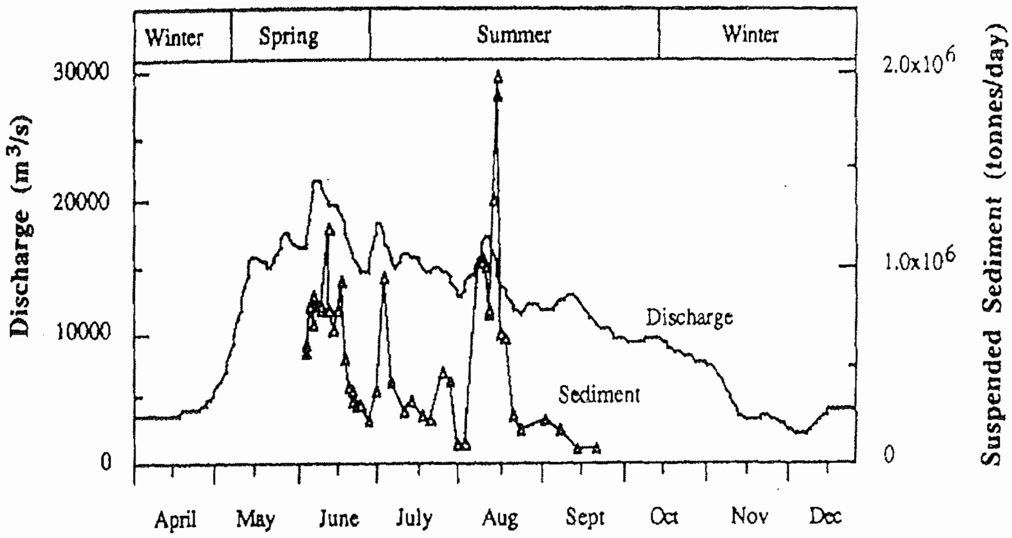


Fig. 3: Annual variability of Mackenzie river discharge and supply of suspended matter (Environment Canada, 1988).

According to all above several problems have to be solved :

- calculate glacier meltwater production and its contribution to annual and seasonal river runoff;
- more accurate calculation on freshwater production from the surface of Greenland ice sheet;
- estimate an iceberg calving and imbalanced part of it (against steady-state condition);

continue mass balance study on benchmark glaciers and make these data accessible for APARD usage.

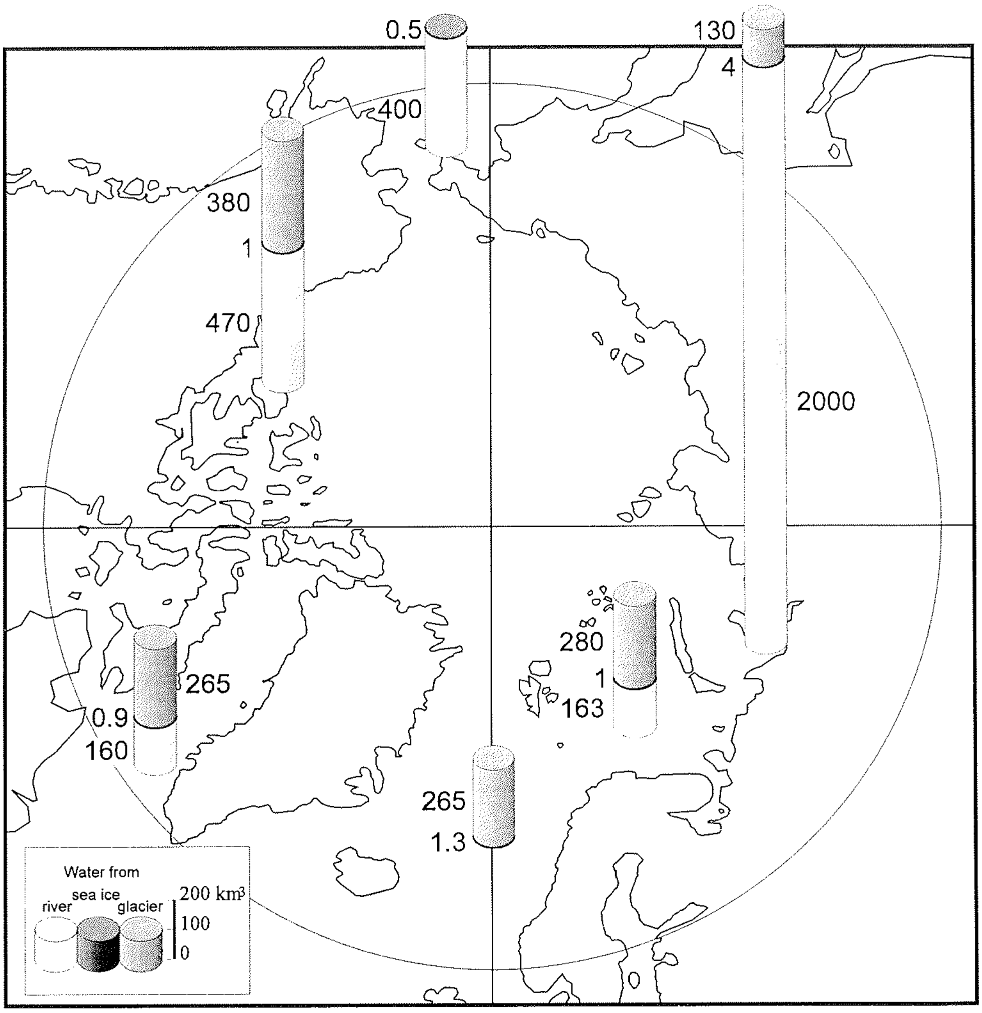


Fig. 4: Annual freshwater discharge by rivers, sea ice and glaciers in km3 per year (Aagaard and Carmack, 1989; Hagen and Jania, 1996).

Freshwater and its fate on the shelves and in the deep Arctic Ocean can be followed by a number of independent tracers. Since evaporation and precipitation in the Arctic are low, the salinity distribution of shelf and ocean waters gives a rough measure of the river (fresh) water inflow (Fig. 5). The system is complicated by sea ice formation and melting, which result in increase or decrease of the water salinity.

The oxygen isotope ratio ($\partial^{18}O$) is widely used as an index of river water input to the ocean. Due to isotopic fractionation both during evaporation and during atmospheric transport from the oceans to the continent, precipitation collected in rivers has a very low $\partial^{18}O$ value (Fig. 6; -17 to -23‰ vs. SMOW in Siberian Arctic rivers, Létolle et al., 1993; Bauch et al., 1995; Schlosser et al., 1995) compared to normal ocean waters (around 0‰ vs. SMOW). Fractionation during sea-ice freezing and melting is very small. The outflow of the Lena and Mackenzie rivers has been successfully traced by oxygen isotope measurements in the adjacent oceanic area (Létolle et al., 1993; Macdonald et al., 1995). In a simple two-component system, the river water component in shelf and ocean waters can be calculated from the oxygen isotope ratio if the values of the sources (ocean water, river water) are known. However, it is also possible to calculate the meltwater component from a ternary system of Ocean water, river water and meltwater (Östlund and Hut, 1984; Bauch et al., 1995).

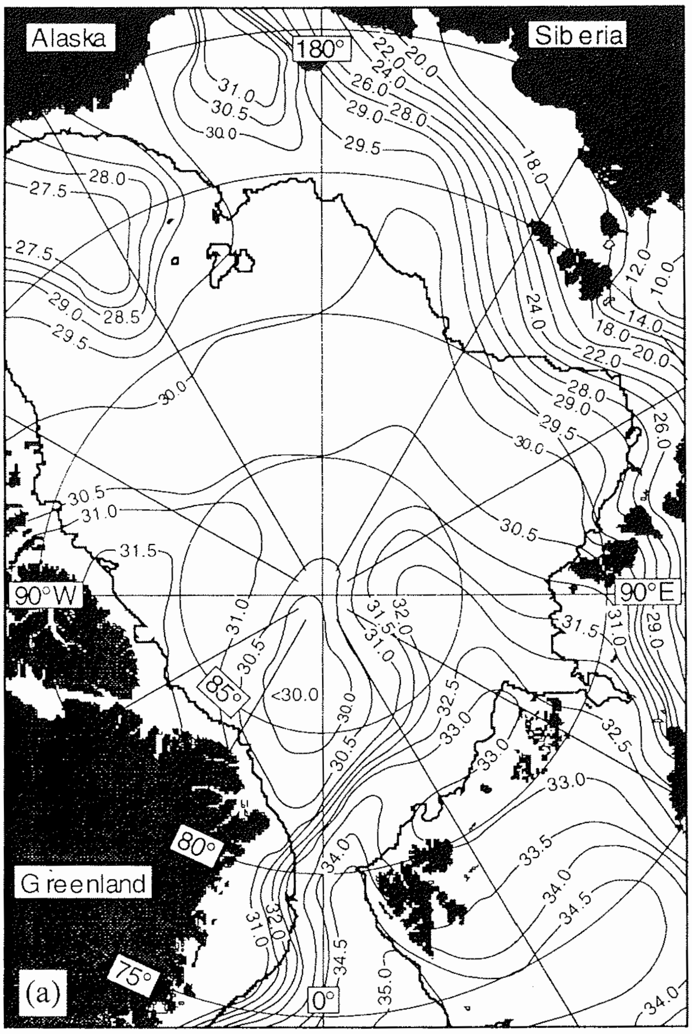


Fig. 5: Salinity distribution in surface water of the Arctic Ocean (from Spielhagen and Erlenkeuser, 1994; according to Gorshkov, 1983).

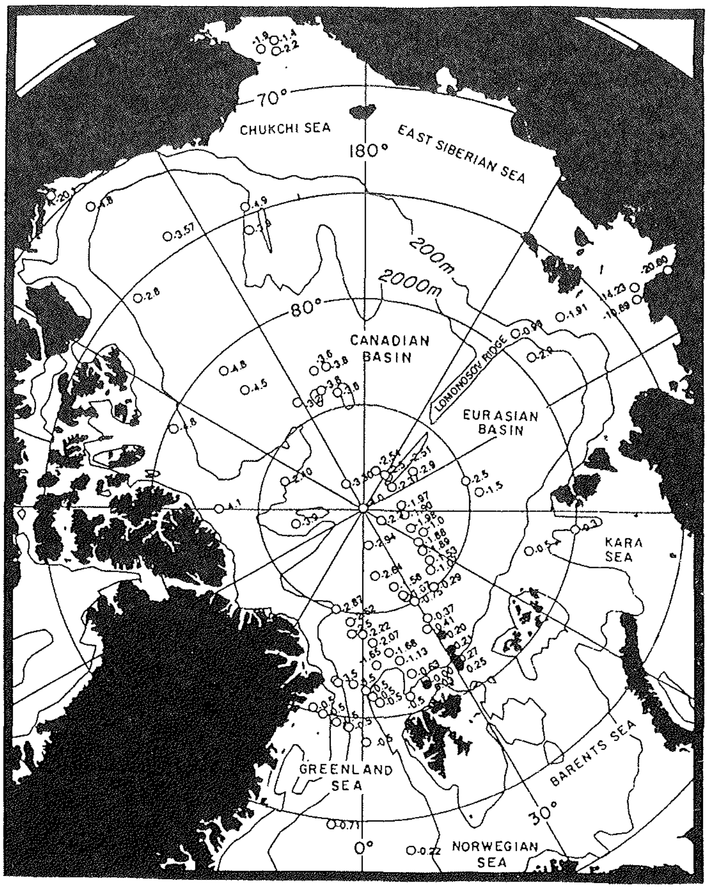


Fig. 6: Distribution of ∂18O in the surface waters of the Arctic Ocean (Bauch et al., 1995; Schlosser et al., 1995).

** Dissolved and particulate organic matter*

Dynamics of organic matter in the Arctic have only recently attracted the attention of the oceanographic community. The important role of the Arctic in global ocean circulation has been recognized, however, questions about the sources and fate of organic matter within the Arctic system remain to be answered. Major players in this respect are Arctic rivers which discharge huge amounts of terrigenous organic matter and nutrients (see below), into the system. The latter may cause enhanced surface-water productivity and, thus, result in increased accumulation of marine organic matter in coastal zones. The discharge of dissolved and particulate organic matter of the River Mackenzie, for example, is estimated as 1.3 * 10^6 and 2.1 * 10^6 tons per year (Tab. 1; Macdonald et al., 1998). The discharge of dissolved organic carbon of the Lena River reaches maximum values of 11 mg/l during summer floods (Martin et al., 1993). The dissolved and particulate organic matter supply of the Lena River is estimated as 3.6 * 10^6 tons per year and 1.3 * 10^6 tons per year, respectively, according to Rachold, et al., (1996), 4.5 * 10^6 tons per year and 0.8 * 10^6 tons per year according to Gordeev et al. (1996). Most of this material is accumulated in coastal-near zones, however, significant amounts of organic matter is further transported offshore by different processes such as sea-ice, ocean currents, turbidity currents (Fig. 7; Stein and Korolev, 1994).

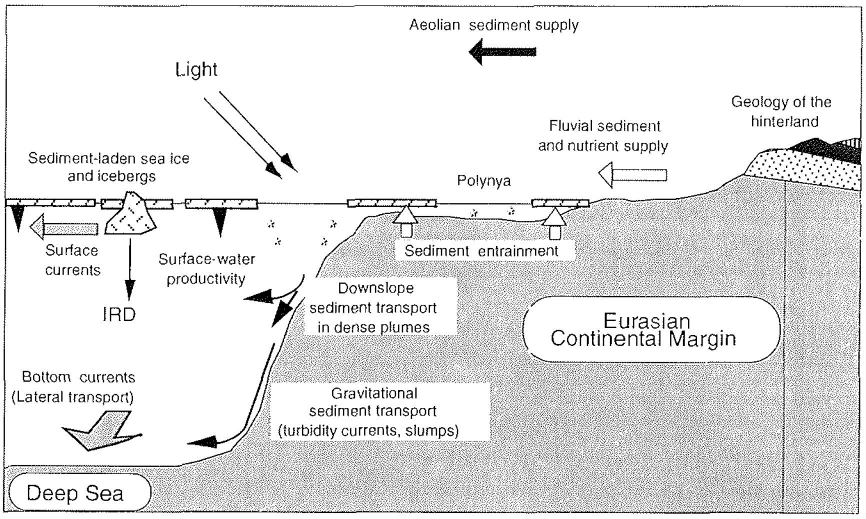


Fig. 7: Summary scheme of factors controlling the sedimentation along the Eurasian continental margin and its shelf-to-basin transport (from Stein and Korolev, 1994).

Sources and pathways of organic matter supply can be identified by organic-geochemical as well as micropaleontological tracers. Biomarkers, for example, may provide a specific signal for terrestrial-derived and marine-derived organic matter (Fig. 8) which can be traced into the shelf sediments and the interior of the Arctic Ocean (e.g., Fahl and Stein, 1997; Schubert and Stein, 1996; Stein, 1996). Freshwater algae are also indicative of river discharge (Fig. 9; Kunz-Pirrung, in press), while dinoflagellate cysts and acritarchs are useful indicators in the Beaufort Sea (Fig. 10; Mudie, 1992). A number of physical, chemical, and biological processes have the potential to transport, remove, or alter the riverine organic matter during its transfer across the shelf. Studies should focus on effects of key processes like estuarine mixing, ice formation and ice transport, photolytical processes, and bacterial utilization/ decomposition and alteration of particulate and dissolved organic matter. In particular, sources and pathways of anthropogenic vs. natural pollutant transport requires detailed study, e.g. natural oil seeps and source rock bitumens from the lower Mackenzie corridor dominate present levels of polycyclic aromatic compounds relative to anthropogenic sources (Yunker et al., 1996).

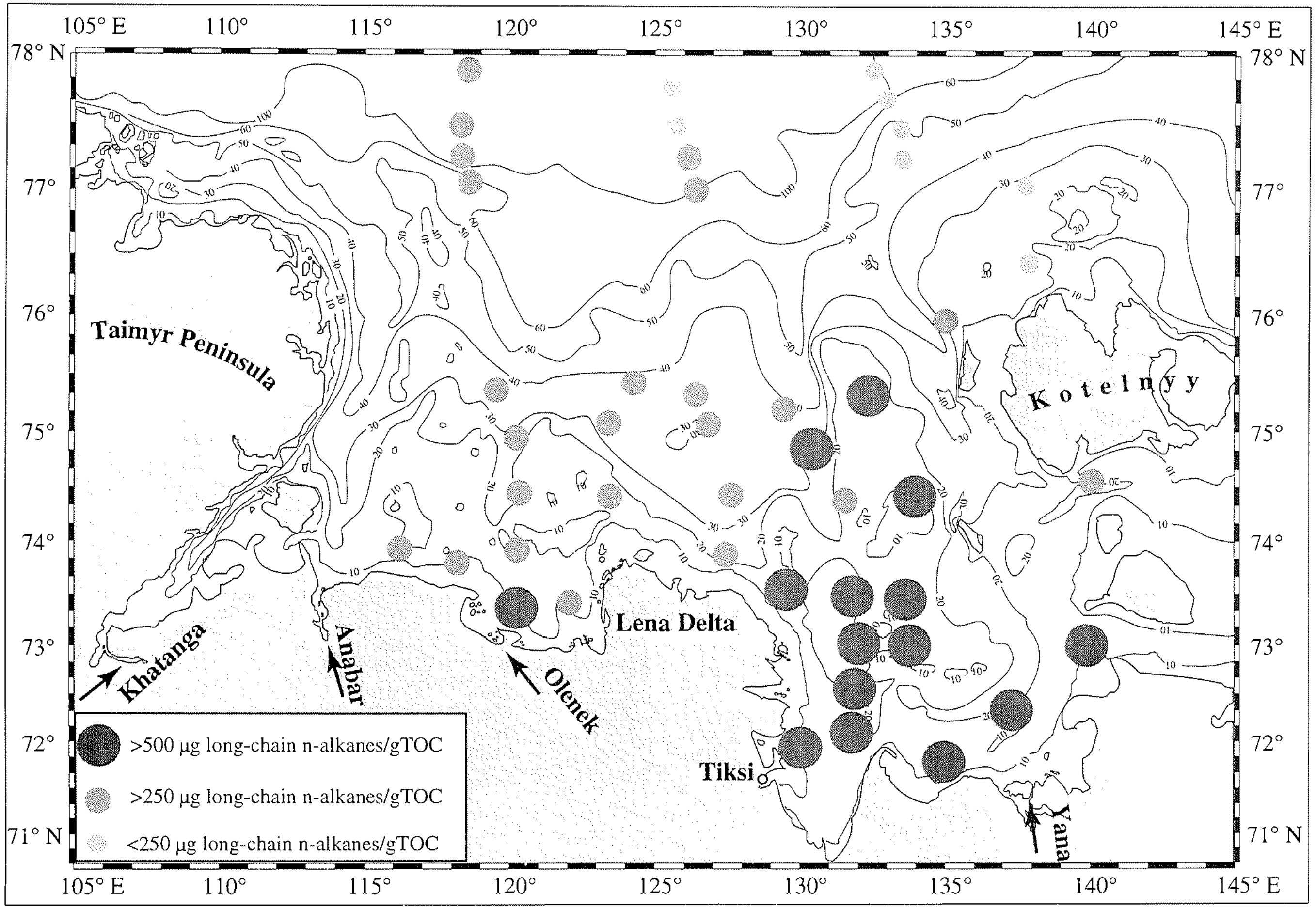


Fig. 8: Distribution of long-chain (indicator for higher terrestrial plants) and short-chain (indicator for marine algae) *n*-alkanes in surface sediments from the Laptev Sea (Fahl and Stein, 1997).

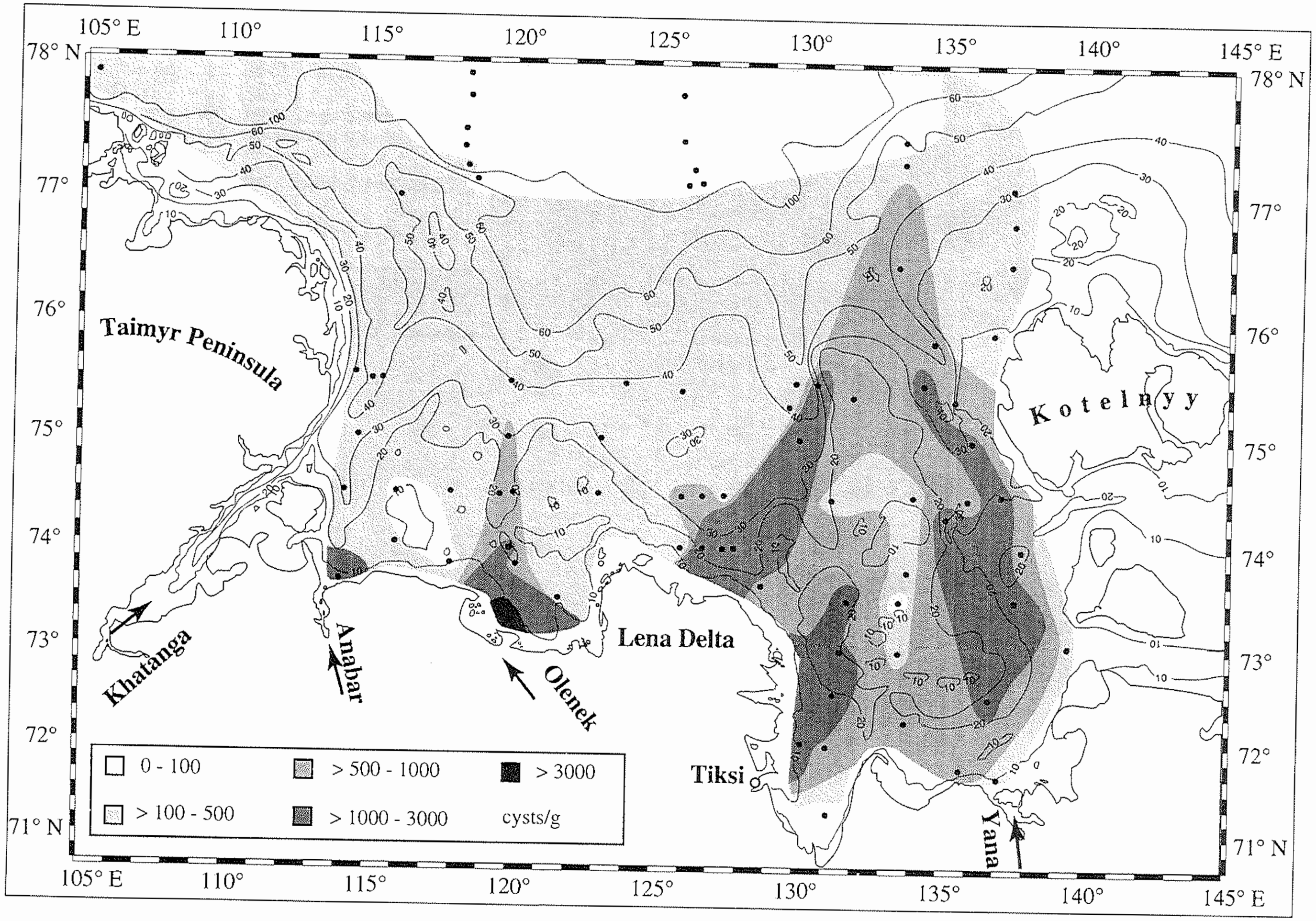


Fig. 9: Concentrations of freshwater algae (chlorophyceans per gram dry sediment) in surface sediments from the Laptev Sea (Kunz-Pirrung, in press)

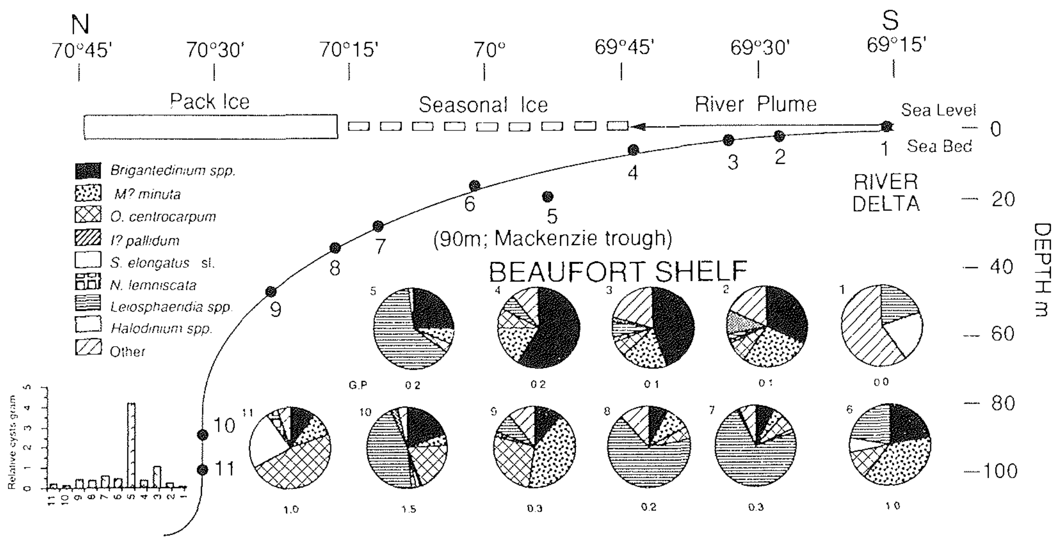


Fig. 10: Schemtatic profile across Beaufort Sea in summer, showing relative abundances of dinocysts and acritarchs in surface sediment samples (Mudie, 1992).

Research will concentrate on the fluxes and composition of organic carbon. Future research will focus on the following subjects:

(1) the quantification and qualification of dissolved and particulate organic matter discharge by representative rivers like the Yenisei, Ob, Lena, and Mackenzie;

(2) the quantification and characterization of marine organic matter produced in the euphotic zone;

(3) micropaleontological tracers to identify organic-carbon sources (e.g., pollen, spores, freshwater algae, dinoflagellates, diatoms); and

(4) sedimentation and transformation processes of organic matter during the transition from the river delta to the shelf and slope.

Chemical characterization of organic matter will include bulk level analysis like elemental and isotopic composition as well as molecular level analysis of the particulate and dissolved fractions in the river, on the shelf and in the open Arctic Ocean.

** Sediment load (inorganic particulate matter)*

The detrital component of Arctic shelf sediments largely consists of riverine material. The largest single source of suspended matter is the Mackenzie River (ca. 127 - 142 * 10^6 tons/yr; Tab. 1). Major proportions are also derived from the Eurasian continent and imported by the large Siberian rivers, i.e. the Ob, the Yenisei and the Lena rivers. The annual discharge of suspended sediments by the Lena River is already 17.6*10^6 tons (Tab. 1; Martin et al., 1993; Gordeev et al., 1996). To understand the contribution of the riverine input to the sedimentary budget of the Arctic Ocean the quantification and characterization of the riverine material transport, its seasonal and interannual variations and the transfer from the river delta/estuary to the shelf and further to the deep sea have to be studied.

In Siberia water discharge and sediment load of the major rivers have been measured at several hydrometeorological stations for 50 years. In the Mackenzie Basin, hydrological records for 15-25 years are available from about 19 stations (Fig. 11). Daily data of many rivers are available through publications (Leningrad Hydrometeorologial Service; Environment Canada Atmosphere & Environment Services). Due to the extreme climate in Central Siberia the major part of the material is transported during spring flood (Fig. 2; Cauwet and Sidorov 1996). In the Mackenzie Basin, peak monthly runoff is in May, June, and July, but there is a second larger peak in sediment discharge in mid-August, associated with annual snow melt in the headwaters and permafrost degradation along flooding banks (Fig. 3; Jenner and Hill, 1991; Lawford, 1994).

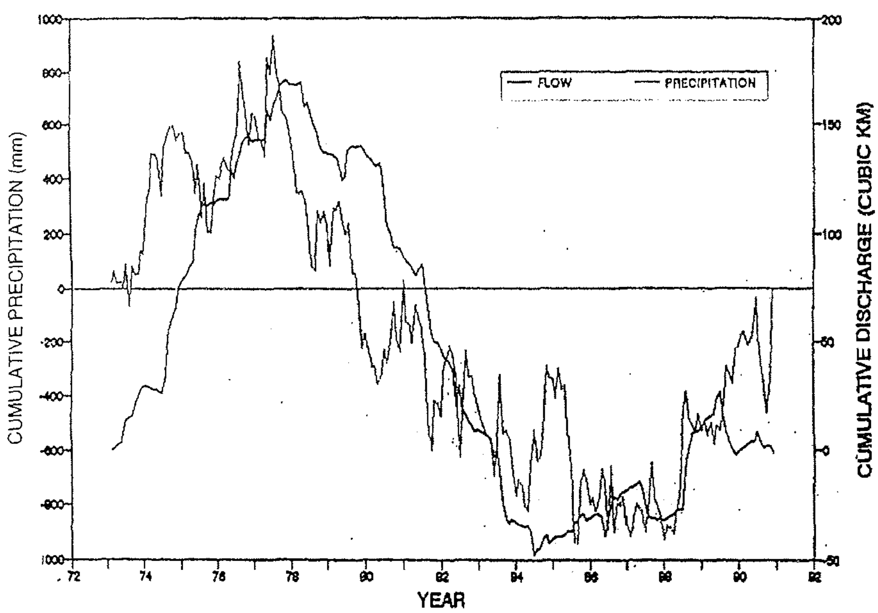


Fig. 11: Cumulative precipitation and runoff patterns for the Mackenzie River, 1972-1992.

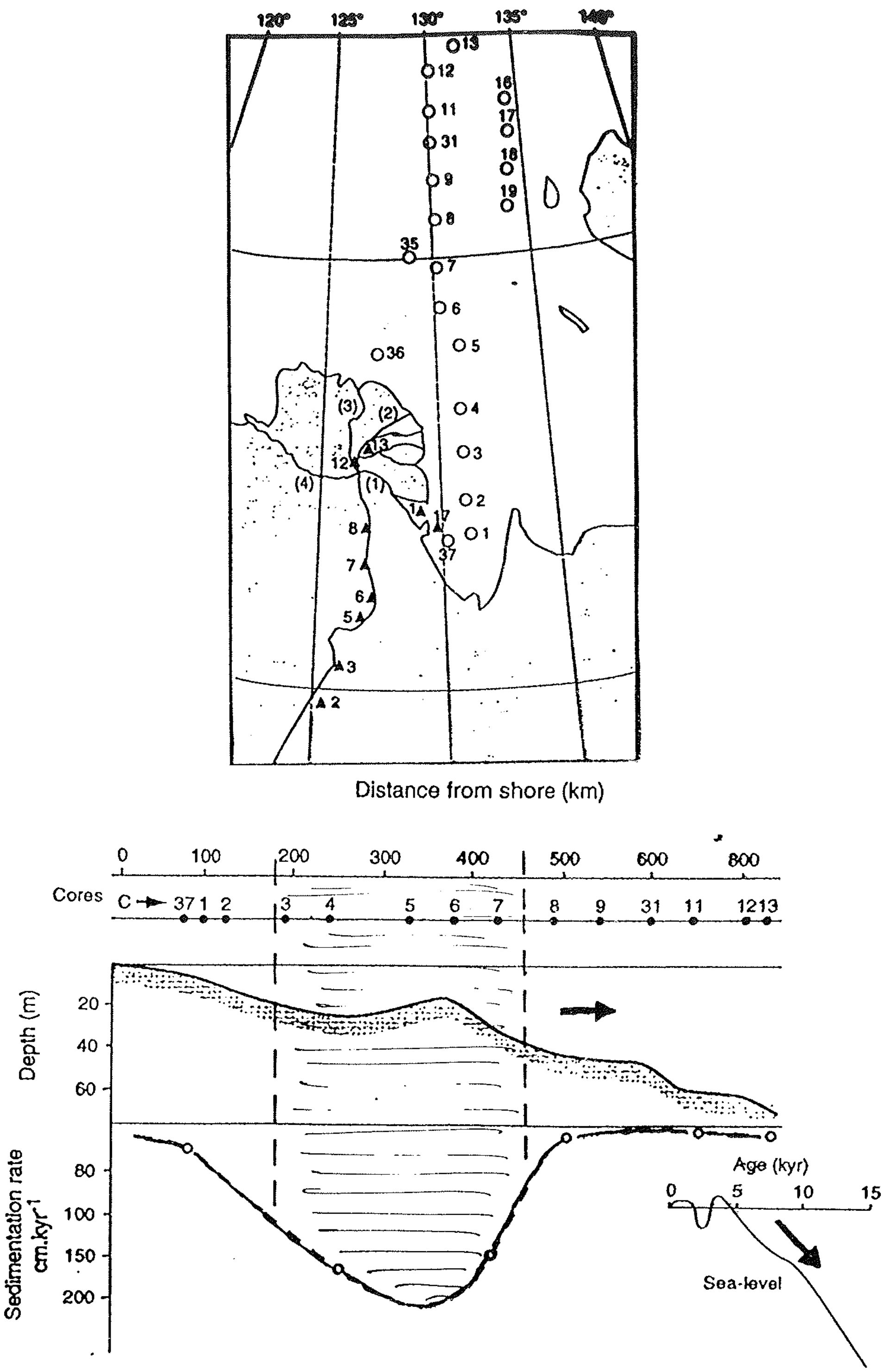


Fig. 12: Station profile and recent sedimentation rates off the Lena River (Kuptsov and Lisitzin, 1996).

The major part of the discharged sediment is settled in the estuaries and at their mouths due to hydraulic and biogeochemical processes, which account for the settling of up to 90-95% of riverine suspended matter and 20-40% of dissolved components. This is indicated by maximum sedimentation rates in areas close to the river mouth (Fig. 12; Kuptsov and Lisitzin, 1996). Still, a significant part of fine-grained sediment is carried off by currents and ice to eventually settle over the sea floor. Observations on light transmissivity indicate two major patterns of sediment dispersal off the river mouths: by surface currents and by bottom resuspension and transport.

Another major sediment source is provided by the coasts of the Arctic seas composed of loose and icy Quaternary sediments. Due to coastal erosion, which can exceed 1m/yr, sedimentation rates off some coast segments are comparable to those north of the Ob and Yenisei estuaries. Erosion off the active Mackenzie delta is > 20m/yr, and cliff erosion is almost 2 m/yr east of the delta (Jenner and Hill, 1991; Solomon et al., 1994).

The different rivers carry suspension loads characterized by different mineralogical and geochemical tracers, dependent on the geology of the hinterland. Thus, the characterization of the suspended particulate material and the sediments reveals important information on the distribution of the riverine material in the Arctic Ocean. For example, the minerals smectite and clinopyroxene are enriched in the surface sediments of the western Laptev Sea (Figs. 13 and 14; Lapina, 1965; Behrends et al., 1996, in press; Wahsner, 1995; Wahsner et al., in press). The distribution of these minerals on the shelves is controlled by the large river outflow of the Ob, Yenisei, and Khatanga. Source rocks are the large flood basalt complexes on the Siberian Platform, which are drained by these river systems.

Besides the mineralogical composition, the chemical analyses of river suspension and surface sediments will provide additional information to identify possible source areas and transport pathways.

Radiogenic isotope ratios ($^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$, etc.) on suspended particulate matter (SPM), marine surface sediments, and ice-rafted material (IRM) can be applied to constrain the fluvial source of Arctic Ocean sediments because the SPM of every Siberian river is distinctively marked by a unique radiogenic isotope ratio. In particular, the $^{87}Sr/^{86}Sr$ ratios of the Siberian rivers are mainly controlled by the characteristic isotopic composition of their lithological endmembers and by its grain size distribution. SPM of the Khatanga river draining the Siberian flood basalts show low $^{87}Sr/^{86}Sr$ of about 0.708 to about 0.710, whereas the Lena River draining metamorphic rocks of phanerozoic age show higher values of about 0.715 to about 0.723. These Sr isotope ratios are arranged along individual mixing arrays for every river controlled by the grain size distribution. By comparing the Sr-isotope ratios of Arctic sediments or IRM to these mixing arrays it is possible to identify the fluvial origin of the material (Fig. 15; Rachold et al., 1997).

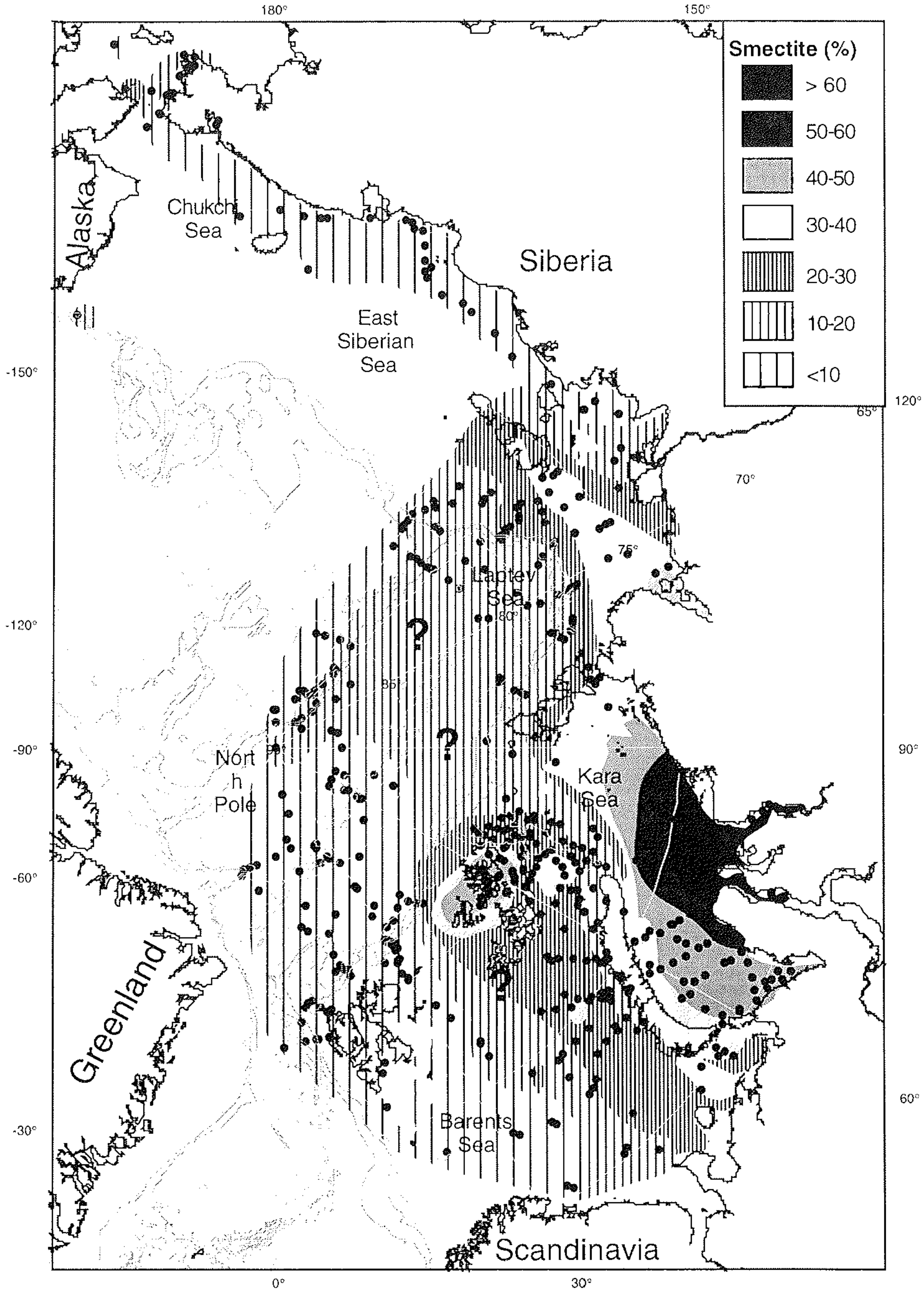


Fig. 13: Distribution of the clay mineral smectite in surface sediments from the Eurasian continental margin and eastern central Arctic Ocean (from Wahsner et al., in press).

Thus, these parameters (such as clay-mineral and heavy-mineral compositions as well as geochemical tracers) determined in marine shelf, slope, and deep-sea sediments, can be used as tracers for specific source areas and riverine input in the Arctic Ocean.

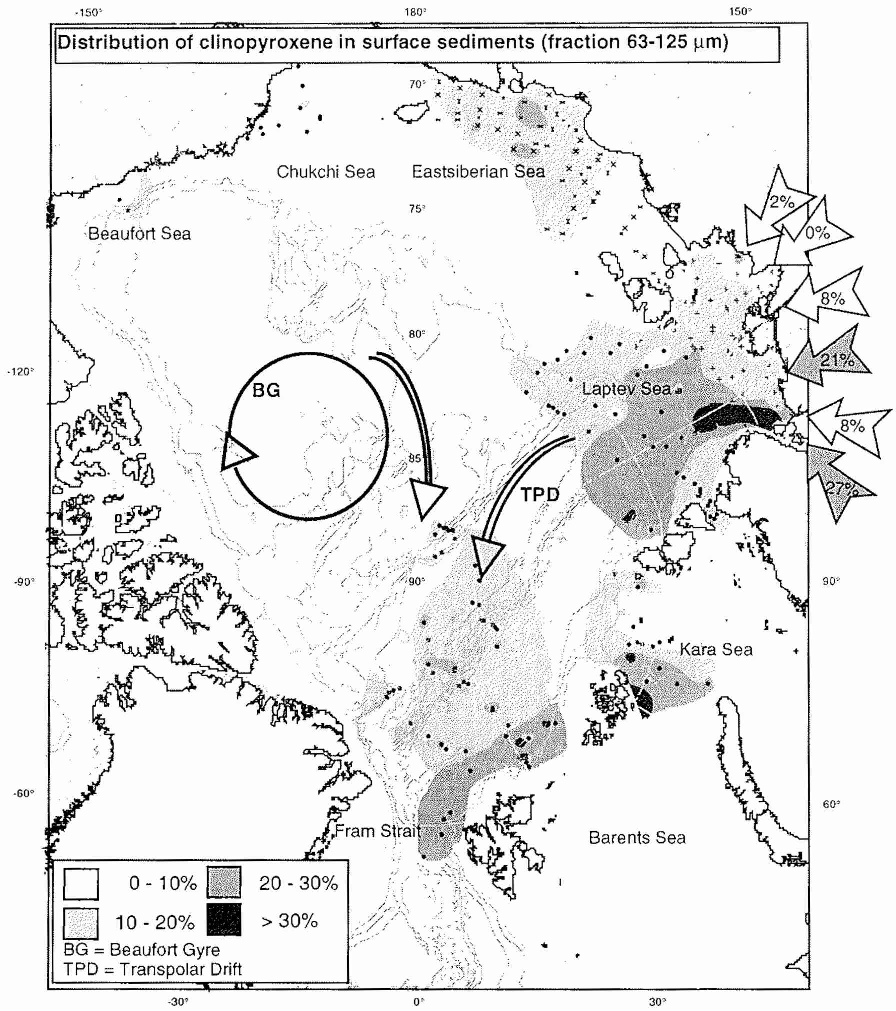


Fig. 14: Distribution of clinopyroxene in surface sediments from the Laptev-Sea continental margin and eastern central Arctic Ocean (Behrends et al., in press).

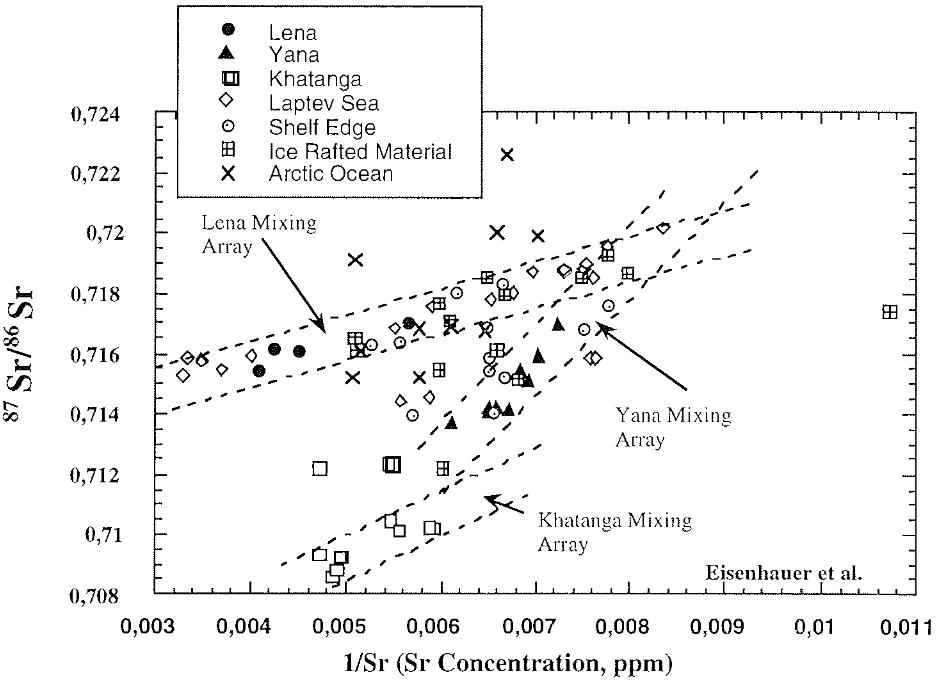


Fig. 15: The $^{87}Sr/^{86}Sr$-ratios plotted as a function of the inverse Sr-concentrations (Eisenhauer et al., in prep.). In addition the "Lena mixing" array and the "Yana mixing" array are plotted in this diagram. It is obvious that almost all of the marine sediment samples and of the ice-rafted material (IRM) follow either the Lena or the Yana mixing array. This means that these sediments can be attributed to Lena and Yana suspended matter, respectively. Samples which plot in between the "mixing arrays" are interpreted as a mixture of Yana and Lena sediments. Note, that four of the Arctic Ocean samples and one IRM sample plot outside the frame provided by the Lena and Yana mixing arrays. These samples have to be attributed to material delivered from yet not identified sediment sources.

Research will include

(1) a monitoring programme of seasonal variations of runoff and supply of dissolved and particulate matter of the major Arctic rivers;

(2) a detailed sampling programme of suspended matter and surface sediments from the river itself, the river mouth area, and the inner and outer shelf;

(3) a detailed sedimentological and geochemical investigation and quantification of the riverine sediments including radiogenic isotope "finger-printing" of the Mackenzie River waters; and

(4) a high-resolution study of surface-near sediments from high-sedimentation rate areas and the correlation of the sedimentary records with historical measured discharge records.

Methods should include determinations of heavy metals; clay minerals; heavy minerals; major, minor, and trace elements; and specific isotopes. Large rivers such as the Lena River drain different climatic and geomorphologic zones. To characterize weathering processes, pedogenesis and material transport in different climatic zones typical tributaries should be included in the investigations.

** Dissolved inorganic material*

The extreme seasonal changes in discharge of rivers at high latitudes have a profound effect on the chemical composition: In the Lena river the average load of dissolved solids changes from 60-70 mg l^{-1} during the flood (June-July), with Ca^{2+} and bicarbonate as major constituents, to up to 300-330 mg l^{-1} during the 60 times lower discharge in March-April, when the composition is determined to a large extent by groundwater inputs with higher chloride contents. On the whole, the chemical denudation rate is low, related to the low intensity of chemical and physical weathering processes resulting from the extensive permafrost in the basin (Gordeev and Sidorov, 1993).

The river Lena can be considered a non-polluted river with dissolved trace metal contents at the lower limit of the range found in (unpolluted) world rivers (Martin et al., 1993). Trace metal concentrations in bottom sediments can increase further off the Lena River delta, probably due to transport and diagenetic processes (Nolting et al., 1996). In such areas, trace metal concentrations cannot be used to trace pathways of river water across the shelf.

Arctic rivers have a high dissolved organic carbon and Fe content, the Fe supposedly organically complexed and in colloidal form. Upon estuarine mixing extensive flocculation and sedimentaton occurs, removing Fe and possibly radionuclides like ^{226}Ra, but a mobilization from suspended material is observed in the Lena delta for the trace metals Cu, Ni and Cd.

In the lower course of the Ob river, oxidation of the large amounts of organic material can bring about oxygen deficiency, apparently in most cases not associated with anthropogenic pollution (Telang et al., 1991). This contrasts with the Yenisei, which is well oxygenated.

Silicate is relatively low in arctic rivers. The average silicate content of the Mackenzie river is 67 μM, compared to a world average of 175 μM, due to high abundance of carbonate rock and lack of easily soluble silica. This low input results in the silicate gradient in arctic surface waters with highest values in the inflow from the Bering Strait. Rivers that drain tundra areas are extremely low in phosphate (mentioned for Yenisei and Colville river). Ob has high fluorine content (Telang et al., 1991).

Northern Eurasian rivers can have distinct differences in their oxygen isotopic signature, decreasing from -13‰ vs. SMOW in northern Scandinavia to -24‰ in the Far East (Létolle et al., 1993). However, isotopic differences between individual rivers of the same region are in most cases too small to be traced near their outflow into the ocean.

A linear relationship between the ^{238}U concentration and salinity has been observed in a number of estuary systems outside the Arctic (Martin et al., 1978). However, there are results from other estuaries, which indicate a non-conservative behaviour for uranium (Toole et al., 1987). The concentrations of Uranium and Thorium isotopes (^{238}U, ^{234}U, ^{232}Th, ^{230}Th) in river water and sea water samples from Kalixälven and near its outflow into the northernmost Baltic Sea have been analyzed (Andersson et al., 1995). Results indicate a rapid drop of ^{232}Th concentrations, when the river water entered the sea and equilibrium with sea water at salinities of 7.5‰. Allmost all of the riverine ^{232}Th must be deposited in the low-salinity regions of the estuary (Andersson et al., 1995).

3.1.2. Estimated importance of riverine input for oceanic circulation, sea-ice formation, and marine biota and productivity

* *Oceanic circulation patterns*

In the present climate state, more than half of the freshwater input to the Arctic Ocean is supplied by rivers from the surrounding continents. This freshwater contributes significantly to the strong stratification of the upper layers of the Arctic Ocean (Fig. 16) and is regarded as the main cause of the perennial sea-ice cover in the central basins. On the other hand, in early summer, a large flood of river discharge supplies a locally strong input of heat and liquid freshwater which initiates the break-up of the fast-ice near the coast.

On the Siberian shelves, the river water plumes initially flow eastwards before they spread into the Arctic Ocean interior. There, most of the river water remains in the upper ocean and, along with the sea ice or the surface water, follows the circulation of the Beaufort Gyre in the Canadian Basin and the Transpolar Drift towards the Fram Strait.

Since the mean residence time of the river water on the shelves and in the upper layers of the Eurasian Basin is of the order of a few years (Bauch et al., 1995), decadal changes in the river water input can be expected to influence the extent of the sea-ice cover and the temperature and salinity structure of the upper water masses. This has consequences for the energy exchange between the atmosphere and the ocean and for the thermohaline circulation. Oceanic variations, such as the "Great Salinity Anomaly" (Dickson et al., 1988) which was observed during the seventies in the North Atlantic, could possibly result from a variation of freshwater of the Arctic Ocean (Aagaard and Carmack, 1989).

Part of the river water sinks to intermediate or deep layers in the central basins via plume convection. The loss buoyancy of the shelf waters, caused by cooling and salinization due to ice formation, leads to convective downward motion on the shelves and draining of shelf water via plumes into the central basins. Since the salinity of the buoyancy plumes determines the depth which they can finally attain, the ventilation of the central basin is sensitive to the amount and distribution of river water in the shelf seas.

a.

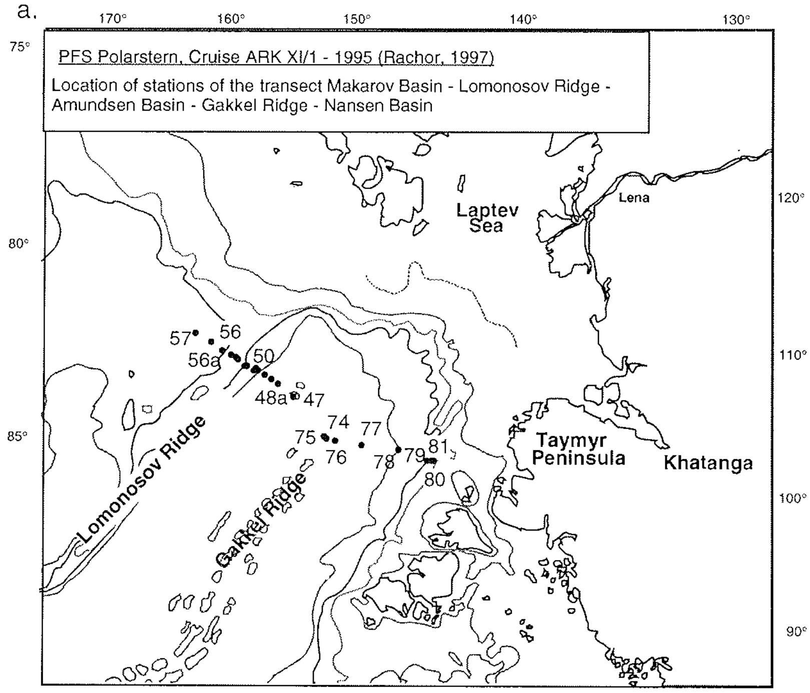


Fig. 16: a. Map with oceanographic stations of the transect from the Makarov Basin to the Nansen Basin.

b.

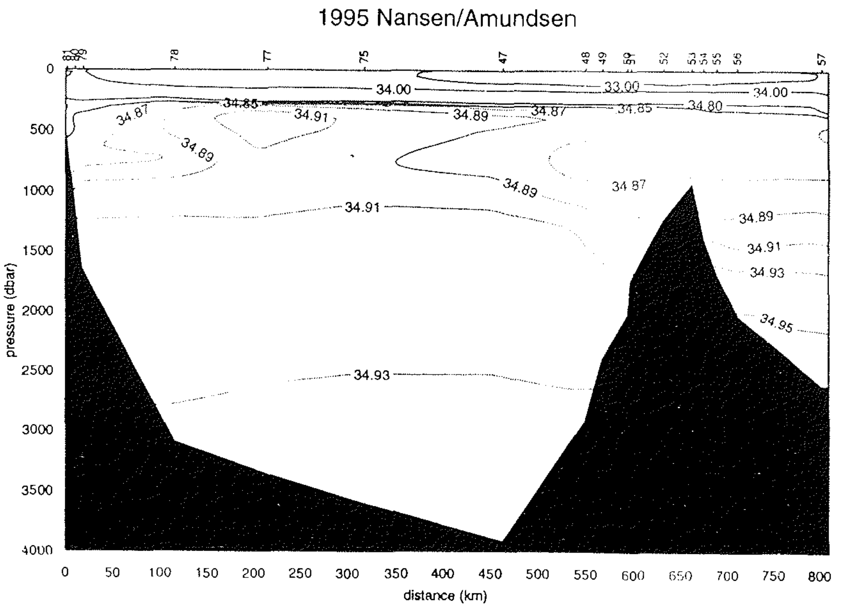


Fig. 16: b. Salinity distribution on a transect from the Makarov Basin to the Nansen Basin (Rudels et al. in Rachor, 1997).

On timescales beyond decades, the freshwater runoff into the Arctic Ocean influences its climatic state as a part of the larger northern hemisphere's climatic system. A number of players interact on this scene: The water exchange through the Arctic Ocean's boundaries (Bering Strait, Canadian Archipelago, Fram Strait and Barents Sea), the circulation pattern and its vertical layering, hydrography and ice cover, precipitation and freshwater runoff and the atmospheric circulation.

The freshwater exported from the Arctic Ocean towards the North Atlantic influences the global thermohaline circulation. The present day annual freshwater export is about 4500 km^3. Most of it leaves the Arctic Ocean through the East Greenland Current as sea ice (2790 km^3/y) or as surface water (820 km^3/y) (Aagaard and Carmack, 1989). The remainder is assumed to exit through the Canadian Archipelago.

Oceanographic research programmes with respect to the present state of the Arctic Ocean should include:

(1) the modification of the river discharge by estuarine processes,

(2) the pathway of river input through the shelf seas into the central Arctic Ocean,

(3) the interaction and mixing processes of river input with shelf waters,

(4) the influence of river water on the sea-ice cover,

(5) the vertical transport of river water by convective shelf water plumes into the deep basins,

(6) the effect of the seasonal and interannual variability of river outflow on the regional shelf sea dynamics,

(7) the effect of seasonal, interannual and decadal variability of river outflow on the large scale circulation and stratification of the Arctic Ocean.

** Sea-ice formation*

The present state and dynamics of the perennial sea-ice cover of the Arctic derive to a large extent from the stable stratification induced by input of riverine freshwater into the Arctic Ocean's halocline. While the net freezing rates over the Arctic Ocean are sensitive to freshwater input by Arctic rivers, reliable quantitative estimates on the impact of discharge variability on ice extent and net ice-growth are still lacking. This issue has already been considered in the context of the diversion of Siberian rivers (Treshnikov and Ivanov, 1980). Early estimates suggesting a significant increase of convective activity in the Eurasian Arctic with concurrent reductions in sea-ice extent (Aagaard and Coachman, 1975) were somewhat put into perspective by later studies employing large-scale dynamic-thermodynamic sea-ice models (Lemke, 1987) as well as regional to global circulation model studies (Semtner, 1984, Cattle, 1985). Nevertheless, due to the extreme sensitivity of the Arctic's perennial ice cover to changes in oceanic heat flux (Maykut, 1986), it appears likely that changes in the density structure of the halocline and the rate of heat entrainment from intermediate and deep waters has strong effects on the ice thickness distribution in the Arctic Ocean. In this context, both increasing the ice-thickness and heat flux data base as well as improving the performance of coupled atmosphere-ice-ocean models are likely to provide us with a more refined picture of the impact of freshwater discharge on the sea-ice cover. Such work would also aid in unravelling long-range transport and teleconnections between hydrological processes and the sea-ice regime in the major Arctic outflow area of the Greenland Sea (and extending down to the Labrador Sea). Climatological studies indicate possible linkages between river discharge, sea-ice distribution and the convective activity at these two major sites of deep convection (Mysak et al., 1996; Dickson, 1997).

A more immediate linkage between river discharge and the sea-ice regime exists over the Siberian and North American shelves, where residence times of freshwater are typically on the order of several months to more than a year (Schlosser et al., 1994, Bauch et al., 1995). In the Beaufort Sea, with a narrow shelf and deep-draft pressure ridges produced by alongshore motion, the sub-ice morphology has been shown to retain significant amounts of Mackenzie river discharge (Macdonald and Carmack, 1990). Adfreezing of river water onto the base of the fast-ice cover furthermore constitutes a significant contribution to coastal ice formation (Macdonald et al., 1995). Through these processes, freshwater remains on the shelf during winter time and is released jointly with the peak discharge in summer.

The Siberian shelves, in particular Laptev and East Siberian Shelf, on the other hand are characterized by an extensional ice regime and a broad fast-ice cover. Here, linkages between the location and areal extent of fast ice have been recently proposed by Dmitrenko et al. (in press). Furthermore, underwater ice formation associated with increasing discharge during the summer months has been observed by Golovin et al. (in press) in the vicinity of the Lena Delta. Given the importance of coastal (fast) ice formation for the thermal evolution of submarine permafrost as well as coastal evolution, these first studies need to be extended in order to fully assess the impact of river discharge on ice production over the shelves and in the coastal areas. Since river runoff may also neutralize or counterbalance the effects of intense sea-ice formation in coastal polynyas on the production of dense brines, the linkages between ice and river-water distribution are also of importance for deep-ocean processes.

Finally, sea ice plays an important role as a transport medium for ice-rafted sediments (Pfirman et al., 1990; Nürnberg et al., 1994). Over the Siberian shelves, and in particular in the Laptev Sea, large amounts of sediments are exported by sea ice into the Arctic Basin and the Greenland and Barents Seas. At present, it is not resolved to what an extent direct entrainment of riverine suspended matter plays a role in Transarctic sediment transport (Eicken et al., 1997; Dmitrenko et al., in press). Recent studies for the Laptev Sea suggest that while ice from the vicinities of the river mouths may be exported to the Arctic Ocean, the bulk of ice-rafted sediments is entrained during ice growth further offshore (Eicken et al., 1997). The latter may nevertheless be still significantly controlled by river-derived freshwater fluxes which play an important role in the fall freeze-up regime.

Thus, apart from extending the sea-ice data base, in particular with the aid of remote-sensing, and improving numerical models of the relevant processes and sub-systems, future work within the framework of ARPAD and beyond will have to further scrutinize the coastal and on-shelf linkages between river discharge and the sea-ice regime. Such work is of particular importance to aid in interpretation of paleo-data representative of vastly different bathymetric and hydrological conditions.

** Marine biota and productivity*

The role of river discharge in the past Arctic Ocean ecology (Fig. 17) cannot be understood without a good knowledge of nowadays biological structures and the functioning of the ecosystem. The larger scale influences of Eurasian rivers and the Mackenzie on Arctic marine ecosystems have not sufficiently been studied so far, except distribution and migration patterns within estuaries and river plume areas and some studies related to productivity. Recent Russian-German cooperation in the Laptev Sea revealed the strong impact of the Lena outflow on marine biota far offshore, beyond the continental slope (> 350 km from the delta). Improvements are especially needed in our knowledge of the relationships between environmental variables, like river discharge, and the biota used to reconstruct past environmental conditions, such as foraminifera, mollusks, dinoflagellates, and diatoms.

Riverine influences in the high Arctic have several components important for environmental and life conditions:

- input of huge amounts of freshwater within the short summer season;
- input of terrigenous matter (dissolved and particular);
- input of heat.

As these influences are of extreme and short duration, they intensify the strong "normal" seasonality in high latitudes (i.e. in solar radiation and ice cover) in the areas of riverine inflow. Almost all of the ecological studies conducted in these environments so far have concentrated on the conditions and processes after the main flushing event and may even have missed the most important events and conditions controlling marine primary and secondary productivity.

Accordingly, the biological component of APARD will concentrate on these processes and provide (first) answers to the following questions:

1. Which are the biological consequences of increased stratification by riverine waters (and ice melt), especially their effects on the intensity of primary production and the ice-pelago-benthic couplings (ending up in the sedimentary records) ?

2. How far will the biological sub-systems be coupled or decoupled by river inflow variability, leading to variations in sedimentation ?

3. What is the role of riverine outflow for the light conditions (turbidity of the plume, ice conditions) and, consequently, for primary production ?

4. Is there a substantial riverine supply of nutrients supporting marine production ?

5. What is the fate and role of introduced organic matter for the marine biota, especially in the bottom sediments ? What is the fate of such material ?

6. Are there contaminants introduced into the marine environment, and what may be their impact ?

7. How far is riverine heat input affecting and sustaining productivity and, thus, promoting marine life ?

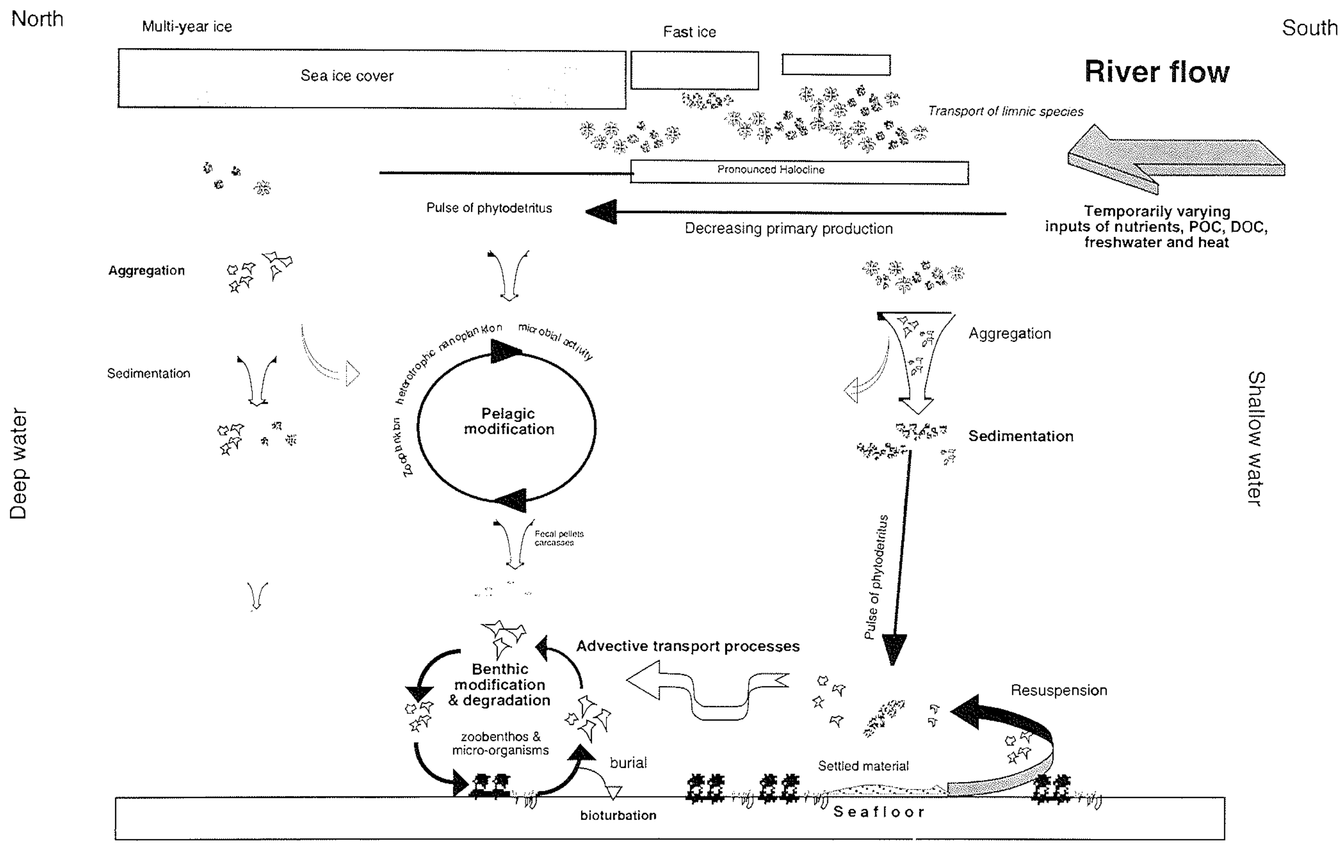


Fig. 17: Biological processes to be investigated in the Kara Sea relevant for transformation of matter originating from large Siberian rivers

8. To what degree is such furthering counterbalanced by the strong salinity stress (gradients and variability in space and time) ? Is this stress expressed in biological zonation and diversity patterns ?

9. How far can high Arctic brackish water zones and their biota be compared with e.g. such of temperate/boreal waters ?

Further problems are related to

- the possible stress by increased sedimentation in the mixing zones (incl. lowered oxygen conditions), and

- riverine influences on biogeographical distribution patterns and on migrating organisms (with emphasis on the still ongoing Holocene recolonization of the shelf sea by migrating organisms).

Special attention should be given to the biotic proxies used for paleoenvironmental reconstructions. Topics to be addressed include (but not limited to):

- the role of temperature, salinity, oxygen contents, and organic matter fluxes on the abundance and species composition of benthic foraminifera,
- the reliability of stable oxygen isotopes in mollusks to record salinity conditions during river runoff and whether that salinity can be statistically related to discharge,
- the role of temperature, salinity, and habitat preferences on the stable oxygen and carbon isotopic composition of living planktonic and benthic foraminifera, and
- the influence of sea ice on the species composition of diatoms and dinoflagellates.

Additionally, we should aim at identification of new biotic proxies that are not commonly used for paleoenvironmental reconstruction but have some potential to be useful.

Major directions of biological investigations

(1) Study biological gradients along the total salinity gradient (limnic to fully marine) in the estuaries of high Arctic rivers, selecting at least one from both eastern and western basins and using previously established transect lines where possible (e.g., Solomon et al., 1992).

(2) Follow production and related ("transforming") biological processes during the whole productive season, covering especially the flushing and ice melting events in spring/early summer. The main processes and stocks of primary producers, grazers and benthic transformers are to be studied.

(3) Compare riverine influences in wide and a narrow shelf environments (Eurasian like Pechora, Ob, Yenisei, Lena versus Mackenzie).

(4) Establish statistically reliable relationships between environmental variables and the biota that can be found in sedimentary records. Such relationships will be invaluable for reconstructing past environments, including past river discharges.

3.1.3 Sediment dynamics and budget

Some of the world's largest rivers discharge into the Arctic Ocean. The largest of these rivers flow across significant climatic gradients: they drain large tracks of permafrost terrain but head in temperate climes. Arctic river hydrographs are sensitive to temperature fluctuations, being strongly snow-melt or ice-melt influenced (Syvitski and Andrews, 1994). Fluxes of sediment in the Arctic are therefore river-dominated and sensitive to climate variability (Andrews and Syvitski, 1994). The large amounts of dissolved and particulate material transported by the major Arctic rivers onto the shelves and further transported by different mechanisms onto the open ocean (Fig. 7), may contribute in major proportions to the entire Arctic Ocean sedimentary and chemical budgets. The rivers also transport major amounts of anthropogenic pollutants (radioactive elements, heavy metals, etc.) which are trapped in coastal-near sediments and/or transported towards the open ocean.

An important goal of APARD is to understand the processes and pathway of sediment that lead to the preservation of strata on the margins of the Arctic Ocean. Within this overall objective there is a specific need to link the riverine sediment sources with the deposits formed on continental margins. This „source to deposit" approach contains a number of processes, with each containing its own set of physics. The first process is the riverine discharge of freshwater and sediment. The second process is the distribution of the sediment across the continental shelves by river induced plumes and the raining out of sediment from the plumes. The resulting plumes and the associated sedimentation is dependent on the magnitude of river discharge, the rate of flocculation of particles within a plume, the resultant settling velocities of the flocculated particles, and the ambient oceanic conditions (currents and density structure). After the particles have rained out of the surface plume they are advected and diffused by the intermediate depth currents as they sink through the water column. This mid-depth advection-diffusion of the river derived sediment is the third process in the „source to deposit" chain. In the Arctic these mid-depth ocean currents flow under ice, with normal pressure fields, often dampened.

Once the particles have fallen through the water column, they are then placed into the bottom boundary layer. The bottom boundary layer (being the forth step in the chain) will advect and diffuse the particles until the energy conditions are low enough to allow for deposition. The initial deposit can then be reworked through time before being preserved in the sedimentary record. It should be noted that few researchers have modeled or measured the path of sediment dispersal from the river mouth to the sea-floor in an open-coastal environment.

There is a strong desire of marine scientists to interpret the offshore sedimentary record on the Russian continental margin, in the belief that proxy indicators would establish a history of paleo-discharge from these arctic mega-rivers. This information would in turn provide a direct record of continental climate with the flux of river sediment providing the strong and integrative record of terrestrial climate dynamics. For the approach to work, however, we need to determine an understanding on the link between water discharge and sediment load at the dynamic level — the level of flood hydrographs. Arctic rivers can discharge over 90% of their sediment load in less than one month. Other temperate or tropical rivers of comparable size do not have this type of dynamic response (Wang et al., 1998). Arctic rivers, frozen for much of the year, are suddenly subjected to a continental-scale thaw over a very short period of time with a consequence of a sudden release of sediment, water, and river ice (Andrews and Syvitski, 1994).

The evolution of the suspended sediment concentration during a flood varies greatly from river to river. Flood conditions may last for a few days or may exceed one month in their duration. Often sediment concentrations concomitantly increase with rising flood waters. Immediately upon reaching peak flood conditions, sediment concentration may decrease by a factor of ten while discharge remains high. Northern and mountainous rivers often show a spring freshet (i.e. melt of snow during the onset of spring). Such floods clean the river bed of readily transportable sediment — sediment that was only temporarily stored within lower-energy reaches of the river. Melt of hinterland ice fields, where they exist, often supplies a near-inexhaustible wash load of glacial flour, and a more gradual decrease in water turbidity after the peak melt-discharge (Wang et al., 1998).

Variations to these simple flood-crest rating pattern have also been observed. Flood conditions on the large Mackenzie River, for example, often show as a slug of highly turbid water that suddenly appears, although river discharge has changed little. The slug of dirty water is derived from an upstream glacifluvial tributary, the Liard River. The tributary wash load is large enough to influence the ambient Mackenzie suspended sediment concentration, but its associated discharge is too small to affect ambient discharge of the main river. In general there is positive relationship between the volume of water discharged through a river system and the concentration of sediment that was suspended by the river, although the pattern shows up better in mountain- dominated rivers.

In order to make progress on understanding the land-sea flux of sediment, the physics of the sediment transfer at the river mouth and through the coastal estuary must also be examined, since up 90% of the sediment is filtered out in this region. Flow under ice and its influence on sediment transport is still poorly understood, with no simple models established. Does flow under sea ice, coupled with brine rejection influence the density structure of the inflowing river water to allow for the establishment of hyperpycnal plumes and turbidity currents?

Downslope-transport riverine material by turbidity currents may control the sedimentation in the deep basins. For example, major proportions of the Late Quaternary sedimentary columns in the Nansen and Amundsen Basins consist of turbidites (Fütterer, 1992). In the southeastern part of the Canada Abyssal Plain adjacent to the Canada polar margin or the Mackenzie cone, near the base of Northwind Ridge, 50 to 70 % of the cored sediments are turbidites (Champbell and Clark, 1977; Grantz et al., 1996), possibly triggered by regional earthquakes (Grantz et al., 1996). Fine-grained material might be transported from coastal areas into the central part of the Arctic Ocean. In this context, the major boundary currents (e.g., Aagard, 1989) and the downslope flow of shelf-brine waters (Aagaard et al., 1985; Schauer et al., 1995) are certainly of great importance.

Last but not least, riverine sediments are incorporated into the sea ice in the shelf areas and then transported as ice-rafted debris (IRD) through the central Arctic Ocean via the Beaufort Gyre (Bischof et al., 1996) and the Transpolar Drift (e.g., Pfirman et al., 1989; Nürnberg et al., 1994). In areas of extensive melting, sediment particles are released and deposited at the sea floor. In these areas, this process may dominate the supply and accumulation of terrigenous material in the polar environment.

Research should include

(1) the quantification (i.e., calculation of flux rates) of riverine components on transects from the river mouth to the shelf-slope-deep-sea environment;

(2) estimates of the importance of riverine input for the Arctic Ocean sedimentary and chemical budget (in comparison to other processes like eolian input and coastal erosion);

(3) redeposition processes of riverine material by sea ice, oceanic currents, turbidity currents, and debris flows.

Furthermore, a geomorphic data base must be established that relates the shape, size and properties of deposits with the scale of the dynamics of rivers and the adjacent shelf environments. Important data rescue must be carried out for the large Russian data bases of Arctic hydrology. These data bases must also be used to define the effects of man and the influence of climate variability.

3.2. Ancient riverine' processes

The importance of the freshwater influx for the oceanography, biology, chemistry and geology of the Arctic Ocean has been demonstrated in the previous chapters. The interaction of both low sea-surface temperatures and lowered salinities cause unique environmental conditions with its characteristic planktic and benthic biota. The freshwater influx has not only a strong impact on the Arctic Ocean itself but also influences the global circulation and hydrography via the conveyour belt circulation (Aagard & Carmack, 1989). Thus, the knowledge of ancient river discharge is of primary importance to understand both environmental change in the Arctic Ocean and the impact of freshwater export through Fram Strait on global change. Additionally, understanding of past processes may provide important clues to how the environment will respond to the anticipated future warming owing to the greenhouse effect.

Therefore, reconstructions of ancient river discharge, its regional extent and absolute rates, are urgently needed to understand its influences on sea-ice formation, stratification of surface-near water masses and finally on biogeochemical cyles, in particular the biota and the productivity.

Modern processes determining the river discharge and the tools characterizing single processes have been identified in the previous chapters. It can be assumed that these processes also are important to recognize ancient river discharge. Today, these processes evolve on the background of relatively stable boundary conditions, i.e. atmospheric climate, catchment areas, discharge rates, basin-shelf-coastal configurations etc.. In contrast, these conditions have changed significantly through glacial-interglacial cycles. Major changes are related not only to atmospheric temperature fluctuations but also to climate induced sea-level fluctuations.

It can be assumed that the modern situation characterizes interglacial conditions, while two different environmental settings can be expected for glacial conditions, with gradual transitions inbetween. Sea-level fall in conjunction with atmospheric cooling cause the propagation of the coast line to the shelf break. The wide shallow shelves being the characteristic environment of the Arctic Ocean progressively disappear, exposing ca. 35% of today´s Arctic Ocean surface area.

The fundamental difference between the two glacial states is associated with the configuration of the drainage system. The rivers might have directly supplied freshwater to the deep ocean basins or they were diverted because of isostatic adjustments owing to the waxing and waning of ice sheets. The freshwater supply may have varied between these two endmembers because of regional differences in drainage, with catastrophic effects on the water column structure of the entire Arctic Ocean. The absence of any freshwater supply might trigger a weakening of the strongly developed halocline in the Arctic Ocean, probably leading to a reduced sea-ice cover or even an ice free Arctic Ocean (Grebmeier & Whitledge, 1996). In addition, brine formation on the shelves which is crucial for the modern deep water formation in the Arctic Ocean cannot occur any longer.

In case of a drainage system which resembled the modern one, the river discharge may have been lower because of principally low atmospheric temperatures. In addition, chemical properties of the river waters may have changed considerably owing to differences in weathering processes.

The effects of a direct supply into the deep Arctic Ocean are even as important as the absence of any supply. The loss of the shelves as sink for chemicals and sediments as well as its equalizing function between open ocean marine water and riverine freshwater may lead to a pronounced strengthening of the water column stratification and changes in chemical and biological conditions.

With the dynamics of the modern system established and marine deposits and proxies related to these dynamics, APARD seeks to understand past climate from the evolution of both landscape and seascape. Mass-balance from air photometry on erosion from valleys are to be related to the formation of river deltas. Stratigraphy of fluvial deposits could also provide important support to the postdiction of past climate from marine proxies.

3.2.1. Changes in paleo-drainage systems (20ka - 0)

Ice sheets and montain glaciers have caused both minor and major diversions to Arctic drainage systems since the Late Pliocene. Major rivers such as the Mackenzie and Yukon in northwestern North America, and the Ob in northwestern Siberia, are glacially emplaced and/or glacially integrated drainage basins. Changes in drainage patterns caused fluctuations in discharge to the Arctic Ocean during each glacial/interglacial cycle. Detailed paleogeographic reconstructions of ice sheets are essential to understanding and quantifying paleo-river discharge.

In North America, the modern course of Mackenzie River is entirely the product of glacial diversion by the Late Wisconsian Laurentide Ice Sheet (Duk-Rodkin and Hughes, 1994). The Yukon River is the oldest known glacially diverted river (ca. 3 Ma; Duk-Rodkin, 1997), and during the Late Wisconsian captured much of the drainage of the Porcupine basin that formerly entered the Arctic Ocean (Duk-Rodkin and Hughes, 1994). In Siberia, the extension of glaciers in main rivers basins resulted in a significant reduction in the discharge of these rivers during ice buildup and the glacial maximum. For example, in the Yana River basin it led to a 40% decrease of the river discharge (Sidorchuk and Panin, 1996). However, during deglaciation rapid discharge increase could result from breakage of ice dams causing catastrophic floods on the rivers. According to some authors, Arctic ice sheets may have blocked all drainages to the Arctic Ocean including the Ob, Yenisei and Lena rivers, leading to the formation of large proglacial lakes that drained to the Aral

Sea via Turgai Valley (Astakhov and Grosswald, 1978; Rutter, 1995; Hughes, 1996). The associated drainage system may have even connected Lake Baikal to the Mediterranean via the Caspian - Black Sea route (Hughes, 1996). The occurrence of paleo-river channels in the former Laptev Sea indicates that most of the Laptev Sea was not covered by an ice sheet during the late Weichselian (see below). Conflicting interpretations about the extent of the last glaciation of western Siberia (Fig. 18), as well as limited chronologic data, hinder the detailed reconstruction of associated hydrologic changes.

Substantial changes in sea level related to tectonism, glacioisostacy and eustacy over the past 20 ka also significantly influenced drainage to the Arctic Ocean. Although the expansion of continental ice masses lowered global eustatic sea level by more than 100 m, isostatic depression of the crust underneath and marginal to major ice sheets resulted in rebound following deglaciation in many areas adjacent to the Arctic Ocean. The associated fall in relative sea level caused incision of drainages and expansion of coastal areas.

The paleo-river systems and the volume of sediment discharged into the Arctic Ocean will be addressed by APARD in the following topics:

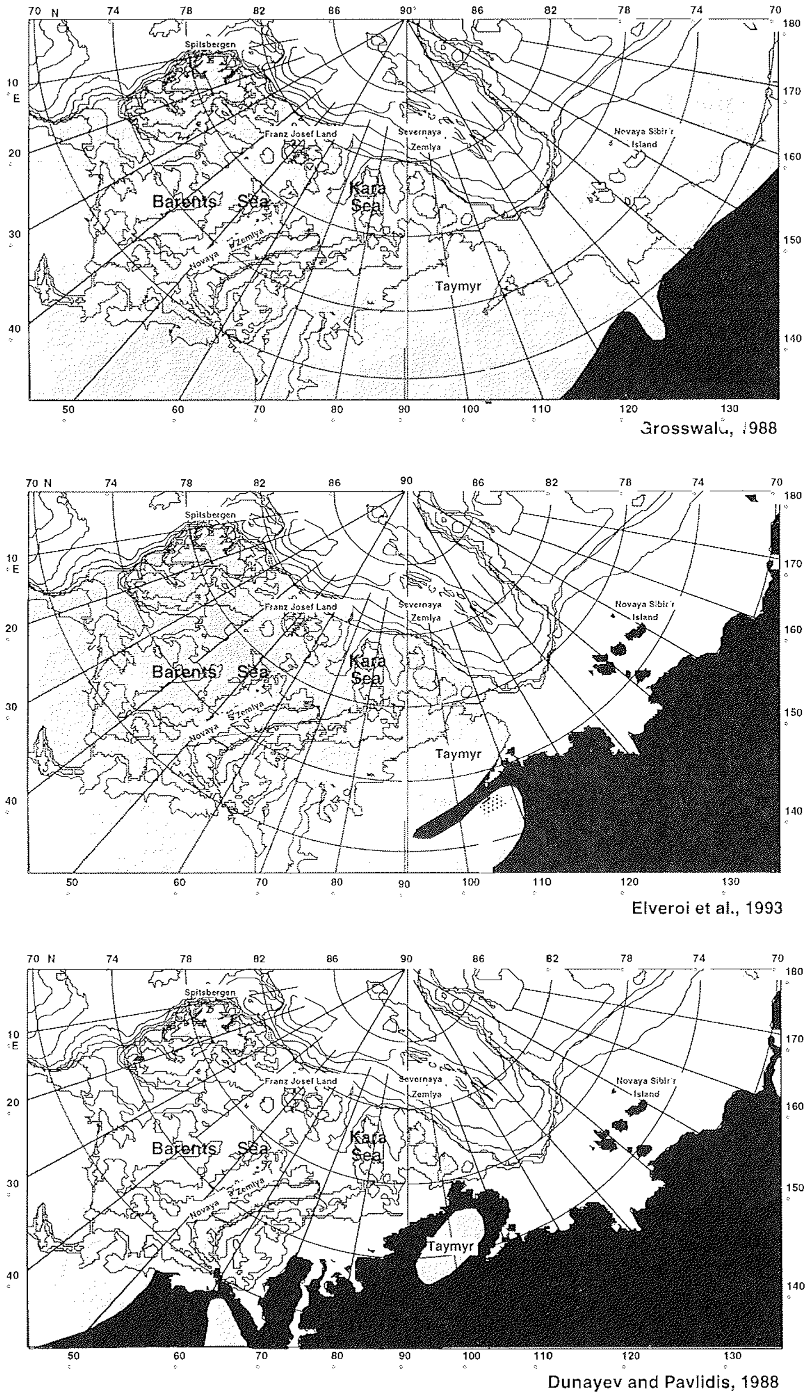
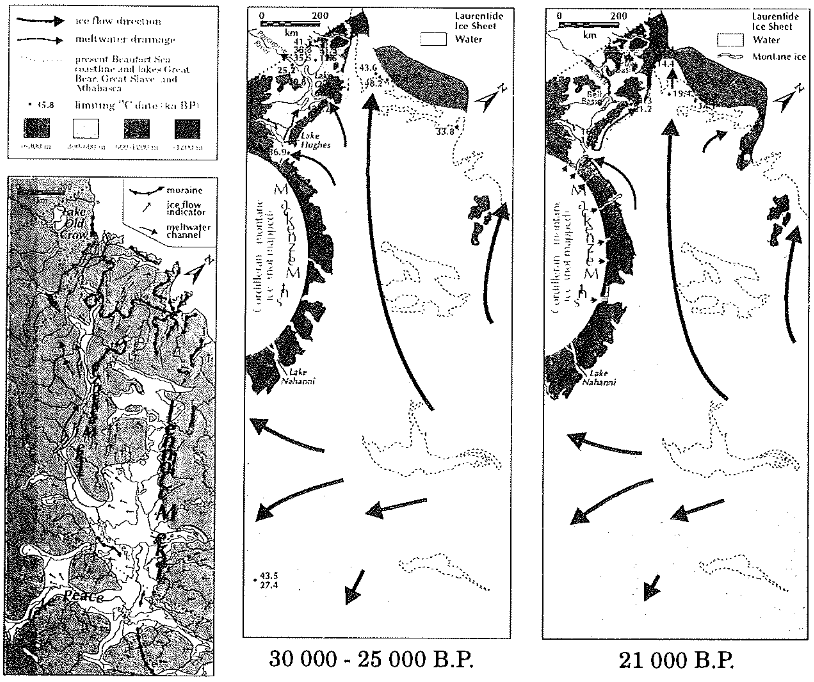


Fig. 18: Map of the Siberian Arctic showing glaciation models according to Grosswald (1988), Elverhoi et al. (1993), and Dunayev and Pavlidis (1988).

** Paleogeographic reconstruction of ice sheets*

Studies of the limits and volumes of Pleistocene ice sheets in North America and Eurasia are crucial for reconstructions of paleoriver discharge. This work is dependent upon detailed mapping and chronologic control, which are available for much of North America but are largely hypothetical for Siberia.



30 000 - 25 000 B.P.

21 000 B.P.

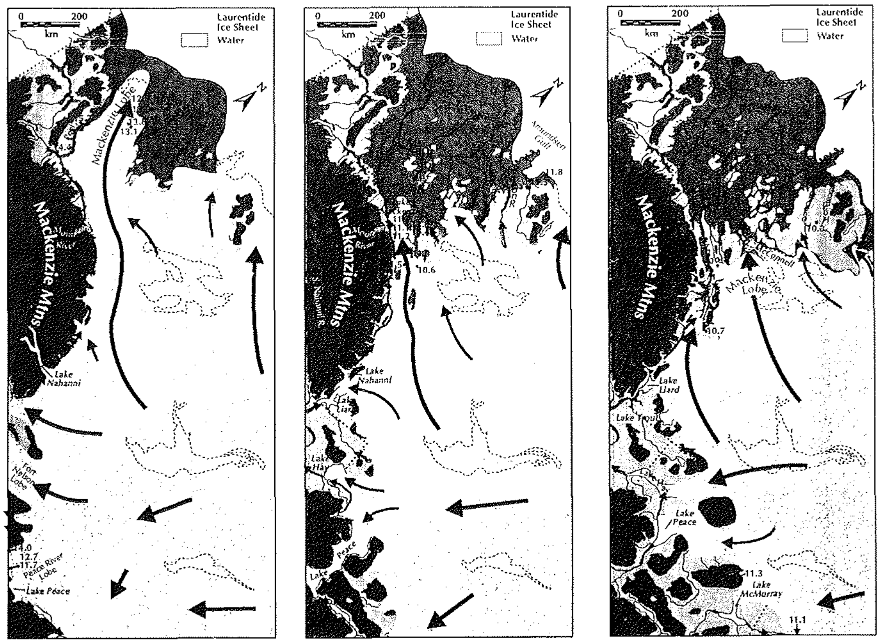
Generalized map of glacial features highlighting the former extent of glacial lake cover. Geology compiled principally from Prest *et al.* (1968), Hughes (1987), and Duk-Rodkin and Hughes (1993).

Last glacial maximum. Key elements: ice-dammed glacial lakes Old Crow, Hughes and Nahanni; proglacial drainage enters Pacific Ocean via Porcupine and Yukon rivers.

Key elements: Katherine Creek glacial phase; demise of Lake Old Crow; proglacial drainage enters Beaufort Sea.

Fig. 19a: Late glacial drainage systems along the northwestern margin of the Laurentide Ice Sheet and their changes between 30000 and 21000 years BP (Lemmen et al., 1994).

In North America, the Late Wisconsian Laurentide Ice Sheet reached its maximum extent in the Mackenzie region about 30 ka (Fig. 19; Hughes et al., 1981). The ice sheet blocked drainage of the Porcupine River to the Arctic Ocean and permanently rerouted that river to Bering Sea via Yukon River. Many other drainages partially reoccupied their former routes following deglaciation, beginning about 22 ka, although large segments were newly established as ice marginal drainages. The modern Mackenzie River outlet was established by ca. 12 ka (Duk-Rodkin and Hughes, 1995). Well defined stages of ice retreat in the Mackenzie region allows detailed reconstruction of the evolution of the newly established Mackenzie River (Lemmen et al, 1994; Duk-Rodkin and Hughes, 1995), including the development of extensive proglacial lakes Mackenzie and McConnell. The possible drainage of glacial Lake Agassiz to the Beaufort Sea between 9.9 and 9.5 ka would have significantly increased discharge of Mackenzie River during that interval (Fisher and Smith, 1994).



13 000 B.P.

Key elements: Tutsieta Lake Moraine; glacial Lake Peace (early Clayhurst stage) with southeastward drainage; extensive proglacial drainage to Beaufort Sea coast.

11 500 B.P.

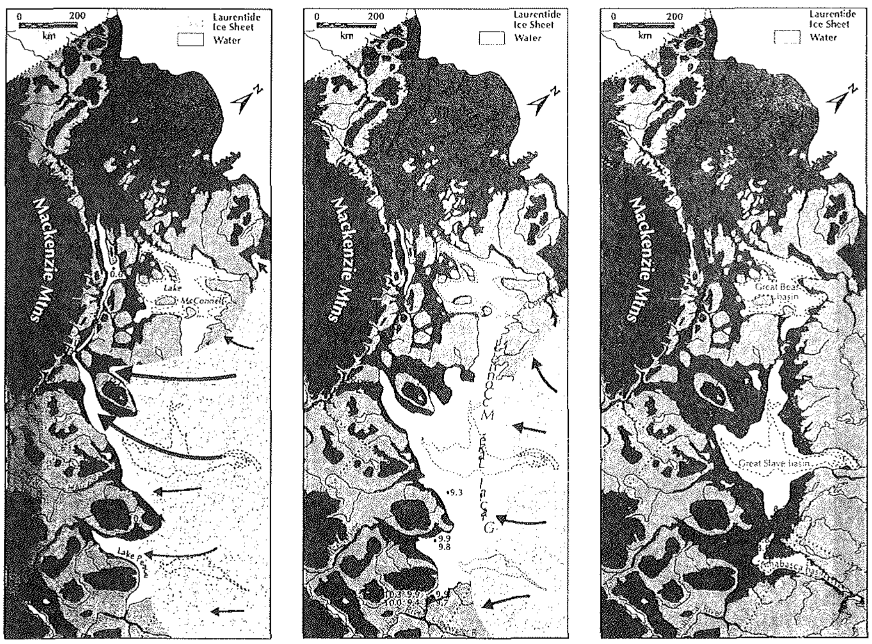
Key elements: Kelly Lake Moraine; glacial lakes Mackenzie and Peace (Indian Creek stage); northern capture of Lake Peace drainage; development of modern lower Mackenzie River.

11 000 B.P.

Key elements: glacial lakes Mackenzie, McConnell (Hare Indian Phase) and Peace (Keg River stage); demise of Lake Nahanni.

Fig. 19b: Late glacial drainage systems along the northwestern margin of the Laurentide Ice Sheet and their changes between 13000 and 11000 years BP (Lemmen et al., 1994).

Paleogeographic reconstructions are far less constrained for Eurasian Arctic. Traces of extensive ice covers in Siberia infer the creation of large proglacial lakes when drainage was blocked by ice sheets formed on the Eurasian Arctic continental shelf (Rutter, 1995; Hughes, 1996). In eastern Siberia, drainage could have discharged into the Okhotsk Sea, whereas proglacial lakes to the west spilled towards the Mediterranean (Arkhipov et al., 1995). The chronology of this proglacial drainage system remains uncertain. The traditional view suggests that it predated the last glaciation (e.g., Astakhov, 1992), whereas Grosswald (1988) relates this diverted drainage to the last glacial maximum at ca. 19 ka. This hypothesis is not supported by evidence from recent investigations that suggest that the last glaciation in Siberia and northeastern European Russia was limited and could not cause major changes in paleoriver discharges (e.g., Astakhov et al., 1998; Mangerud et al., 1998). However, the damming of rivers by the Barents-Kara Ice Sheet was possible on the Eurasian Arctic shelf (Polyak et al., 1997). The reconstruction of the extents of ice sheets in Eurasia during the last glaciation and the maximum post-Eemian glaciation, which are the objectives of programmes related to APARD, such as QUEEN, GRAND and CAPE, will form a basis for paleohydrological studies.



10 500 B.P.

Key elements: Snake Creek Moraine; glacial Lake McConnell (Great Bear Phase), glacial lakes Mackenzie (upper and lower basins) and Peace.

10 000 B.P.

Key elements: Cree Lake and Slave moraines; coalescence of glacial lakes McConnell, Mackenzie, and Peace to form the maximal (Mackenzie) phase of glacial Lake McConnell.

8500 B.P.

Key elements: separation of Great Bear, Great Slave and Athabasca basins; cessation of Laurentide meltwater flow in Mackenzie drainage basin.

Fig. 19c: Late glacial drainage systems along the northwestern margin of the Laurentide Ice Sheet and their changes between 10500 and 8500 years BP (Lemmen et al., 1994).

** Relative sea-level changes and post-glacial incision*

The weight of ice masses causes loading and isostatic depression of the earth's crust. Reduction of these ice masses (deglaciation) reduces this loading and initiates crustal rebound, which occurs synchronously with a rise in eustatic sea level as water formerly stored in ice sheets is returned to the oceans. Isostatic rebound of the earth's crust continues long after final deglaciation. The amount of isostatic rebound can be determined by mapping and dating paleo-shorelines and coastal ponds (e.g., Hill et al., 1985; Blasco et al., 1990; Hill, 1996). Most coastlines adjacent to the Arctic Ocean relate to either formerly glaciated areas associated with continuous postglacial rebound, areas well beyond the last ice limit, characterized by continuous postglacial submergence, or areas at and immediately beyond the ice margin which experience initial emergence followed by submergence (Clark et al., 1978).

Raised marine shorelines are exceptionally common in the Canadian Arctic, and extend to as high as 285 m asl around Hudson Bay. Beaches associated with glacial Lake McConnell extend more than 150 m above modern lake levels and reflect postglacial isostatic tilting (Lemmen et al., 1994). Changes in base level associated with isostatic rebound, glacial erosion and changes in drainage patterns have direct implications for associated fluvial systems. Postglacial incision in the Mackenzie region is as great as 500 metres on plateaus and 50 m on the adjacent plains. Holocene sediments of the upper part of the Mackenzie delta average 40 m in thickness. Up to 30 m of Holocene sediments cover the Beaufort shelf (e.g., the Mackenzie Trough (Blasco et al., 1990; Hill, 1996) and infill. On the eastern Beaufort shelf, these surface sediments are underlain by probable deltaic deposits up to 80 m thick (Hill et al., 1985). Information on drainage changes and postglacial incision can be used to derive estimates of sediment discharge to the Arctic Ocean.

Data on sea-level changes, shoreline mapping and paleoenvironmental change in the Canadian Arctic has been recently synthesized by A.S. Dyke of the Geological Survey of Canada in Open File Report 3296; "Preliminary paleogeographic maps of glaciated North America". Research to determine ice volumes for the Laurentide Ice Sheet is being conducted by T. James and A. Dyke of the GSC. The history of sea-level change and paleoshorelines of the Beaufort Sea area, remain uncertain (Hill, 1996) and should be a major part of APARD research activity in order to constrain depositional models.

The age and origin of raised shorelines in northern Siberia are even more uncertain and need further investigations.

** Paleo-river discharge*

Climatic change during the Late Glacial and Holocene is reflected in the river channels of the Arctic Ocean basin. The change from glacial and periglacial environments to the boreal environments were accompanied by increased discharge of water during the periods of ice melting with maximum discharges during the periods with the permafrost. Mean flows

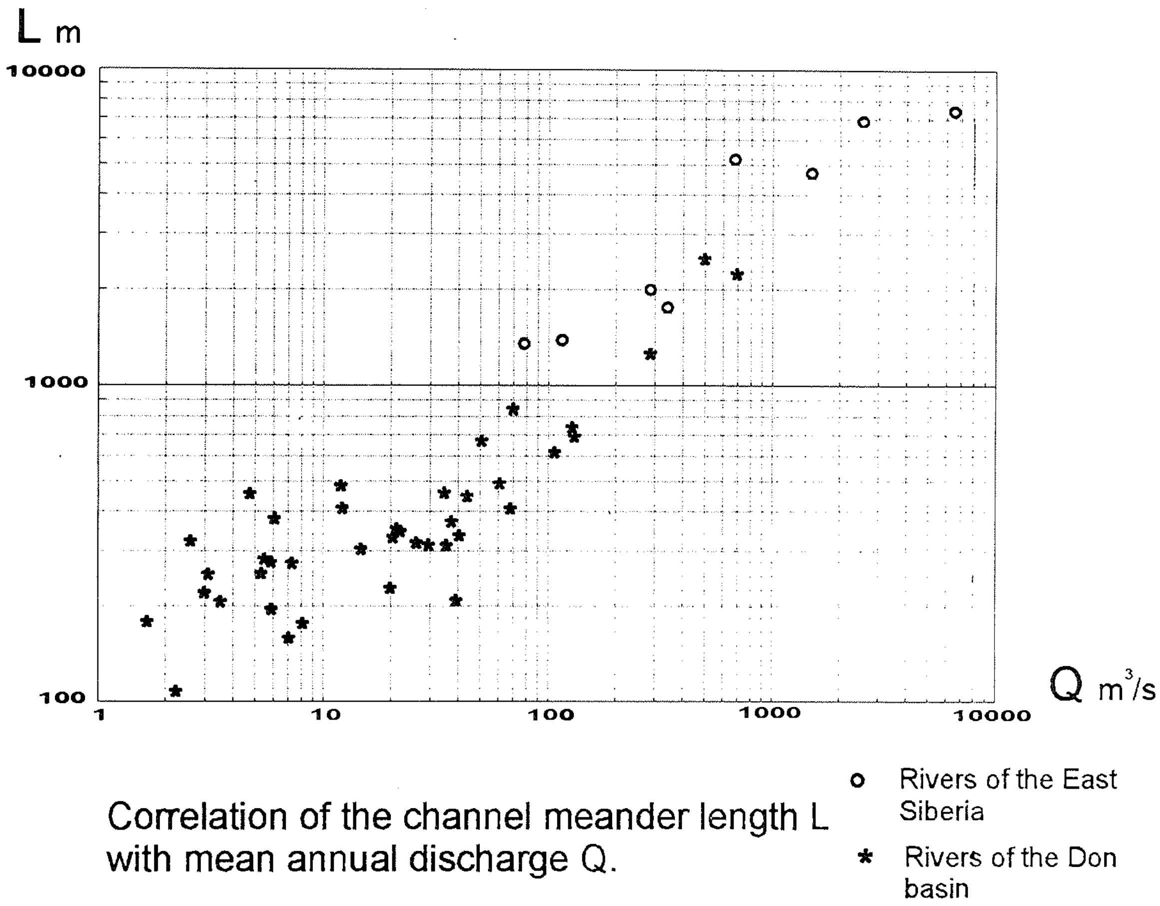
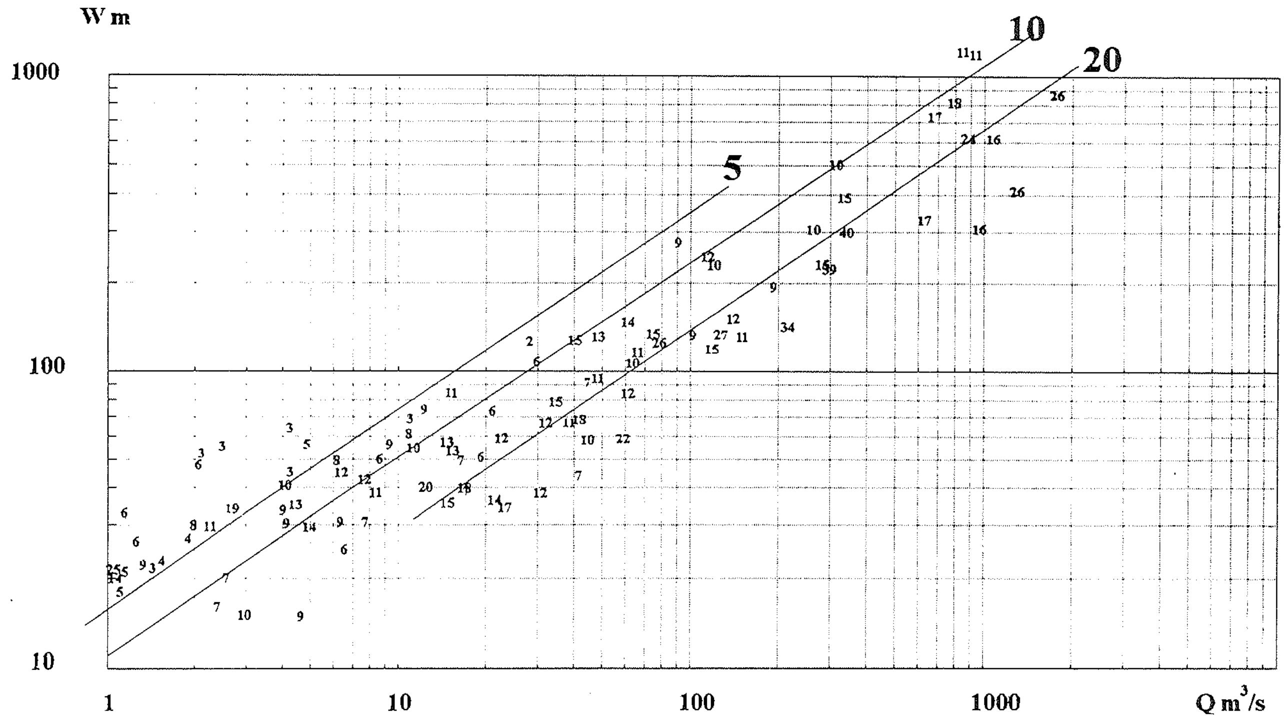


Fig. 20: Correlation of the channel length and mean annual discharge (Panin et al., 1992).



Correlation of the channel width W with the mean annual discharge Q for the Ob' River basin (numbers shows mean/maximum discharge ratio in %)

Fig. 21: Correlation of the channel width and mean annual discharge for the Ob River basin (Sidorchuk et al., in press).

decreased during the arid periods and maximum flow decreased during permafrost melting and growth of boreal forests. Paleo-river channels along the margin of the Arctic Ocean are also evidence of past climatic changes. These channels have meanders 5 to 7 times greater than recent meanders in the floodplain of the Yana River and reflect much greater discharges of water. Large rivers commonly destroy the remnants of paleorelief on their floodplains during channel deformation. Paleohydrological research should be done in medium and even small rivers, with smaller rates of channel transformation.

Estimates of paleo-river discharge of water and sedirnent can be obtained by empirical-geomorphic analysis and calculation of sediment volumes in both on-shore and off-shore area (seismic surveys, drilling, core analysis, and empirical data).The estimates of paleo-river discharge of water and sediment should involve the following types of analysis:

i. Water budget calculations are based on paleoclimatological indicators. The reconstructed paleo-landscape of a river for a given period in the past is compared to a recent hydrological analogue, selected from the Atlas of the World Water Budget (1978).

ii. Paleodischarge estimates are based on correlations between paleochannel characteristics and recent channel characteritics and discharge. The most common are meander length - discharge (Fig. 20) and channel width - discharge (Fig. 21) (Panin et al., 1992; Sidorchuk et al., in press).

iii. The maximum discharge can be calculated from any hydraulic formula (Chezy formula, for example) applied to the paleo-cross-section geometry. Accurate reconstruction of paleochannel geometry and paleo-waterlevels require subsurface information.

iv. Mean discharge is determined on the basis of hydrologic analoques, detailed dating and landscape types.

v. Photogrametric analysis can be used to calculate volumes of sediments produced by the incision of new drainage systems established during deglaciation. This method is best applied in regions where the patterns of deglaciation are well established.

** History of deltas and estuaries*

The deltas provide useful paleohydrological information and study of modern deltas is important for interpretation of offshore subsurface features and seismic profiles. The complexities of multiple channels and the restricted age (Holocene) of the deltas mandate the study of the entire basin in order to determine paleodischarge. Hydrological, geomorphological and paleo-hydrological investigations conducted on Arctic river deltas in Russia are as follows (e.g., Korotayev et al., 1980; Harrison et al., 1981; Korotayev et al., 1987; Korotayev et al., 1990; Sidorchuk and Panin, 1996):

1. River Severnaya Dvina. Current topography and hydrology information is available for the delta. The paleogeomorphology and paleohydrology of the Vychegda Channel are currently being investigated by Moscow State University (A.Sidorchuk, A.Panin). The geometry of several paleochannels was reconstructed from air photographs and their age dated with ^{14}C.

2. River Pechora. Only current topography and hydrology is available for the delta.

3. River Ob. Paleogeomorphology and sea-level changes in the delta area were investigated by University of Sankt Petersburg (O.Sen'kin, V.Makeev). Geomorphological constructions of the Middle and Upper Ob and Chulym River basins were provided by Moscow State University (A.Chernov). Paleochannel geometry was reconstructed from air photographs and field investigation, and their age dated by ^{14}C and pollen analysis.

4. Rivers Taz and Pur. The paleogeomorphology, paleohydrology and sea level changes for the delta and adjacent river sections were investigated by Moscow State University (V.Korotaev, A.Sidorchuk). Paleo-discharges for the Late Glacial and Holocene were reconstructed from the geometry of paleomeanders and sea-level changes were reconstructed from the dated marine terraces elevations.

5. River Yenisei. The paleogeomorphology and paleohydrology of the delta and adjacent river sections were investigated by Moscow State University (V.Korotaev, A.Sidorchuk). Paleodischarges for the Holocene were reconstructed from the width of paleochannels (Fig. 21).

6. River Lena. The paleogeomorphology and cryolithology for the delta and adjacent river sections were investigated by Moscow State University (V.Korotaev) and Institute of Permafrost in Yakutsk (M.Grigoriev).

7.River Yana. The paleogeomorphology and paleohydrology for the delta and adjacent river sections were investigated by Moscow State University (A.Sidorchuk, A.Panin, B.Matveev). Paleo-discharges for the Late Glacial and Holocene were reconstructed from the geometry of paleo-meanders. Paleo-discharges for the Late Neogene-Pleistocene were reconstructed with the method of paleohydrological analogue, based on pollen analysis. The history of river channel incision in the Kular Ridge section during tectonic uplift was calculated with the mathematical model.

8. River Indigirka. The paleogeomorphology of the delta and adjacent river sections was investigated by Moscow State University (V.Korotaev).

Joint government and industry projects in the Mackenzie delta entailed continuous borehole sampling to depths of 600 m (see Hill, 1996). Studies of thermokarst lake history on Richards´s Island, in the inactive area of the delta were also undertaken (Solomon et al., 1992; Solomon and Mudie, in prep.). The late Holocene history of channel migration in the active part of the delta has been studied (Jenner and Hill, 1991) using short (10 m) cores, air photographs, and high-resolution (Seistec) seismic profiles obtained from the Canadian Coast Guard amphibious search-and-rescue vehicle Arktos-B. These projects include sedimentological, geochemical, and micropaleontological studies to determine the response of the delta to global climate change over the past 2-20 ka. The delta studies are essential for (I) interpretation of buried features seen in offshore seismic profiles and core samples; (ii) for reconstruction of sea-level history of the Beaufort Sea; and (iii) for evaluation of the importance of delta lakes for storage of sediment and carbon.

** Paleo-river channels on the shelf/slope*

Mapping of paleo-river systems and channels in shelf areas have been undertaken using sub-bottom acoustic profiling techniques (e.g., PARASOUND, SEISTEC) with penetration of up to 100m and a vertical resolution of about 0.2m. Estimates of paleo-river discharge are based on the geometry of the channels. Bottom and sub-bottom reflection patterns received by the PARASOUND system in the Laptev Sea area, for example, document 22 refilled paleo-river channels in the uppermost sediments (1-13m) of the Laptev Sea shelf, ranging in water depths between 25-94 m (Fig. 22; Kleiber and Niessen, in press). Channels are incised into stratified sediments of probable Pleistocene age. The width/depth ratio (Füchtbauer, 1988) of the Laptev Sea shelf paleo-rivers as well as their filling geometry suggest braided to meandering river systems. The river channels must have been active during Weichselian time when the inferred sea level was up to 120 m below present sea level (Niessen, 1995, Nürnberg et al., 1995). Channel infilling likely occured during termination 1 and continued until it reached the present-day 25m isobathe during the early Holocene (Blanchon and Shaw, 1995).

Most likely the observed paleo-river channels are related to the Olenek, Lena and Jana rivers and to drainage systems north of the Taymyr Peninsula and the New Siberian Islands and not to the major Siberian rivers. It is suggested that these paleo-channels may be the result of rivers formed at the termination of Weichselian glaciations caused by melting of local ice sheets and/or glaciers on the Taymyr Peninsula and the New Siberian Islands. The occurrence of an Anabar-Khatanga paleochannel remains uncertain.

A post sedimentary reflector is interpreted as the surface of submarine permafrost in the Laptev Sea. In some areas, paleo-channels are difficult to distinguish from the hummocky, unconformable permafrost surface. Where the truncation of Pleistocene sediments at the channel base is not evident, the channel locations were mapped as doubtful (Fig. 22). The formation of thick permafrost is also associated with subaerial exposure of the shelf during times of the Weichselian sea-level low stand (Romanovsky, 1996).

The paleo-river channels as well as the permafrost suggest that most of the Laptev Sea area was not covered by a large ice sheet during the last glacial maximum as has been suggested by Grosswald (1990; cf., Fig. 13). If so, Central Siberian river drainage continued to carry terrigenous sediment into the Arctic Ocean during the Weichselian glacial period. At the glacial maximum (ca. 30-22 ka; Lemmen et al., 1994) most of the glacial ice on the Beaufort shelf did not extend beyond the inner shelf east of the Mackenzie Trough, even though the delta was covered by thick (1 km) ice from an ice tongue in the Mackenzie Trough. A regional basal hummocky reflector suggests this event was followed by a brief interval of postglacial flooding. A succession of ice readvances and formation of large lakes (Tutsieta and Mackenzie lakes) from 13 to 10 ka would have reduced sediment discharge into the Arctic Ocean. In contrast, the outflow of water from glacial Lake Agassiz at 9.9 ka (Fisher and Smith, 1994) would have discharged 21 * 10^3 km^3 of sediment-laden water to the Arctic Ocean, raising the global sea level by 6 cm.

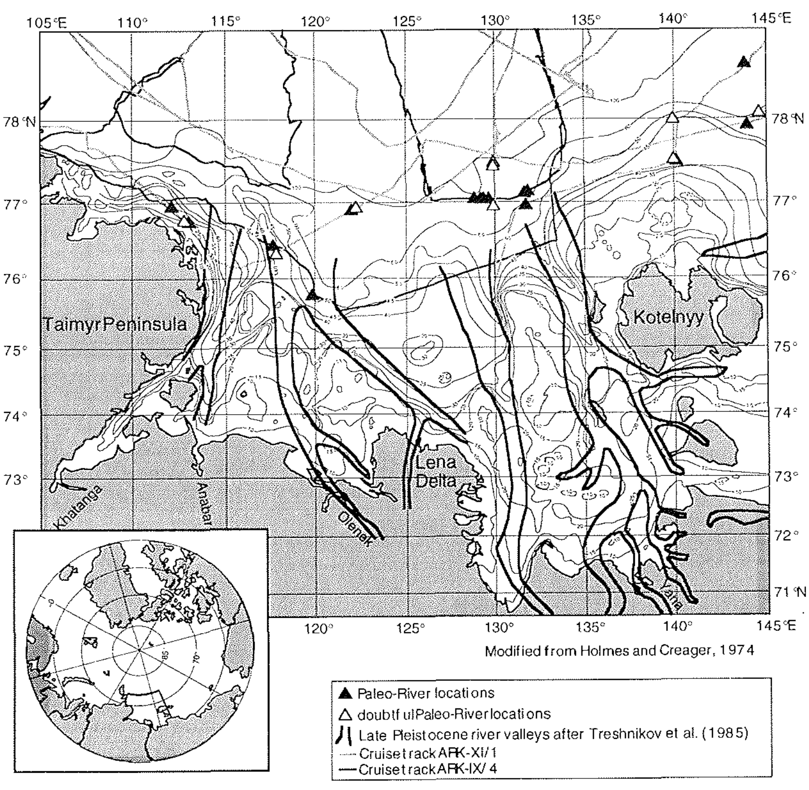


Fig. 22: a. Map of the Laptev Sea showing the distribution of observed paleo-river channels (Kleiber and Niessen, in press).

The main objectives for future work are:

(1) to study paleo-channels on the shelf, floodplains and lower terraces;

(2) to organize field work: coring and sampling to contruct cross-sections, dates and paleo-landscapes.

(3) to work out the method of paleohydrological analogue for the Arctic.

(4) to work out the co-relations between recent channel width and meander length and discharge for paleohydrological reconstructions.

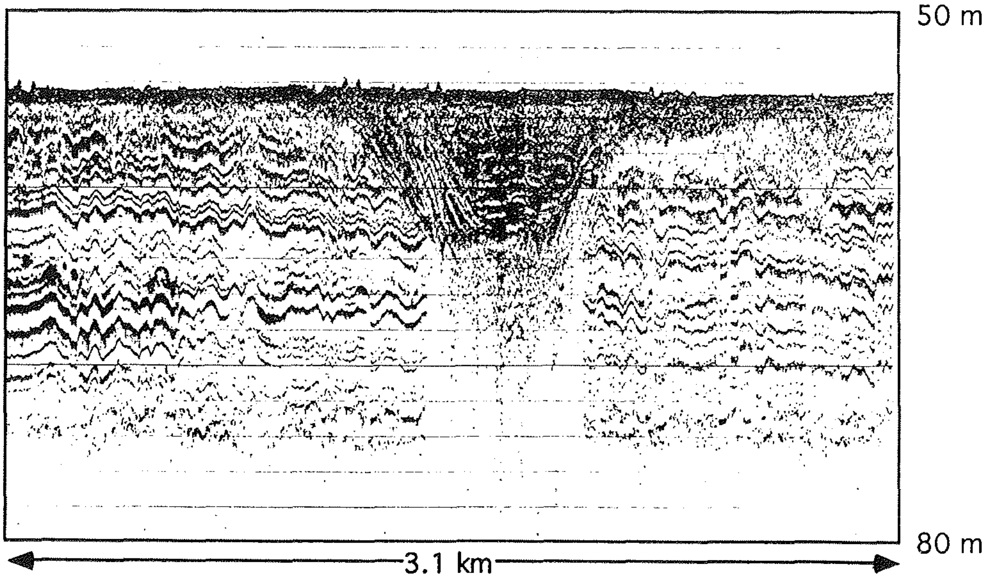


Fig. 22: b. PARASOUND profile north of the New Siberian Islands, showing a refilled paleo-river channel cutting into the well-stratified sediments (Kleiberand Niessen, in press).

3.2.2. Sediment paleo-dynamics

** Paleo-erosion*

To understand the ancient sedimentary budget of the Arctic Ocean in addition to paleo-river supply paleo-erosion has to be taken into account. Processes such land slides, coastal and glacial erosion have to be studied.

Since water and sediment discharge are controlled by the climatic situation in the drainage area paleo-river discharge investigations are strongly related to the paleoclimate of the basin. During the last glacial maximum precipitation in central Siberia was significantly reduced and the rivers were much smaller than today (Dubikov and Baulin, 1981). Therefore most of the riverine sediments accumulated on the continent and only small amounts were transported to the Arctic Ocean. The central Yakutian plain, for example, forms a key area because during the glacial maximum this region acted as an intercontinental delta. When precipitation increased at 14 ka BP these continental sediments were exposed to fluvial erosion (Katasonova and Siegert, 1982). To understand the sediment dynamics accumulation and erosion processes on land in regard of periglacial cryolithogenesis have to be studied.

To quantify the contribution of coastal erosion to the sediment supply to the Arctic Ocean studies of the coastal zone have to be carried out. Ice-rich shores that are very common in northern Central Siberia are extremely sensitive to coastal erosion. Recent studies demonstrated that today the retreat of the shoreline may account for 10 m per year and more as a result of thermoabrasion (Grigoryev and Kunitsky, 1996). For that reason it seems apparent that destructive cryogenic processes in coastal zones strongly effect the sediment budget of the Arctic Ocean.

The effect of glacial erosion cannot be accurately assessed due to the uncertainties in paleoglaciological reconstructions. Prominent erosional unconformities on the continental shelf of the Barents and Kara seas and adjacent lowlands are apparently related to glacial erosion (e.g., Gataullin et al., 1993; Polyak et al., 1997), but the chronology of erosional events remains poorly constrained. The investigations of ice sheet extents during the Last Glacial Maximum and previous glaciations will facilitate the estimates of the rates and volumes of glacial erosion.

* *Sediment transfer (river/delta - shelf - slope - deep sea)*

The ancient sedimentary budget of the Arctic Ocean is not only controlled by the paleodischarge but also by the sediment transfer from the river to the shelf and further to the deep sea. For that reason the evaluation of the sediment transfer is required for quantifying the contribution of material supplied by individual rivers and its change through time.

Due to sea level changes during the last 20 ka the depocenters of the Siberian rivers shifted dramatically. Based on radiocarbon ages of bottom deposits of the Lena River and the Laptev Sea shelf area Kuptsov and Lisitsin (1996) recently demonstrated, that the depocenter of the Lena River varied with time in relation with sea-level changes (Fig. 12). During sea-level lowering, riverine material may have been transported more close to the shelf edge, and the generation of turbidity currents and failure-related debris flows across the continental slope may have become much more important for the sediment budget in the deep-sea areas.

To quantify the river to deep sea transfer it is essential to identify regions of ancient accumulation and erosion on the shelf. For this purpose sediment cores from the shelf and the shallow water coastal zone have to be retrieved and studied for accumulation rates based on radiocarbon dating or other geochronometers. Likewise, precise dating of deep-sea sediments is needed to calculate sediment accumulation rates and compare with the volume of influx from ice-rafting versus bottom resuspension (see Amos, 1985; Mudie, 1985).

3.2.3. Quantification and characterization of ancient riverine input

** Freshwater supply*

Very few tracers in sedimentary records allow an easy correlation to ancient riverine output. Many tracers are chemically very mobile and not recorded in the sediment in correlation to their concentration in sea water. Planktic foraminifers are believed to record accurately changes in the oxygen isotope ratio of the seawater. Apart from global ice volume changes, such changes may result from the variability of continental freshwater discharge to marginal areas of the ocean. If the influence of ocean temperature changes can be widely excluded (as it is the case in most ice-covered Arctic areas), planktic foraminifers living in these ocean waters will in their shells truthfully record the variability of freshwater input through time (cf., Spielhagen and Erlenkeuser, 1994). While many case studies have been conducted of the mouths of middle to low latitude rivers, attempts to establish oxygen isotope records of planktic foraminifers from sediment cores obtained near the mouths of major Arctic rivers are still in a preliminary state. One problem is the comparatively low planktic productivity of Arctic surface waters. Accordingly the content of foraminifer shells in the sediments is low and often decreased by carbonate dissolution. The second problem deals with the habitat of the planktic foraminifers. They do not live on shallow shelves but only in water depths of >200 m, and they may descend from the surface waters when salinities fall below 28-30‰, e.g. because of an increased river water outflow. For continental shelves, the oxygen isotopic ratio and faunal composition of benthic foraminifers can be used to measure salinity if carbonate dissolution is not a problem (e.g., Vilks and Deonarine, 1989). Organic-walled dinoflagellates, prasinophytes and other acritarchs or algae (e.g., *Pediastrum*) are acid resistant and can also be used for semi-quantitative estimates of fluvial influx (Mudie, 1992; Kunz-Pirrung, in press; cf., Fig. 8) or for quantitative estimates of surface-water salinity (summer/winter) and ice cover, using the transfer function method (e.g., de Vernal et al., 1994).

** Carbon flux and composition*

The mapping of sedimentological, geochemical and biological proxies reflecting the surface water productivity and terrigenous organic-carbon flux in surface sediments, and the subsequent comparison to recent oceanographical and biological parameters will allow to decipher processes most important for the carbon budget in the Arctic Ocean. The transfer of these findings to sediment cores will then allow to reconstruct the paleo-situation - dependant on the stratigraphic framework. Since surface-water productivity may affect the concentration of atmospheric CO_2 (i.e., in areas and at times of high production rate of organic matter, the ocean may act as a sink for CO_2) which is an important factor controlling the global climate, the quantification of the organic carbon budget in the Arctic Ocean and its change through time may yield important insights into the role of the Arctic Ocean during global climate change.

In respect to marine productivity, differences to the recent situation should become evident for the glacial Arctic Ocean. During times of drastically lowered sea level, the broad Eurasian shelves will no longer serve as traps for huge amounts of sediments and storage of organic carbon. The potentially thicker and seasonally stable sea ice cover will paralyze biological productivity. Nevertheless, due to the steady freshwater supply by Arctic river systems even during glacials (e.g. Stein et al., 1994; Spielhagen et al., 1997), a continuous supply of nutrients can be expected at least in areas directly influenced by river outflows. Furthermore, terrigenous organic matter will be transported close to the shelf edge.

Research will concentrate on detailed organic-geochemical investigations of the amount and composition of organic matter, including determinations of bulk parameters and biomarkers and calculation of flux rates, and the interpretation of the records in relationship to climate change and sea-level rise after the Last Glacial Maximum. On the Laptev-Sea shelf, for example, maximum accumulation of 10-15 gC cm^{-2} ky^{-1} were recorded between about 9,000 and 10,000 Calender Years BP, i.e., during times when the shelf seas became widely flooded at the end of the post-glacial sea-level rise, probably resulting in enhanced sea-floor/coastal erosion and/or increased Siberian river discharge (Fig. 23; Stein and Fahl, submitted). In addition to geochemical parameters, micropaleontological parameters should be used. Palynology is a useful tool for showing long-term changes in marine plankton activity (dinoflagellate cysts), influx of particulate terrigenous carbon (pollen, spores, leaf fragments) and sources of detrital carbonate as indicated by the provenance of reworked palynomorphs correlated to oxygen isotope stages (Mudie, 1985; Aksu et al., 1988). Driftwood is a further useful tracer of paleodischarge (Dyke and Morris, 1990; Dyke, in press) and can be used to show that the Transpolar Drift Current flowed southwestward towards Ellesmere Island during warmer Holocene intervals.

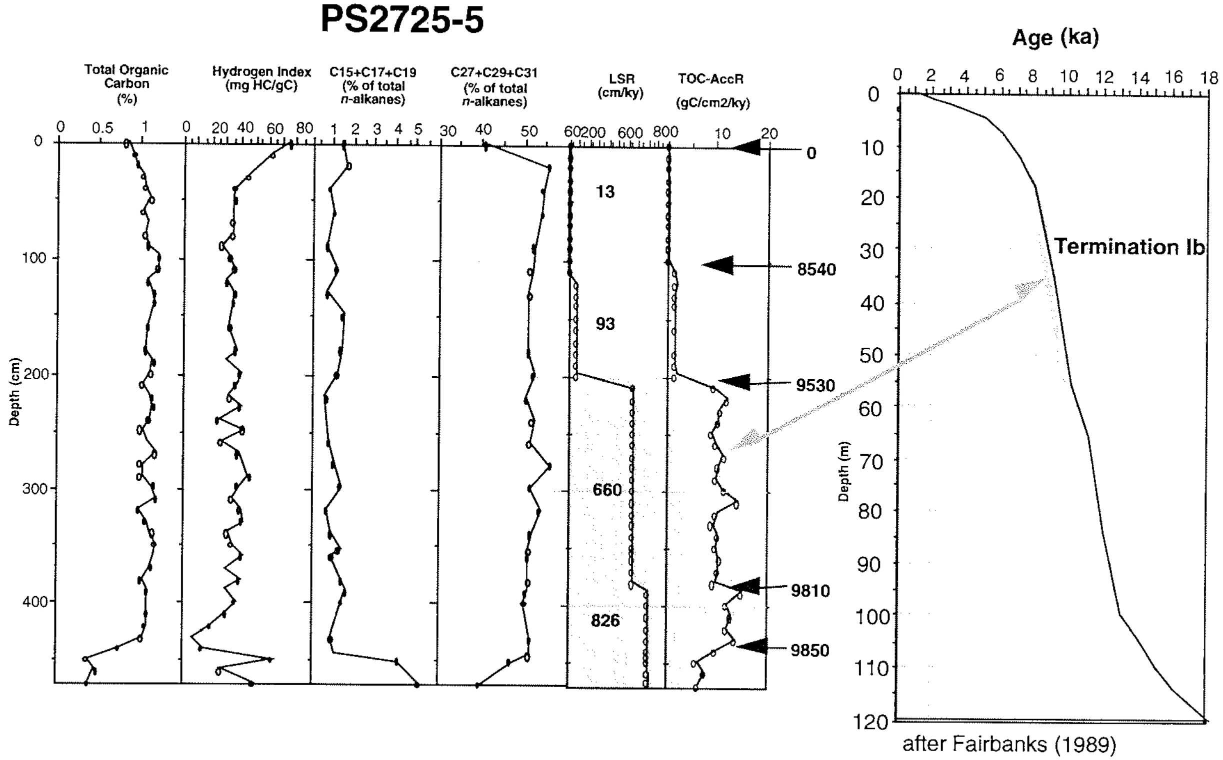


Fig. 23: Total organic carbon contents , hydrogen index values, short-chain (C15+C17+C19) and long-chain (C27+C29+C31) n-alkanes, linear sedimentation rates, and accumulation rates of total organic carbon, determined at sediments from Core PS2725-5. The maximum in total organic carbon accumulation is related rapid sea-level rise during Termination Ib in the global sea-level curve of Fairbanks (1989). Black arrows and numbers indicate Calender Years BP (Stein and Fahl, submitted)

** Inorganic particulate and dissolved matter*

Geological investigations, based on numerous studies on sediment cores have already shown, that the Arctic Ocean has responded frequently and in a dramatic and extreme manner to changes over the past few million years. Distinct changes in sediment texture, colour, and mineralogy were recorded in the entire Arctic Ocean during the Late Neogene and Quaternary (e.g., Clark et al., 1980; Darby et al., 1989; Thiede et al., 1990; and further references therein). Detailed studies of cores from Alpha Ridge (Scott et al., 1989; Darby and Bischof, 1996), the western Arctic (Bischof et al., 1996), and from the Lomonosov Ridge (Spielhagen et al., 1997) show that clay and sand mineral composition has changed significantly at least 6 times over the past 1 million years. These changes are very probably related to glacial/interglacial changes in sedimentary processes and paleoceanographic circulation patterns.

Climatic changes during the late Quaternary cause the formation and the melting of huge ice shields on land and the shallow shelf and of a thick and extensive ice cover. The consequence of these processes are strong sea-level changes, which had a strong impact on the sedimentological environment. A main part of the shallow shelves, as they are existing today in the Eurasian part of the Arctic, felt dry and the rivers could bring their sediment load directly or close to the shelf edge. Sea-ice formation with sediment entrainment, which today happens mainly in the Laptev Sea, could occur in the Kara or Barents seas because of the shallower water depths during glacial times. This led to the incorporation of different source material in comparison to the modern situation, and possibly will give a different signal in the sediment cores from the deep basins. Changes in the paleoenvironment, therefore, will strongly influence the supply, the transport, and the accumulation of the terrigenous sediment material in the Arctic Ocean coastal/shelf to deep-sea areas.

Based on the results of the investigation of the modern system, the change of sedimentary processes in relation to (global) climatic changes should be studied in sediment cores from the major river mouth areas and shelf-slope transects. Of highest priority is the multidisciplinary investigation of the last glacial-interglacial transition ("Termination I") in areas of very high sedimentation rates where AMS^{14}C-dated high-resolution studies of terrigenous sediment supply and climate change are possible. Methods should include determinations of mineralogical (clay minerals, heavy minerals, etc.) and geochemical tracers (rare earth elements, Sr and Nd isotopes, etc.) as used for studies of the recent situation.

3.3. Modelling goals and approaches

There are many aspects of arctic land-sea interactions about which we have little understanding, e.g. climate impact on Arctic hydrology, and feedback mechanisms between river discharge and sediment load. APARD proposes to examine these uncertainties through:

i) Development and use of coupled regional-scale climate-river delivery models under specific Arctic climate conditions;

ii) Development and use of coupled land-sea models for shelf/slope system response;

iii) Development and use of models for sediment production, retention and accretion in coastal and marginal systems;

iv) Development and use of models of coastline response under different scenarios of climate change and human impact.

Model simulations should include both global change scenarios, such as a times two CO_2 atmospheric increase (i.e. coupling of GCM model predictions with hydrologic and sediment transport models). Model verification should involove data sets obtained from hydrological systems in Alaska, Canada and Russia. Field data providing proxies of paleo-temperature, precipitation and drainage basin characteristics would be required for postdictions through the Quaternary.

A common approach to postdictions would involve regime theory to help properly scale dynamics with deposits. Sensitivity analysis with calibration to offshore data would be required. APARD assumes that relatively accurate boundary conditions could be obtained for the last few thousands of years. Prior to that field data would be required to help constrain, shorelines and placement of river mouths over time.

Models would be designed to provide assessment of a) a water budget, b) a sediment budget, c) time history of water and sediment fluxes from land to the sea floor (Fig. 24). The modeling exercise would also include development of a set of tools to understand climate change, and other large scale perturbations of man (forest fires, dams etc).

Hydrological Models

Specifically hydrological models must predict the magnitude and timing of water and sediment discharge (Q, Qs, respectively) to the ocean, on a variety of scales, i.e. from yearly hydrographs to those involving longer term trends. Physics of the models should include the effects of permafrost, seasonality, shorter term river events, river ice, tundra terrain, sources of water, and landslides on the production and transport of sediment. APARD is also particularly interested in the effect of climate on trends in Q and Qs and longer term variability (Fig.24).

Hydrological models must be designed to deal with sources of water; sources of sediment; input of variable paleo-temperatures, precipitation, basin relief, vegetation cover; large arctic data sets; scaling issues within a river basin.

River mouth models should include the effects of bedload dumping, estuarine circulation of sediment and carbon (where applicable), and the effects of tides and waves on the advection and diffusion of sediment.

Coastal Ocean Models

These models are designed to transport and deposit carbon and sediment under time varying conditions. Boundary conditions will be time variant, with paleogeography needed on the placement of ice (glacial and sea ice), past climate variability, changes in river basins concomittant with fluctuations in sea level.

Shelf processes to be modeled include the effects of storms, near shore ice and sediment inclusion, river discharge, sediment contribution from aeolian sources, variable ocean margin bathymetry (connection to Arctic Basin Group), paleo-channel locations and sediment delivery, brine formation, lateral transport, landward transport, settling of particles.

It would also be useful to develop and apply models useful in understanding the linkages of the continental shelf and the ocean basin. Such models would need to include the effects of gravity flows (i.e. from failures, or direct input from rivers), canyon development and their effects on sediment focusing, shelf (non-canyon) effects (i.e. distributed line sources), sea ice transport, iceberg transport, and brine formation. Models should be designed to provide reasonable constraints to those working on biological and chemical tracers recovered from sediment cores.

Ocean Basin Models

These group of models are to focus on the input and export of freshwater to and from the Arctic Ocean. Such models would include flow around the Canadian islands and Greenland, flow from the Bering Strait, flow from rivers and ocean evaporation. Models would be designed to balance water and salt, involve large-scale circulation dynamics and be able to predict the spatial distribution of salinity and temperature, including stratification. Boundary conditions would also involve paleogeography with respect to ice, climate and sea level. The models would need to incorporate the importance of sea-ice cover and be useful to help constrain our understanding of Arctic Ocean primary productivity, distribution of nutrients and other biogeochemical products.

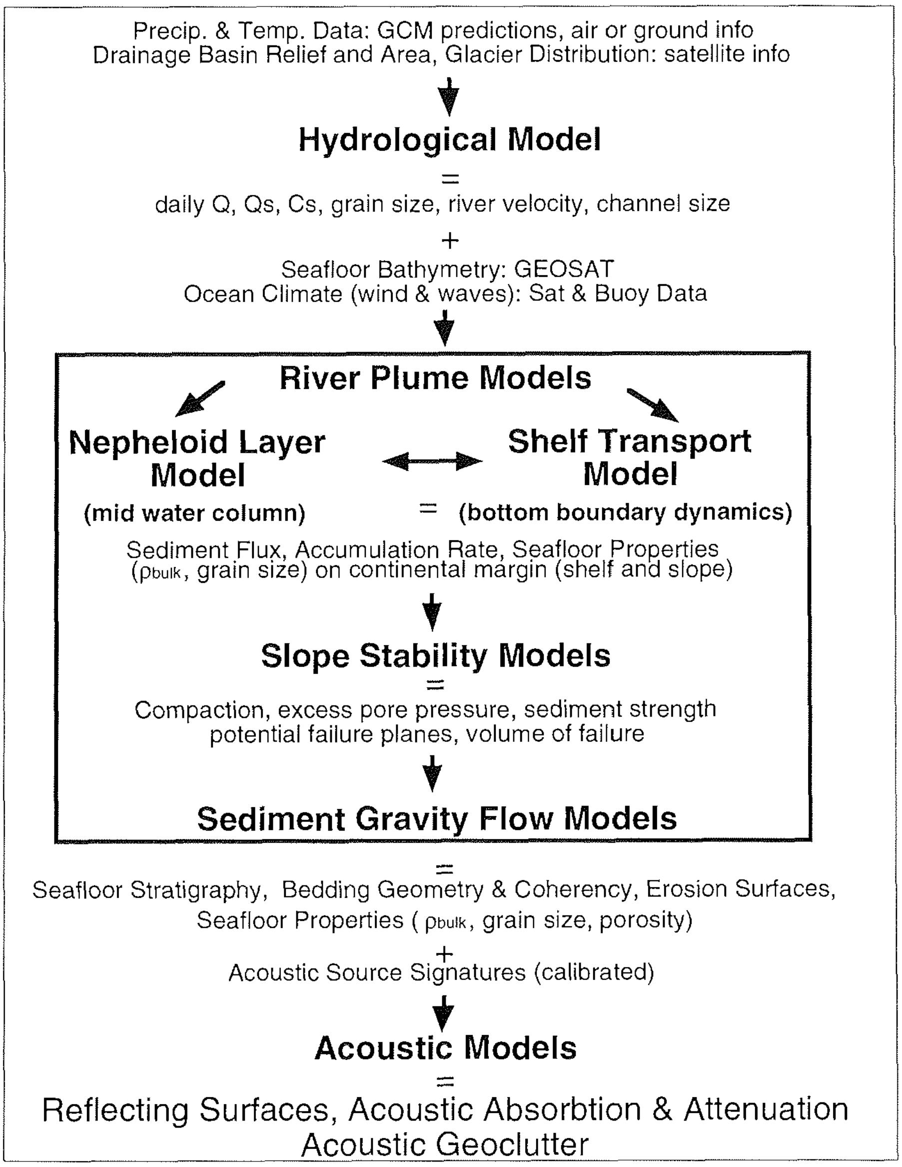


Fig. 24: Modelling approach of river discharge (J. Syvitski, INSTAAR).

3.4. Time intervals and key study areas

In Phase 1, APARD research efforts should focus on specific Late Quaternary time intervals to reconstruct changes in the influence of freshwater discharge:

- when the atmospheric climate varied while the boundary conditions remained fairly stable, e.g. comparison of the modern state with the

Holocene climatic optimum to assess the impact of temperature change, and

- when strong climatic fluctuations induced changes both in atmospheric temperatures and the environmental setting, e.g. comparison of the modern state with the Younger Dryas and the Last Glacial Maximum, when the sea-level was much lower than today.

These periods are also of importance to understand past global changes.

Within a multidisciplinary research programme on Arctic paleo-river discharge one should concentrate on studies of (1) modern processes and (2) ancient processes on different time scales: (2a) the last 100 years (historical data); (2b) high-resolution studies of the Holocene time interval (i.e., in 1000 years time slices); and (2c) the last deglaciation (i.e., the transition from the Last Glacial Maximum to the modern: LGM -Termination Ia - Younger Dryas - Termination Ib - Recent).

In a second future phase, APARD studies should be extended to older time periods, i.e., times of development of major Northern Hemisphere ice sheets during the Plio-Pleistocene. For these long-term reconstructions of paleo-river discharge in relationship to climate history, scientific drillings off major river systems are needed, such as planned within the Nansen Arctic Drilling (NAD) programme.

Since several national/international research programmes in shelf areas influenced by major river discharge are already in progress or planned (see Chapter 4), it is supposed to concentrate these international efforts on the following river systems:

- MacKenzie River
- Lena and Khatanga River system
- Ob and Yenisei River system
- Pechora River

In addition, other appropriate smaller Arctic rivers and settings as case studies are useful.

4. Related programmes

The APARD programme may significantly contribute to other multidisciplinary international programmes which need information about specific aspects of ancient river discharge to obtain their goals. Vice versa, it should be attempted to incorporate available data into the programme to provide detailed circum-arctic reconstructions.

APARD is in close relationship to:

* CAPE (Circum Arctic Paleoenvironments)

CAPE acts as an umbrella organization within IGBP-PAGES with a mission to facilitate Arctic paleoenvironmental science, focusing on past terrestrial and adjacent marine environments, and interactions between them. CAPE will serve primarily to promote hemispheric syntheses, enhance data compilation and exchange, and coordinate regional and global modeling efforts. Thus, data sets on paleo-river discharge obtained within the APARD programmeme may contribute significantly to the primary CAPE goals.

* IASC-LOIRA (Land-Ocean Interactions in the Russian Arctic)

LOIRA is a comprehensive, multidisciplinary programme, devoted to investigations of the exchange processes of matter and energy in the coastal zone of the Russian Arctic. LOIRA contain seven major foci: (1) the effects of changes in external forces or boundary conditions on coastal fluxes; (2) permafrost of the coastal zone; (3) terrestrial, freshwater and coastal ecosystems: changing environments under anthropogenic impact; (4) studies on the structure and functions of the biological components of marine ecosystems; (5) geomorphology and prediction of topography development in the coastal zone; (6) carbon fluxes and trace gas emissions; and (7) social and economic development of the Arctic coastal zone. For most of these foci, the Arctic river discharge and its change through time is of major importance.

* GRAND (Glaciation and Reorganization of Asia's Network of Drainage)

GRAND, UNESCO IGCP 415, is aimed at a better understanding of the development of Asia´s drainage systems in connection with the Quaternary glaciations. This aim is intimately related to the APARD´s objectives, especially in studying ancient riverine processes in Eurasia. A close interaction should be maintained between the APARD and GRAND components focussing on the reconstruction of paleo-river discharge into the Arctic Ocean and the modeling of drainage pattern changes and their climatic implications.

* ESF-QUEEN (Quaternary Environment of the Eurasian North)

The QUEEN programme is mainly dealing with reconstructions of the extent and history of Late Weichselian and earlier glaciations in the Eurasian Arctic, land to ocean sediment transport, correlation of terrestrial, ice-core and marine paleoenvironmental records, and Arctic permafrost studies. Furthermore, APARD-related studies of glacial/interglacial variations in riverine freshwater supply in the Barents, Kara, and Laptev Seas are also of key interest within QUEEN.

* NAD (Nansen Arctic Drilling)

The primary goals of NAD are to understand (1) the short- and long-term climatic and paleoceanographic evolution of the Arctic region and its effects on global climate, the biosphere and the dynamics of the world ocean and atmosphere, and (2) the nature and evolution of the major structural features of the Arctic Ocean Basin and circum-Arctic continental margins. Within goal (1), APARD-related studies of paleo-river discharge and its paleoenvironmental significance are of major importance. In APARD phase 2, high-resolution long-term changes of river discharge during late Neogene times will be addressed. For these studies scientific drillings (e.g., on the Laptev-Sea shelf) are needed which are planned within the NAD programme.

5. References

Aagaard, K. and Carmack, E.C., 1989. The role of sea ice and other fresh water in the Arctic circulation. J. Geophys. Res., 94 (C10): 14485-14498.

Aagaard, K. and Coachman, L.K., 1975. Toward an ice-free Arctic Ocean. EOS, 56: 484-486.

Aagaard, K., Swift, J.H., and Carmack, E.C., 1985. Thermohaline circulation in the Arctic Mediterranean Seas. J. Geophys. Res., 90: 4833-4846.

Aagard, K., 1989. A synthesis of the Arctic Ocean circulation. Rapp. P. v. Réun. Cons. Int. Explor. Mer., 188: 11-22.

Aksu, A.E., Mudie, P.J., Macko, S.M., and deVernal, A., 1988. Upper Cenozoic history of the Labrador Sea, Baffin Bay, and the Arctic Ocean: a paleoclimatic and paleoceanographic summary. Paleoceanography, 3: 519-538.

Alabyan, A.M., Chalov, R.S., Korotaev, V.N., Sidorchuk, A.Y., and Zaitsev, A.A., 1995. Natural and technogenic water and sediment supply to the Laptev Sea. Ber. Polarforsch., 176: 265-271.

Amos, C.L., 1985. Bottom photography and sediment analyses on CESAR. Geol. Surv. Can. Pap. 84-22: 25-46.

Andersson, P.S., Wasserburg, G.J., Chen, J.H., Papanastassiou, D.A., and Ingri, J., 1995. ^{238}U-^{234}U and ^{232}Th-^{230}Th in the Baltic Sea and in river water. Earth Planet. Sci. Lett., 130: 217-234.

Andrews, J.T. and Syvitski, J.P.M., 1994. Sediment fluxes along high latitude glaciated continental margins: Northeast Canada and Eastern Greenland. In: W. Hay (ed.) Global Sedimentary Geofluxes. National Academy of Sciences Press, Washington: 99-115.

ARCSS Workshop Steering Committee, 1990. Arctic System Science: Ocean-Atmosphere-Ice Interactions. Lake Arrowhead Workshop Report, JOI Inc., Washington DC: 132 pp.

Arkhipov, S.A., Ehlers, J., Johnson, R.G. and Wright, H.E., Jr., 1995. Glacial drainage towards the Mediterranean during the Middle and Late Pleistocene. Boreas, 24: 196-206.

Astakhov, V. and Grosswald, M.G., 1978. New data on the age of the Turgai Valley sediments. Doklady Acad. Sci. USSR, 242: 891-894.

Astakhov, V., 1992. The last glaciation in West Siberia: In A. M. Robertsson, B. Ringberg and L. Brunnberg (eds.), Quaternary stratigraphy, glacial morphology and environmental changes. Sveriges Geologiska Undersoekning: 21-30.

Astakhov,V., Mangerud,J.,A.,M., Svendsen,J.I., Maslenikova,O. and Tveranger,J. 1998. Marginal features of Late Pleistocene shelf-centered ice sheets in northern European Russia. Boreas, in press.

Bauch, D., Schlosser, P., and Fairbanks, R.G., 1995. Freshwater balance and the sources of deep and bottom waters in the Arctic Ocean inferred from the distribution of $H_2{}^{18}O$. Prog. Oceanog., 35: 53-80.

Behrends, M., Hoops, E., and Peregovich, B., 1998. Distribution patterns of heavy minerals in the Arctic Ocean: An approach to identify sources, transport, and pathways of terrigenous matter, Lecture Notes on Earth Sci., in press.

Behrends, M., Peregovich, B., and Stein, R., 1996. Terrigenous sediment supply into the Arctic Ocean: Heavy-mineral distribution in the Laptev Sea. In: Stein, R., Ivanov, G., Levitan, M, and Fahl, K. (eds.), Surface-sediment composition and sedimentary processes in the central Arctic Ocean and adjacent Eurasian continental margin, Ber. zur Polarforsch., 212: 37-42.

Bischof, J., Clark, D.L., and Vincent, J.S., 1996. Origin of ice-rafted debris: Pleistocene paleoceanography in the western Arctic Ocean. Paleoceanography, 11: 743-753.

Blanchon, P. and Shaw, J., 1995. Reef drowning during the last deglaciation: Evidence for catastrophic sea-level rise and ice-sheet collapse. Geology, 23: 4-8.

Blasco, S.M., Fortin, G., Hill, P.R., O´Connor, M.J., and Brigham-Grette, J.K., 1990. The late Neogene and Quaternary stratigraphy of the Canadian Beaufort continental shelf. In: Grantz, A., Johnson, L., and Sweeney, J.F. (eds.), The Arctic Region, Geol. Soc. Amer., The Geology of North America, Vol. L: 491-502.

Brooks, G.R., 1995. The fluvial geomorphic character of major Mackenzie River tributaries, Fort Simpson to Noman Wells, Northwest Terretories. Geol. Surv. Canada, Bull. 495: 28 pp.

Campbell, J.S. and Clark, K.D., 1977. Pleistocene turbidites of the Canada Abyssal Plain of the Arctic Ocean. J. Sed. Pet., 47: 657-670.

Cattle, H., 1985. Diverting Soviet Rivers: Some possible repercussions for the Arctic Ocean. Polar Rec., 22: 485-498.

Cauwet, G. and Sidorov, I. 1996. The biogeochemistry of Lena River: organic carbon and nutrients distribution. Mar. Chem., 53: 211-227.

Clark, D.L., Whitman, R.R., Morgan, K.A., and Mackay, S.D., 1980. Stratigraphy and glacio-marine sediments of the Amerasian Basin, central Arctic Ocean. Geol. Soc. Amer. Spec. Paper, 18: 57 pp.

Clark, J.A., Farrell, W.E., and Peltier, W.R., 1978. Global changes in postglacial sea level: a numerical calculation. Quat. Res., 9: 265-287.

Darby, D.A. and Bischof, J.F., 1996. A statistical approach to source determination of lithic and Fe oxide grains: an example from the Alpha Ridge, Arctic Ocean. J. Sed. Res., 66: 599-607.

Darby, D.A., Naidu, A.S., Mowatt, T.C., and Jones, G., 1989. Sediment composition and sedimentary processes in the Arctic Ocean. In: Herman, Y. (eds.), The Arctic Seas - Climatology, Oceanography, Geology, and Biology., New York: 657-720.

de Vernol, A., Turon, J.-L., and Guiot, J., 1994. Dinoflagellate distribution in high latitude environments and quantitative reconstruction of sea-surface temperature, salinity and seasonality. Can. Earth Sci., 31:48-62.

Dickson, B., 1997. From the Labrador Sea to global change. Nature, 386: 649-650.

Dickson, R.R., Meincke, J., Malmberg, S., and Lee, A.J., The "Great Salinity Anomaly" in the Northern North Atlantic 1968-1982, Prog. Oceanogr., 20: 103-151, 1988.

Dmitrenko, I., Golovin, P., Gribanov, V., and Kassens, H., 1998. Oceanographic causes for Transarctic ice transport of river discharge. In: Kassens, H., H. Bauch, I. Dmitrenko, H. Eicken, H.-W. Hubberten, M. Melles, J. Thiede, L. Timokhov (eds.), *Land-Ocean Systems in the Siberian Arctic: Dynamics and History.* Springer-Verlag (Lecture Notes in Earth Sciences), Berlin, in press.

Dubikov, G.I. and Baulin, V.V., 1981. History of development of permafrost of Eurasia. Publishing House Nauka, Moscow (in Russian).

Duk-Rodkin, A. and Hughes, O.L., 1995. Quaternary geology of the northeastern part of the central Mackenzie Valley Corridor. Geol. Sur. Canada Bull. 458.

Duk-Rodkin, A., and Hughes, O.L., 1994. Tertiary-Quaternary drainage of the pre-glacial Mackenzie basin. Quat. Intern., 22/23: 221-241.

Dunayev, N.N. and Pavlidis, J.A., 1988. A model of the Late Pleistocene Glaciation of Eurasiatic Arctic Shelf. In: Kotlyakov, V.M. and Sokolov, V.E. (eds.), Arctic research - Advances and prospects (Vol. 2), Proceedings of the conference of Arctic and Nordic Countries on coordination of research in the Arctic, Academy of Sciences of the USSR, Leningrad, December 1988: p. 70-72.

Dyke, A.S. and Morris, T.F., 1990. Postglacial history of the bowhead whale and driftwood penetration: implications for paleoclimate, central Canadian Arctic. Geol. Surv. Canada Paper, 89-24: 17 pp.

Dyke, A.S., England, J., Reimnitz, E., and Jette, H., 1997. Changes in driftwood delivery to the Canadian Arcticv Islands: a hypothesis of postglacial oscillations of the Transpolar Drift. Arctic and Alpine Res.

Dyurgerov, M.B. and Meier, M.F., 1997. Year-to-Year fluctuation of global mass balance of small glaciers and their contribution to sea level changes. Arctic and Alpine Res., 29, (4): 392-401.

Eicken, H., Reimnitz, E., Alexandrov, V., Martin, T., Kassens, H., and Viehoff, T., 1997. Sea-ice processes in the Laptev Sea and their importance for sediment export. Continent. Shelf Res., 17: 205-233.

Elverhoi, A., Fjeldskaar, W., Solheim, A., Nyland-Berg, M., and Russwurm, L., 1993. The Barents Sea ice-sheet - a model of its growth and decay during the last ice maximum. Quatern. Sci. Rev., 12: 863-873.

Fahl, K. and Stein, R., 1997. Modern organic carbon deposition in the Laptev Sea and the adjacent continental slope: Surface-water productivity vs. terrigenous supply. Org. Geochem., 26: 379-390.

Fairbanks, R.G., 1989. A 17000-year glacio eustatic sea level record: incfluence of glacial meting rates on the Younger Dryas event and deep-ocean circulation. Nature, 342: 637-642.

Faustova, M. A. and Velichko, A. A., 1992. Dynamics of the last glaciation in northern Eurasia, In: Robertson, A.M., Ringberg, B., and Brunnberg, L. (eds.), Quaternary stratigraphy, glacial morphology and environmental changes. Sveriges Geologiska Undersoekning: 113-118.

Fisher, T.G., and Smith, D.G., 1994. Glacial Lake Agassiz: its northwest maximum extent and outlet in Saskatchewan (Emerson Phase). Quaternary Science Review, 13: 845-858.

Füchtbauer, H., 1988. Sedimente und Sedimentgesteine, 4. Auflage. E. Schweizerbart´sche Verlagsbuchhandlung, Stuttgart: 868 pp.

Fütterer, D.K. (eds.), 1992. ARCTIC´91: The Expedition ARK-VIII/3 of RV "Polarstern" in 1991. Ber. Polarforsch., 107: 267 pp.

Fütterer, D.K. (eds.), 1994. Die Expedition ARCTIC `93. Der Fahrtabschnittm ARK-IX/4 mit der FS "Polarstern" 1993. Ber. Polarforsch., 149: 111-115.

Gataullin, V.N., 1988. The upper Quaternary sediments of the western coast of the Yamal Peninsula. Ph.D. thesis, VSE-GEI, Leningrad.

Gataullin, V.N., Polyak, L.V., Epstein, O.G. and Romanyuk, B.F., 1993. Glacigenic deposits of the Central Deep: A key to the Late Quaternary evolution of the eastern Barents Sea. Boreas, 22: 47-58.

Golovin, P., Dmitrenko, I., Kassens, H., and Hölemann, J., 1998. Frazil Ice formation during spring flood and its role in the transport of sediments to the bottom surface of fast ice. In: Kassens, H., H. Bauch, I. Dmitrenko, H. Eicken, H.-W. Hubberten, M. Melles, J. Thiede, L. Timokhov (eds.), *Land-Ocean Systems in the Siberian Arctic: Dynamics and History.* Springer-Verlag (Lecture Notes in Earth Sciences), Berlin, in press.

Gordeev, V.V. and Sidorov, I.S., 1993. Concentrations of major elements and their outflow into the Laptev Sea by the Lena River. Mar. Chem., 43: 33-45.

Gordeev, V.V., Martin, J.M., Sidorov, I.S., and Sidorova, M.V., 1996. A reassessment of the Eurasian river input of water, sediment, major elements, and nutrients to the Arctic Ocean. Amer. Journ. Sci., 296: 664-691.

Gorshkov, S.G., 1983. World Ocean Atlas, 3. Arctic Ocean. Pergamon Press, Oxford: 184 pp.

Grantz, A., Phillips, R., Muller, M.W., Starratt, S.W., Jones, G.A., Naidu, A., and Finney, S.P., 1996. Character, paleoenvironment, rate of accumulation, and evidence for seismic triggering of Holocene turbidites, Canada Abyssal Plain, Arctic Ocean. Mar. Geol., 33: 51-73.

Grebmeier, J.M. and Whitledge, T.E. (eds.), 1996. Arctic System Science Ocean-Atmosphere-Ice Interactions, Biological Initiative in the Arctic: Shelf-Basin Interactions Workshop, ARCSS/OAII Report Number 4, University of Washington, Seattle: 39 p.

Grigoryev, M.N., and Kunitsky, V.V., 1996. Development of excessively iced shores of the Arctic Sea during forecasted rise in sea level. Terra Nostra 9: 15.

Grosswald, M.G., 1988. Late Pleistocene ice sheet in the Soviet Arctic. In: Kotlyakov, V.M. and Sokolov, V.E. (eds.), Arctic research - Advances and prospects (Vol. 2), Proceedings of the conference of Arctic and Nordic Countries on coordination of research in the Arctic, Academy of Sciences of the USSR, Leningrad, December 1988: 18-23.

Grosswald, M.G., 1993. Extent and melting history of the Late Weichselian ice sheet, the Barents-Kara continental margin. In: Peltier, W.R. (Ed.), Ice in the Climate System. Springer Verlag,: p. 1-20.

Grosswald, M.G., 1996. New approach to the Ice Age paleohydrology of Asia. Second International Meeting on Global Continental Paleohydrology, Toledo, Spain, 1996,: 72.

Guieu, C., Huang, W.W., Martin, J.-M., and Yong, Y.Y., 1996. Outflow of trace metals int the Laptev Sea by the Lena river. Mar. Chem., 53: 255-267.

Harrison, L., Korotayev, V.N., and Sidorchuk, A.Y., 1981. Paleogeomorphological analysis of the Enisey River Delta. Vestnic of the Moscow Univ. Ser. Geogr. 6: 103-109 (in Russian).

Hill, P.R., 1996. Late Quaternary sequence stratigraphy of the Mackenzie Delta. Can. Journ. Earth Sci., 33: 1064-1074.

Hill, P.R., Mudie, P.J., Moran, K., and Blasco, S.M., 1985. A sea-level curve for the Canadian Beaufort Shelf. Can. J. Earth Sci., 22: 1383-1393.

Hughes, O.L., Harington, C.R., Janssens, J.A., Matthews, J.V., Jr., Morlan, R.E., Rutter, N.W., and Schweger, C.E., 1981. Upper Pleistocene stratigraphy, paleoecology and archeology of the northern Yukon interior, east Beringia. Bonnet Plume Basin. Arctic, 34: 329-365.

Hughes, T.J. 1996. Workshop on questions of Arctic Ice Sheet development, Grosswald's vision and interpretation for paleoclimatic interpretations. Geology of the Pacific Ocean, 12: 629-636.

Jania, J. and Hagen, J.O., 1996. Mass balance of Arctic glaciers. IASC report 5, 62pp.

Jenner, K.A. and Hill, P.R., 1991. Sediment transport at the Mackenzie Delta-Beaufort Sea interface. In: Marsh, P and Ommanney, C.S. (eds.), Mackenzie Delta Environmental Interactions and Implications of Development. Environment Canada National Hydrology Research Institute Symposium No. 4: 39-52.

Katasonova, Ye.G. and Siegert, C., 1982. Slope sediments in river valleys of Central Siberia. In: Geology of the Cenozoic of Yakutia. Yakutian Department of the Siberian Branch of the USSR Academy of Sciences, Yakutsk: 122-132 (in Russian).

Kleiber, H.P. and Niessen, F., 1998. Late Pleistocene paleo-river channels on the Laptev Sea shelf - implications from high-resolution seismic data. In: Kassens, H., H. Bauch, I. Dmitrenko, H. Eicken, H.-W. Hubberten, M. Melles, J. Thiede, L. Timokhov (eds.), *Land-Ocean Systems in the Siberian Arctic: Dynamics and History.* Springer-Verlag (Lecture Notes in Earth Sciences), Berlin, in press.

Korotaev, V.N., Sidorchuk, A.Y., and Chalov, R.S., 1980. Lithodynamics of the river deltas at Northern Siberia. Water resources 1: 138-145 (in Russian, English translation available).

Korotayev, V.N., Sidorchuk, A.Y., and Harrison, L., 1987. Paleo-geomorphological analysis of river deltas in the Taz Estuary. In: Paleohydrology of the temperate zone. Vol. 1: Rivers and lakes. Tallinn: 30-43.

Korotayev, V.N., Sidorchuk, A.Y., and Tarasov, P., 1990. Paleogeomorphology of river deltas in the Taz Estuary. Geomorphology, 2: 78-84 (in Russian).

Kunz-Pirrung, M., 1998. Distribution of aquatic palynomorphs in surface sediments from the Laptev Sea, Eastern Arctic Ocean. In: Kassens, H., H. Bauch, I. Dmitrenko, H. Eicken, H.-W. Hubberten, M. Melles, J. Thiede, L. Timokhov (eds.), *Land-Ocean Systems in the Siberian Arctic: Dynamics and History.* Springer-Verlag (Lecture Notes in Earth Sciences), Berlin, in press.

Kuptsov, V. M. and Lisitsin, A. P., 1996. Radiocarbon of Quaternary along shore and bottom deposits of the Lena and the Laptev Sea sediments. Mar. Chem., 53: 301-311.

Lapina, N.N., 1965. The determination of distribution paths of sediments, based on mineralogical investigations of marine deposits (example Laptev Sea). Uchennye Zapiski NIIGA, Ser. Region. Geol., 7: 139-157 (in Russian).

Lawford, R.G., 1994. Knowns and unknowns in the hydroclimatology of the Mackenzie River Basin. Environment Canada Mackenzie Impact Study Int. Rep., 2: 173-195.

Lemke, P., 1987. A coupled one-dimensional sea ice-ocean model. J. Geophys. Res., 92: 13164-13172.

Lemmen, D.S., Duk-Rodkin, A., and Bednarski, J. 1994. Late glacial drainage systems along the northwestern margin of the Laurentide Ice Sheet. Quat. Sci. Rev., 13: 805-828.

Létolle, R., Martin, J.-M., Thomas, A.J., Gordeev, V.V., Gusarova, S., and Sidorov, I. S., 1993. ^{18}O abundance and dissolved silicate in the Lena delta and Laptev Sea (Russia). Mar. Chem., 43: 47-64.

Macdonald, R.W., and Carmack, E.C., 1990. The role of large-scale under-ice topography in separating estuary and ocean on a arctic shelf. Atmosph. Ocean, 29: 37-53.

Macdonald, R.W., Paton, D.W., Carmack, E.C., and Omstedt, A., 1995. The freshwater budget and under-ice spreading of Mackenzie River water in the Canadian Beaufort Sea based on salinity and $^{18}O/^{16}O$ measurements in water and ice. J. Geophys. Res., 100 (C1): 895-919.

Macdonald, R.W., Solomon, S.M., Cranston, R.E., Welch, H.E., Yunker, M.B., and Gobell, C., 1998. A sediment and organic carbon budget for the Canadian Beaufort Shelf. Mar. Geol., 144: 255-274.

Mangerud,J., Svendsen,J.I., Astakhov,V.I. 1998. The age and extent of the Barents and Kara Sea ice sheets in Northern Russia. Boreas, in press.

Martin, J.M., Guan, D.M., Elbaz-Poulichet, F., Thomas, A.J., and Gordeev, V.V., 1993. Preliminary assessment of the distributions of some trace elements (As, Cd, Cu, Fe, Ni, Pb and Zn) in a pristine aquatic environment: the Lena River estuary (Russia). Mar. Chem., 43: 185-199.

Maykut, G.A., 1986. The surface heat and mass balance. In: Untersteiner, N.(ed.), *The geophysics of sea ice.* Martinus Nijhoff Publ., Dordrecht (NATO ASI B146): 395-463.

Mudie, P.J., 1985. Palynology of the CESAR cores, Alpha Ridge. Geol. Surv. Can. Pap. 84-22: 149-174.

Mudie, P.J., 1992. Circum-Arctic Quaternary and Neogene marine palynofloras: paleoecology and statistical analyses. In: Head, M.H. and Wrenn, J. (eds.), Neogene and Quaternary Cysts. American Association Stratigraphic Palynologists Foundation, Dallas: 347-390.

Mysak, L. A., Ingram, R. G., Wang, J., and van der Baaren, A., 1996. The anomalous sea-ice extent in Hudson Bay, Baffin Bay and the Labrador Sea during three simultaneous NAO and ENSO episodes. Atmosphere-Ocean, 34: 313-343.

NAD Science Committee, 1992. The Arctic ocean record: Key to global Change (Initial Science Plan of the Nansen Arctic Drilling Program). Polarforschung, 61: 102 pp.

Niessen, F., 1995. Seismic Evidence for Local Ice Sheets on the Siberian Shelf during the Last Glacial. EOS, Transactions, American Geophysical Union, 76 (46) supplement: 183.

Nolting, R.F., van Dalen, M., and Helder, W., 1996. Distribution of trace and major elements in sediment and pore waters of the Lena Delta and Laptev Sea. Mar. Chem., 53: 285-299.

Nürnberg, D., Fütterer, D.K., Niessen, F., Nørgaard-Pedersen, N., Schubert, C.J., Spielhagen, R.F. and Wahsner, M., 1995. The depositional environment of the Laptev Sea continental margin: Preliminary results from the R/V POLARSTERN ARK-IX/4 cruise. Polar Research 14(1): 43-53.

Nürnberg, D., Wollenburg, I., Dethleff, D., Eicken, H., Kassens, H., Letzig, T., Reimnitz, E., and Thiede, J., 1994. Sediments in Arctic sea ice - Implications for entrainment, transport, and release. Mar. Geol., 119: 185-214.

Östlund, H.G., and Hut G., 1984. Arctic Ocean water mass balance from isotope data. J. Geophys. Res., 89 (C4): 6373-6381.

Panin A.V., Sidorchuk A.Yu., and Chernov A.V., 1992. Macromeanders on the rivers of European USSR and problems of paleohydrological reconstructions. Water Resources, 4: 93-97 (in Russian).

Pfirman, S., Lange, M. A., Wollenburg, I., and Schlosser, P., 1990. Sea ice characteristics and the role of sediment inclusions in deep-sea deposition: Arctic - Antarctic comparisons. In Bleil, U., Thiede, J.(eds.), *Geological history of the Polar Oceans: Arctic versus Antarctic.* Kluwer Academic Publishers, Dordrecht: 187-211.

Pocklington, R., 1987. Arctic Rivers and their discharges. Mitt. Geol. Paläont. Inst. Univ. Hamburg, SCOPE/UNEP Sonderband, 64: 261-268.

Polyak, L., Forman, S.L., Herlihy, F.A., Ivanov, G. and Krinitsky, P., 1997. Late Weichselian deglacial history of the Svyataya (Saint) Anna Trough, northern Kara Sea, Arctic Russia. Marine Geology, 143: 169-188.

Rachold, V., Eisenhauer, A., Hubberten, H.-W., Hansen, B., Meyer, H.,1997. Sr isotopic composition of suspended particulate material (SPM) of East Siberian rivers: sediment transport to the Arctic Ocean. Arctic and Alpine Research 29(4): 422-429

Rachold, V., Lara, R., and Hubberten, H.-W., 1996. Concentration and composition of dissolved and particulate organic material in the Lena River - Organic carbon transport to the Laptev Sea. Third Workshop on Russian-German Cooperation: Laptev Sea System, October 16-19, 1996, St. Petersburg, Abstract Volume, 24-25.

Rachor, E. (ed.), 1998. Scientific cruise report of the 1995 Arctic expedtion ARK XI/1 of R/V *Polarstern*. Ber. Polarforsch., in press.

Romanovsky, N., 1996. Permafrost distribution on the Laptev Sea shelf. In: Kassens, H., Lindemann, F. & Rohr, B. (eds.): Third workshop on Russian-German cooperation: Laptev Sea system. Terra Nostra. Schriften der Alfred-Wegener-Stiftung, 96/9: 111.

Rutter, N., 1995. Problematic Ice Sheets. Quat. Intern. 28: 19-37.

Schauer, U., Rudels, B., Muench, R.D., and Timokhov, L., 1995. Circulation and water mass modification along the Nansen Basin slope. In: Kassens, H., et al. (eds.), Russian-German Cooperation: Laptev-Sea System. Ber. Polarforsch., 176: 94-98.

Schlosser, P., Bauch, D., and Fairbanks, R.G., 1994. Arctic river-runoff: mean residence time on the shelves and in the halocline. Deep-Sea Res., 41: 1053-1068.

Schlosser, P., Swift, J.H., Lewis, D., and Pfirman, S.L., 1995. The role of the large-scale Arctic Ocean circulation in the transport of contaminants. Deep-Sea Res., 42: 1341-1367.

Schubert, C. and Stein, R., 1996. Deposition of organic carbon in Arctic Ocean sediments: Terrigenous supply vs marine productivity. Org. Geochem., 24: 421-436.

Scott, D.B., Mudie, P.J., Baki, V., MacKinnon, K.D., and Cole, F.E., 1989. Biostratigraphy and late Cenozoic paleoceanography of the Arctic Ocean: foraminiferal, lithological and isotope evidence. Geol. Soc. Amer. Bull., 101: 260-277.

Semtner, A.J., 1984. The climatic response of the Arctic Ocean to Soviet River Diversions. Climatic Change, 6: 109-130.

Sidorchuk, A.Y. and Panin, A.V., 1996. Water supply from the Yana River basin since Late Pliocene. Terra Nostra 9: 97.

Sidorchuk, A., Panin, A.V., Borisova, O., Kovalyukh, N., and Chernov, A., in press. Paleohydrology of the lower Vychegda River (Northern Russia) in the Late Glacial and the Holocene. Vestnik MGU, Geografiya, 5, 1998 (in Russian).

Solomon, S.M., Forbes, D.L., and Klerstead, R.B., 1994. Coastal impacts of climate change. Beaufort Sea erosion study, Canadian Climate Centre Report, 94-2, 50 pp.

Solomon, S.M., Forbes, D.L., and Mudie, P.J., 1992. Report of 1991 NOGAP coastal surveys in the Beaufort Sea. Geol. Surv. Canada, Open File No. 2579.

Spielhagen, R.F. and Erlenkeuser, H., 1994. Stable oxygen and carbon isotopes in planktic foraminifers from Arctic Ocean surface sediments: Reflection of the low salinity surface water layer. Mar. Geol., 119: 227-250.

Spielhagen, R.F., Eisenhauer, A., Frank, M., Frederichs, T., Kassens, H., Mangini, A., Nowaczyk, N.R., Nörgaard-Pedersen, N., Schäper, S., Stein, R., Thiede, J., Tiedemann, R., Wahsner, M., Bonani, G., and Kubik, P.W., 1997. Arctic Ocean evidence for Late Quaternary onset of northern Eurasian ice sheet development. Geology, 25:783-786.

Stein, R. and Korolev, S., 1994. Shelf-to-basin sediment transport in the eastern Arctic Ocean. Ber. Polarforsch. 144: 87-100.

Stein, R., 1991. Accumulation of organic carbon in marine sediments. Lect. Notes Earth Sci., Springer Verlag Heidelberg, 34: 217 pp.

Stein, R., 1996. Organic carbon and carbonate distribution in surface sediments from the eastern central Arctic Ocean and the Eurasian continental margin: Sources and pathways. In: Stein, R., Ivanov, G., Levitan, M, and Fahl, K. (eds.), Surface-sediment composition and sedimentary processes in the central Arctic Ocean and adjacent Eurasian continental margin, Ber. Polarforsch., 212: 243-266.

Stein, R. and Fahl, K., submitted. Holocene Accumulation of Organic Carbon at the Laptev-Sea Continental Margin (Arctic Ocean) and its Paleoenvironmental Significance.

Stein, R., Schubert. C., Vogt, C., and Fütterer, D.K., 1994. Stable isotope stratigraphy, sedimentation rates, and salinity changes in the latest Pleistocene to Holocene central Arctic Ocean. Mar. Geol., 119: 333-355.

Stein, W., 1996. ^{18}O and ^{3}H investigations in the Arctic Ocean. Diploma thesis, University of Heidelberg: 101 p.

Syvitski, J.P.M. and Andrews, J.T., 1994. Climate Change: Numerical modeling of sedimentation and coastal processes, Eastern Canadian Arctic. Arctic and Alpine Res., 26(3): 199-212.

Telang, S.A., Pocklington, R., Naidu, A.S., Romankevich, E.A., Gitelson, I.I., and Gladyshev, M.I., 1991. Carbon and Mineral transport in major north American, Russian Arctic and Siberian rivers: The St. Lawrence, the Mackenzie, the Yukon, the Arctic Alaskan rivers, the Arctic Basin rivers in the Soviet Union, and the Yenisei. in Biogeochemistry of major world rivers, SCOPE 42, edited by E. T. Degens, S. Kempe, and J. E. Richey (eds), Wiley, New York: 75-104.

Thiede, J., Clark, D.L., and Hermann, Y., 1990. Late Mesozoic and Cenozoic paleoceanography of the northern polar oceans. In: The Geology of North America, Vol. L, The Arctic Ocean Region, 427-458.

Treshnikov, A. F., ed., 1985. Arctic Atlas. Arctic Antarctic Research Institute, Nauchno Issled. Inst. Moscow: 204 pp.

Treshnikov, A.F., and Ivanov, V.V., 1980. Studies of the Arctic environment in connection with the partial withdrawal of discharge of Siberian rivers. Probl. Arkt. Antarkt. (English translation), 55: 6-12.

Velichko, A. A., L. L. Isayeva, V. M. Makeyev, G. G. Matishov and M. A. Faustova 1984. Late Pleistocene glaciation of the Arctic Shelf, and the reconstruction of ice sheets. In Velichko, A. A., Wright, H. E. J., and Barnosky, C. W. (eds.), Late Quaternary environment of the Soviet Union. Univ. Minn. Press: 35-41.

Vilks, G. and Deonarine, B., 1989. Labrador shelf benthonic foraminifera and stable oxygen isotopes of *Cibicides lobatulus* related to the Labrador Current. Can. Journ. Earth Sci.: 26.

Wahsner, M., 1995. Mineralogical and sedimentological characterization of surface sediments from the Laptev Sea. Ber. Polarforsch., 176: 303-313.

Walker, H. J.,1973. Spring discharge of an Arctic river determined from salinity maesurements beneath sea ice. Water Resources Res., 9 (2): 474-480.

Wang Y., Ren, M.-E and Syvitski, J.P.M., 1998. Sediment Transport and Terrigenous Fluxes. In: Brink, K.H. and Robinson, A.R. (eds) The Sea: Volume 10 - The Global Coastal Ocean: Processes and Methods. John Wiley & Sons, New York: 253-292.

Yunker, M.B., Snowdon, L.R., Macdonald, R.W., Smith, J.N., Fowler, W.G., Skibo, D.N., McLaughlin, F.A., Danyushevskaya, A.I., Petrova, V., and Ivanov, G., 1996. Polycyclic aromatic hydrocarbon composition and potential sources for sediment samples from the Beaufort and Barents Seas. Environm. Sci. Technol., 50: 1310-1320.

6. Appendix (proposed/ongoing projects)

In this Appendix, short summaries of ongoing and proposed projects dealing with Arctic paleo-river discharge are presented. The projects are listed in alphabetical order taking the first (principal) author.

Title:
River discharge to the Arctic Ocean:
Its impact on deep water ventilation and carbon flux.

Institutions:
(A) Department of Analytical and Marine Chemistry
Goteborg University
SE-412 96 Goteborg, Sweden
(B) Department of Geophysics
Allegt. 70, University of Bergen
N-5007 Bergen, NORWAY

Investigators:
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Objectives:
1. To trace the river runoff over the Eurasian shelves and out into the deep Arctic Ocean.
2. Evaluate the inorganic carbon transport by the runoff and its fate in the Arctic Ocean
3. Model the air-sea exchange of carbon dioxide in the Eurasian shelf seas, taking into account the carbon, salinity and temperature effects of the runoff.
4. Estimate the impact of biogeochemical processes on the carbon cycle in the Eurasian shelf seas.

Material:
Water samples from the surface to the bottom in the Eurasian shelf seas and adjacent deep Arctic Ocean.

Methods:
Determination of carbonate species (alkalinity, dissolved inorganic carbon and pH), delta O-18, delta C-13, as well as oxygen, nutrients, salinity and temperature.

Selected results from previous projects:
Production and remineralization of carbon in the Eurasian sector have been estimated based on a combined data set of recent expeditions to the area. The water masses investigated are composed of Atlantic water, river-runoff and sea ice melt water, and their fractions are evaluated from salinity and alkalinity. By combining preformed concentrations of the source waters and the measured concentrations of different constituents, the deficits are calculated. Applying a appropriate carbon ratios and the deficits in waters along the slope and deep basin, it is seen that the shelf areas are the dominant productivity sites and that the productivity is in the order of 30 g C/m2/y in the Barents Sea and about 6 g C/m2/y in the Kara Laptev Seas. Using literature values of the inflow of Atlantic water over these shelf seas result in a utilization of carbon of about 0.022 Gton C/y.

The distribution of total alkalinity in the surface waters of the Laptev Sea and along the continental slope of the Eurasian Basin (sampled in 1993 to 96) reveal that the majority of the river runoff that enters the Kara Sea flows into the Laptev Sea before entering the deep basin. The Atlantic and Pacific oceans provide source waters for the Arctic Ocean that can be distinguished by their differing nitrate and phosphate concentration relationships. Using these relationships, the amount of Atlantic and Pacific waters in the surface layer of the Arctic Ocean can be estimated. Data collected during the 1990s show that Atlantic source water is dominant in most of the Eurasian Basin and is present in significant amounts in the Makarov Basin north of the East Siberian Sea. Pacific source water is dominant in most of the Canadian Basin and is present in significant amounts in the Amundsen Basin north of Greenland. This information is, together with the information of river runoff distribution, essential to estimate the possibility for production of waters over the shelves that has the potential to ventilate the deep Arctic Ocean.

By applying a plume-entrainment model the ventilation and sequestering rate of anthropogenic carbon dioxide can be computed for the Arctic Ocean. The plume is initiated by water leaving the shelf break, followed by entrainment during the descent of the plume. The model is constrained by the CFC distribution in the central Arctic Ocean, together with the concentrations of CFCs in the source waters. Running this model from 1750 to present it is obvious that deep water production in the Arctic Ocean is as active as in the Greenland Sea. The sink of anthropogenic carbon dioxide to waters below 500 m in the Artcic Ocean is in 1991 equal to 0.026 Gton C/y. This amounts to about 1 % of the total oceanic uptake of anthropogenic CO^2.

Timing of the project:
Ongoing

Title:
Calculations of sediment volume in the Mackenzie River Basin

Institution:
Geological Survey of Canada
3303-33rd Street N.W. Calgary, Alberta, Canada. T2L 2A7

Investigator:
A. Duk-Rodkin
Phone: (403) 292-7188; email: Aduk-Rodkin@gsc.nrcan.gc.ca

Objectives
(1.) To determine the volume of sediments removed by treams during ice retreat in the Mackenzie region and (2) to compare it to the volume of sediment in the Mackenzie Delta.

Calculations of sediment volumes will be done based on the assumption that the Mackenzie River is a recent feature not more than 12 k years old. 14 k metres of sediments have been accumulated since the early Tertiary in the Beaufort-Mackenzie basin, and was deposited by a drainage system equivalent to 4% of present Mackenzie River Basin. The Mackenzie River was established as a result of deglaciation of the Laurentide Ice Sheet during Late Wisconsinan, which resulted in the integration of different drainage basins that previously occupied the Mackenzie region. Therefore calculating the volume sediment removed by the new drainage system should give an indication of the amount of material deposited in the offshore area during the last 12 k years. It is known that the maximum incision in mountainous areas since deglaciation is about 500 metres, contrasting 30 to 50 metres of incision on the plains area. Mountainous areas cover approximately 40% of the basin.

These volumes will be compared to the accumulated wedge of sediments in the Beaufort-Mackenzie offshore-onshore area, as estimated from sediment thicknesses determined during the Mackenzie Delta Borehole Project. In addition, available mineral, lithological and fossil data from the delta cores will be compared with the continental data to look for indicators of provenance. These indicators may corroborate interpretations of sediment sources during different stages of retreat of the ice sheet in the Beaufort-Mackenzie offshore-onshore area.

Material and methods
Calculations of sediment volumes in the Mackenzie Basin will be accomplished using air photographs, topographic maps and available information on sediment discharge.

Timing of the project
04/1999-03/2002

Cooperation
A. Sidorchuk, Moscow State University

Title:
Spatial and Temporal Reconstruction of the Origin and the Budget of Arctic Ocean Sediments.

Institution:
Institute for Geochemistry, Göttingen University, Goldschmidtstr. 1, 37077 Göttingen
Germany

Investigator:
Eisenhauer, Anton
(Contact: Email: aeisenh@gwdg.de)

Objectives:
1. Identification of the fluvial origin of Arctic Ocean sediments.
2. Correlation of the sediment sources with Arctic Ocean sediments in space and time.
3. Reconstruction of climatic induced changes of sediment transport.
4. Modelling of the the mechanical and chemical weathering of sediments during transport.
5. Modelling of the sedimentary budget in space and time.

Materials:
1. Long and short sediment cores from all parts of the Arctic Ocean.
2. Sediment trap samples.
3. Ice rafted material.
4. fluvial water samples of all rivers draining into the Arctic Ocean.

Methods:

Thermal Ionization Mass-Spectrometry
- Precise deteermination of $^{87}Sr/^{86}Sr$ isotope ratios.
- Precise determination $^{87}Rb/^{86}Rb$ element ratios.
- Precise determination of $^{143}Nd/^{144}Nd$ ratios (eNd)
- XRD determination of major elements
- Grain size measurements.
- U/Th determination

Selected Results from Previous Projects
In order to constrain transport and origin, we compared Rb- and Sr-isotope ratios and concentrations of Arctic Ocean sediments, Laptev Sea sediments and ice rafted sediments (IRS) with the Rb/Sr-systematic of suspended particulate material (SPM) of the Khatanga, Lena and Yana rivers. The marine sediments and the river SPM form unique Rb/Sr-isochrons and Sr-mixing envelopes which are characterised by distinct positive slopes and initial $^{87}Sr/^{86}Sr$ ratios. These envelopes are caused by natural Sr-isotope fractionation due to grain size separation processes. Sediment samples with high concentrations of fine grained material are more radiogenic relative to samples enriched in more coarse grained particles. Individual envelope slopes and intercepts reflect geochronological, geological and mineralogical differences of their drainage areas. The three Sr-mixing envelopes are referred to as Lena

Mixing Envelope (LME: $^{87}Sr/^{86}Sr=0.84\cdot(1/Sr)+0.713\pm0.001$), Yana Mixing Envelope (YME: $^{87}Sr/^{86}Sr=3.81\cdot(1/Sr)+0.689\pm0.003$) and Khatanga Mixing Envelope (KME: $^{87}Sr/^{86}Sr = 1.39\cdot(1/Sr)+0.702\pm0.001$). All samples from the eastern Laptev Sea (east of 125°E) fall along the LME whereas all samples from the western Laptev Sea (west of 125°E) fall in between LME and KME. This implies that all samples corresponding to the LME are grain size derivatives of Lena SPM, whereas all samples in between LME and KME are a mixture of Lena SPM, Khatanga SPM and, most likely, Kara Sea sediments drained by the Ob and Yenisei river. SPM of the Ob/Yenisei river system are isotopically indistinguishable from those of the Khatanga river because all are draining the Siberian flood basalts. Although in average about 50 to 60% of the western Laptev Sea sediments are Lena grain size derivatives a non-binary mixing model indicate a decreasing trend of Lena influence on the western Laptev Sea shelf from the east to the west. However, at least 30% of the western Laptev Sea sediments originate from the Lena. Calculation of the budget for particulate Sr indicate an input of about 20 to 40 % of Kara Sea sediments and Ob/Yenisei SPM, respectively, to the western Laptev Sea. In the open Arctic Ocean, along the Transpolar Drift sediments originate from the Lena drainage area. However, sediments at the western Arctic Ocean margins are, most likely, related to the Ob/Yenisei river system. Other sediments from close to the Fram Strait and Greenland have to be attributed to other yet not identified sediment sources.

Cooperation with other institutions:
Alfred Wegener Institute, Bremerhaven
Alfred Wegener Institute, Potsdam
Geomar, Kiel
P.P. Shirshov Institute of Oceanology, Moscow
VNIIOkeangeologiya, St. Petersburg

Title:
The nature of continental run-off from the Siberian rivers and its behavior in the adjacent Arctic basins

Scientific Coordination:
Dieter K. Fütterer (AWI Bremerhaven)
Eric Galimov (Vernadsky Institute Moscow)
Contact person:
Dieter K. Fütterer, email: dfuetterer@awi-bremerhaven.de

German sub-projects and principle investigators

* River discharge and biological processes
(M. Klages, AWI Bremerhaven)
* River run-off and water mas distribution: oxygen and carbon signals
(J. Thiede, AWI Bremerhaven / GEOMAR Kiel)
* Modern riverine processes: Composition and transformation of dissolved organic matter and nutrients
(G. Kattner, AWI Bremerhaven)
* The carbon and silicate system in the water column and sedimentary records
(V. Ittekott, IBMC Hamburg)
* Terrigenous sediment and particulate organic carbon fluxes: Sources, pathways, and sinks
(R. Stein, AWI Bremerhaven)
* Modelling of oceanographic circulation and biogeochemical fluxes
(R. Schlitzer, AWI Bremerhaven)
* Data management: PANGAEA
(H. Grobe, AWI Bremerhaven)

Objectives

1. Nature of river supply.
2. Modification of fluvial output in the estuaries.
3. Dispersal and deposition pattern of river supply and material exchange between Kara Sea and the Arctic Ocean
4. Variations of coastal marine processes in relation to river supply.
5. Responses of the benthic system to changes at the sea surface
6. Dispersal and distribution pattern of contaminants.
7. Gas release and its distribution pattern on the Kara Sea shelf
8. Reconstruction of the Kara Sea paleoenvironment
9. Modelling of transport processes and biogeochemical fluxes

Material and Methods

1. Field methods and measurements

The field methods will involve the collection of:

- Hydrographic data
- Water, plankton, suspended matter samples
- Settling particles

- In-situ screening for radioactive elements in the water colunmn
- Surface sediments and sediment cores
- Sub-bottom echosounding (PARASOUND)

2. Laboratory studies

Mineralogical and sedimenfological investigations

- Grain size analyses
- Bulk, clay, and heavy mineralogy
- Physical properties, core logging

Chemical analyses (organic and inorganic)

- Flux and composition of organic matter
- Biomarkers and Tracers
- Elemental distribution
- Bulk geochemistry
- Isotope biogeochemistry

Isotope biogeochemistry

- Organic matter and its fractions
- Intermolecular isotope distribution patter

Gas analyses

- Individual hydrocarbons
- Isotope composition

Radiochemical analyses in the water column and sediments ^{137}Cs, ^{90}Sr, Pu, U

Biological investigations

- Productivity (ice and water)
- Phytoplankton distribution patterns
- Zooplankton distribution patterns
- Zoobenthos communities and biomass distribution
- Biogeographical distribution patterns
- Micropaleontological studies

Modelling of transport processes and biogeochemical fluxes

Timing of the project:
01/1999 - 12/2001

Cooperation partners in Germany and Russia

- Alfred Wegener Institute for Polar and Marine Research , Bremerhaven
- GEOMAR Research Center for Marine Geosciences, University of Kiel
- Institute of Biogeochemistry and Marine Chemistry, University of Hamburg
- Bundesanstalt für Hydrographie und Seeschiffahrt (BSH), Hamburg

- Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow
- Shirshov Institute of Oceanology, Moscow
- Institute of Ocean Geology (VNIIOkeangeologia), St.Petersburg

- Murmansk Marine Biological Institute, Russian Academy of Sciences (MMBI)
- Institute of Geology and Mineralogy of Mineral Deposits (IGEM), Moscow
- Arctic and Antarctic Research Institute (AARI), St. Petersburg

Title:
Environmental and sedimentary history of the Lena Delta

(Subproject of "Russian-German Cooperation: Laptev Sea System 2000")

Institution:
Alfred Wegener Institute, Research Unit Potsdam
Telegrafenberg A43
14473 Potsdam
Germany

Investigator(s):
Hubberten, Hans-Wolfgang
Rachold, Volker
(contact: V. Rachold, Phone: +49-331-288-2141, Fax: +49-331-2137, email: vrachold@awi-potsdam.de)

Objectives:
1. Reconstruction of the sedimentary history of the Lena Delta
2. Reconstruction of the influences of climatic variability on the sedimentation in the Lena Delta
3. Implications for the sediment budget of the Laptev Sea and the Arctic Ocean

Materials:
- sedimentary sequences obtained by shallow coring and/or through natural exposures
- lake sediment cores

Methods:
- AMS 14C dating, OSL dating
- geomorphology
- grains-size measurements
- study of satellite and aerial photographs
- shallow seismic
- multidisciplinary lake sediment studies

Selected results from previous projects:
1. The sediment budget of the Laptev Sea
The Laptev Sea is strongly influenced by the runoff of the Siberian rivers Lena, Yana, Khatanga, Olenyok, Anabar, and Omoloy. Daily water and suspended sediment discharge of these rivers are recorded at several hydrometeorological stations since ca. 1930. The total annual freshwater discharge and sediment yield measured at the lowermost station of each river amount to 700 ckm and 27 Mio tons, respectively. The main portion (520 ckm of water and 21 Mio tons of suspended sediment) is transported by the Lena. However, measurements of the suspended load along the different channels of the Lena delta indicate that a significant fraction (up to 80 %) of the material entering the delta does not reach the Laptev Sea but is deposited in the delta area. Similar processes have to be taken into account for the others rivers.

Field investigations and the study of air and satellite photos indicate that the material flux from coastal erosion has to be considered for quantifying the sediment budget of the Laptev Sea. In central and northern Yakutia including the coastal zone ice complexes are a common feature. The retreat of ice-rich coasts of the Laptev Sea which contain up to 70 % of ice amounts to 2.5 m per year on average and can reach 6 m per year. Estimates of the solid material input to the Laptev Sea resulting from the retreat of coastlines clearly show that the flux is in the same order as the total riverine sediment transport.

2. Source areas and pathways of sediments of the Laptev Sea

Geochemical and mineralogical data of river sediments and suspended particulate material (SPM) and of Laptev Sea surface sediments, cores and ice-rafted detritus (IRD) clearly show that the Laptev Sea can be divided into an eastern and western province. While the eastern part is dominated by material imported through the Lena the western part is controlled by sediments supplied by the Khatanga and imported from the Kara Sea through the strait of Vilkitsky. Both the Khatanga and the Yenisey which supplies the major portion of Kara Sea sediments drain the Siberian flood basalts. The mineralogical and chemical signature of the basalts is clearly seen in Khatanga SPM and sediments. Due to the size and the heterogenic lithology of the catchment the chemical composition of Lena SPM, on the other hand, is close to that of the average upper continental crust after weathering. The differences in the lithology of the catchments are documented in the chemical and mineralogical composition of marine samples.
Further studies of Arctic sediments indicate that parameters, such as the Sr isotope composition and the heavy mineral distribution, can be applied to identify sediments originating from the Laptev Sea in the central Arctic Ocean.

3. Late Quaternary environmental and climatic history of northern Central Siberia

The knowledge about the climatic and environmental history of northern Central Siberia has been significantly improved by the field and laboratory work within the scope of the Russian-German research project "Taymyr".
During the Early Weichselian stadial (Zyrian) glaciers from the Byrranga Mountains or Putoran Plateau advanced to the Labaz Lake area in the Taymyr Lowland. Probably at the end of the Early Weichselian, the Taymyr Lowland as well as the western Byrranga Mountains and western Putoran Plateau became unglaciated.
The Middle Weichselian interstadial (Kargin) was characterized by a more continental and probably more unstable climate than that of the Holocene, with similar summer but lower winter temperatures. The higher continentality could be due to exposed Siberian shelf areas during the Middle Weichselian as a consequence of a lower sea level.
During the Late Weichselian stadial (Sartan) valley glaciers appeared in the western Putoran Plateau, whilst its foreland as well as the Taymyr Lowland and low altitudes of the western Byrranga Mountains remained unglaciated.
The transition from the Weichselian to the Holocene is characterized by a climatic warming trend during the Bølling, Allerød and Preboreal periods,

which is interrupted by cooling during the Middle and Younger Dryas events. In similarity to some intervals in the Middle Weichselian, the Holocene climatic warming resulted in enhanced thermokarst processes, leading to the formation of shallow lakes and ponts and subsequent peat formation.
The Holocene climatic optimum occurred within the Boreal period. During that time, vegetation zones were located 200-400 km to the north of their present position. Relatively warm climatic conditions remained during the Atlantic and Subboreal periods. Since the end of the Subboreal, a more or less continuous climatic deterioration takes place.

Timing of the project (beginning/end):
03/1998 - 12/2000

Cooperation with other institutions:
- Technical University of Freiberg, Germany
- GEOMAR Research Center, Kiel, Germany
- Permafrost Institute, Yakutsk, Russia
- Arctic and Antarctic Research Institute, St. Petersburg, Russia
- Moscow State University, Russia
- Lena Delta Reserve, Tiksi, Russia

Title:
Assessment of pathways of sediments flux in the Pechora Sea.

Institution:
All-Russia Research Institute for Geology and Mineral Resources of the World Ocean (VNIIOkeangeologia), St.Petersburg, Russia

Investigator(s):
Ivanov, Gennady
Contact:: Ivanov, Gennady
Fax (812) 114-14-70, tel. (812) 114-59-98, e-mail: givanov@g-ocean.spb.su

Objectives:
1. Study of the input of Pechora river derived suspended particulate matter (SPM).
2. Assessment of pathways of transportation in suspension by current systems in the water column
3. Evaluation of gravitational flows (turbidity currents, debris flows)
4. Investigation of sea-ice transport of sediments

Material:
Surface sediment samples from the Pechora Sea(more 107 stations)

Methods:
- Grain size measurements
- Clay mineralogy
- Sr86/sr87
- Coarse fraction composition
- Organo-geochemistry

Timing of the project (beginning/end):
03/1998 - 02/2000

Cooperation with other institutions:
- Alfred-Wegener-Institute, Bremerhaven
- Geochemisches Institut, Goldschmidtstr. 1, 37077 Gottingen,
- P.P. Shirshov Institute of Oceanology, Moscow

Title:
Modern riverine processes: Composition and transformation of dissolved organic matter and nutrients

(Subproject of the Russian-German Project "The nature of continental run-off from the Siberian rivers and its behavior in the adjacent Arctic basins" coordinated by Dieter K. Fütterer, AWI Bremerhaven, and Eric Galimov, Vernadsky Institute Moscow)

Institution:
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Investigators:
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Amon, Rainer
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email gkattner@awi-bremerhaven.de)

Objectives:
1. Chemical characterization and quantification of dissolved organic matter (DOM) discharge by representative Arctic rivers (like the Jenissej, Ob, Lena) along the salinity gradient from the riverine to the marine endmember.

2. Transformation processes of dissolved organic matter during the transition from the river delta to the slope on the Arctic shelf, focused on bacterial mineralization, floculation and photooxidation.

Methods:
Determination of dissolved bulk parameters, as DOC/DON, humic substances, isotopic composition of DOC in rivers, shelves and open ocean

Molecular level characterisation of DOM, as amino acids, carbohydrates, lignin phenols in comparison to that of POM.

Physical-chemical processes, as floculation of DOM, photolyses of DOM, freeze-out of DOM, stripping

Biological processes, biodegradation, modification by bacteria

Selected results from previous projects:
The composition of DOM in the Lena River seems to be mainly determined by soil-derived inputs and not by autochtonous sources. The isotopic composition of the suspended particulate material supports this assumption. Therefore the low concentrations of inorganic nitrogen and phosphate are probably characteristic for the river and not the result of algal uptake. In contrast to the high input of silicate, the Lena River as

direct source of nitrate and phosphate for sustaining primary production in the Laptev Sea seems to be not of relevance at least during summer.

The high concentrations of dissolved organic matter (DOM) and silicate in the Lena River provide a concentration gradient offshore in the Laptev Sea. Enhanced concentrations of several parameters were found in a branch like structure of low salinity water extending from south to north on the Laptev Sea shelf and slope and the boundary of the Eurasian Basin. Dissolved organic carbon (DOC) in the Lena delta, with a mean of 550 µM C, was 4 to 5 times higher than in the Laptev Sea, whereas dissolved organic nitrogen (DON) was only 2 times higher at about 11 µM N in the Lena. The resulting C/N ratios of DOM in the open ocean were 18 to 25, half of those measured in the Lena. Significant correlations between salinity and DOC as well as DOC values close to an estimated dilution line show a largely conservative mixing of DOC in the Laptev Sea. The distribution of carbohydrates and amino acids are quite variable but also exhibit higher concentrations in the low saline water. Lignin phenols which are unequivocal tracers for terrestrially derived organic matter have concentrations of 23 nM in the Lena delta decreasing from 7 nM in the lower salinity water to about 2 nM in less riverine influenced areas. From these values the proportion of terrigenous DOM in the surface layer can be estimated to range from 60 % of total DOM in the Laptev Sea to 20 % in the adjacent Eurasian Basin.

Timing of the project:
1999 to 2001

Co-operation with other institutions:
Geomar, Kiel
Institute for Biogeochemistry, Hamburg

Title:
The significance of biological processes for the transformation of matter in the Kara Sea

Institution:
Alfred Wegener Institute for Polar and Marine Research, Columbusstrasse, 27568 Bemerhaven, Germany

Investigators:
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Hans-Jürgen Hirche
Eva-Maria Nöthig
Eike Rachor

Objectives
Biological processes and their relevance for particle fluxes and transformation will be studied in detail during different seasons of the year. Sediment traps, Influx current metres and other deployments will be used along transects starting at the river mouths of Ob and Jenissei up to the Nansen basin in the north in cooperation with other project partners (sedimentology, geochemistry, chemistry, oceanography).

1. Phytoplankton ecology
- Identification of pathways of carbon in pelagic communities of unicellular organisms.
- Examination of the relevance of unicellular organisms (producers and consumers) for the vertical particle flux.
- Studies on the interrelationships between input of fresh water by Eurasian rivers, sea ice cover, primay production and sedimentation in the Kara Sea.

Studies on plankton ecology and particle flux will start with studies on species composition and the quantitative importance of aut- and heterotrophic communities both regional - starting form the estuaries up to the open Kara Sea - and under seasonal aspects. Subsequently, experiments on the relevance of unicellular producers and consumers on particle flux and transformation processes will follow. The main objective of these studies is to shed light on the interplay of fresh water supply, sea ice cover and primary production.

2. Zooplankton ecology
- Determination of trophical structures of zooplankton communities.
- Description of the seasonal development and productivity of mesozooplankton communities.
- Verification of the role of the northern Kara Sea continental shelf and slope as interface for the exchange of zooplankton communities between the Kara Sea shelf and the adjacent Nansen basin.

Main objectives of our experiments on zooplankton ecology are studies on major trophic relationsships determinig the particle flux within certain zooplankton communities. Of special interest is, to which extend zooplankton species do contribute to the sedimentation of material to the seafloor and how do these species respond on terrigenous detritus, e.g. are *Calanus* species able to utilize this material or its derivates. Following the proposed transects from the estuaries of Ob and Jenissei up to the Nansen basin the function of the northern Kara Sea as exchange interface between the shelf and the Nansen basin will be verified.

3. Benthos ecology
- Studies on the impact of alterations in the euphotic zone along gradients from the estuaries up to the north on composition and biological performance of benthic communities.
- Investigations concerning the contribution of benthic organisms on transfromation, consumption and deposition of fluvial material and its relevance for these organisms.
- Studies on the effects of variability in food supply for benthic organisms (target species).

Generally, studies on transformation and consumption processes within the benthic as well as in the pelagic communities are of relevance for most other subprojects since they are part of the fate of fluvial matter on the way from the estuaries to the central Arctic ocean. All studies on population dynamics, storage and utilization of lipids and physiological experiments will be accompanied by long term aquaria experiments with selected target species at the AWI.

Material:
Water sampler, plankton nets, sedimets traps, current metres, box and multi - corer, trawls

Methods:
- Particle flux measurements using sediment traps
- Quantification of suspended matter concentration and its advective transport using Influx current metres
- Seasonal sampling of zooplankton along salinity gradients by means of multinet and plankton suctor (microscopy, incubation experiments)
- Perfoming incubation experiments and long term live maintenance of target species onboard and at the institute (respiration measurements)
- Benthological sampling profiles along gradients by using multi box corers, trawls and other gears

Selected results from previous studies:
A total of 52 quantitative macrobenthos samples were taken at water depths between 10 and 40 m in 1997 during the expedition of RV *Akademik Boris Petrov* into the Ob and Yenisei estuaries. Additional material for species diversity analyses was sampled by a small dredge at 20 stations. Grab samples yielded a total of 17 major taxa: bivalves, polychaetes, cumaceans, amphipods and isopods showed the highest frequency of occurence and were present in more than 80 % of the grab samples. All other taxa were found in less than 45 % of the samples. Total biomass per sample showed values between 0.2 and 150 g wet weight per m^2 (mean of 37.1 ±32.6 g wet weight per m^2). Again, bivalves, polychaetes and isopods represented the dominant major taxa with maximum biomasses of 85, 52 and 80 g, respectively. The total biomass and the biomass of single major taxa did not show correlation to local

oxygen concentration or sediment properties. Echinoderms, usually dominant benthic taxon at high latitudes were only scarcely found in our samples and only at deeper stations (> 20 m) with at least 30 PSU salinity and bottom temperatures below 0 °C. Low abundance of echinoderms is likely to be indicating that seasonal river run-off is a severe problem for such organisms.

Timing of the project:
07/1997 - 07/2001

Cooperation:
IPÖ Kiel
MMBI Murmansk
Komarov Institute St. Petersburg,
Shirshov Institute Moscow

Title:
Benthic foraminifera in the Ob and Yenisei estuaries, Russian Arctic

Institution:
Murmansk Marine Biological Institute,
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Investigator(s):
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Objectives:
1. Detailed distribution of modern benthic foraminifera in the Ob and Yenisei estuaries.
2. The foraminiferal fauna and environmental variables.
3. Implementation of the results into paleoecological reconstructions.

Material:
surface sediment is sampled for foraminifera at 22 stations from the area of discharge of the Ob and Yenisei rivers. The samples are preserved in alcohol and stained with Bengal Rose for further distiguishing of live and dead specimens. Environmental data are owned by the AWI (Germany) and the Vernadsky Institute of Geochemistry (Russia).

Timing of the project (beginning/end):
01.1998-12.1998

Cooperation with other institutions:
- Alfred-Wegener-Institute, Bremerhaven
- Vernadsky Institute of Geochemistry, Moscow

Title:
Paleovalleys of Ob and Yenisei Rivers on the Kara Sea floor: Sediments and topography

Institution:
P.P.Shirshov Institute of Oceanology RAS
Nakhimovsky pr. 36, 117851, Moscow, Russia

Investigators:
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Objectives:
1. Reconstruction of the location of paleo-hydrographic net on the Kara Sea floor during Holocene: main valleys of Ob and Yenisei Rivers, their tributories, paleodeltas position, and so on.
2. Reconstruction of river valleys paleotopography: their longitudinal and latitudinal profiles, paleodepths, types of slopes, etc.
3. Reconstruction of hydrologic processes within paleo-river valleys based on paleotopography and sediment filling (structure, facies changes, sediment composition and fluxes).
4. Reconstruction of paleo-river sediment discharge from the Kara Sea into the Arctic Ocean in Holocene (in relation to deglaciation, rising of sea level, retreat of coast line, climate changes)

Materials:
Bathymetric and seismoacoustic profiles, side-scan sonar and space imagies, long and short sediment cores from the Kara Sea shelf and adjacent continental slope and rise and abyssal plain.

Methods:
- High-resolution seismoacoustic profiling, multi-beam and side-scan sonar mapping;
- Interpretation of space imagies for sea surface;
- Lithology of paleo-river sediments;
- Grain-size composition;
- Coarse fraction composition;
- Heavy mineral studies;
- AMS 14C dating, oxygen isotope stratigraphy.

Selected results and problems from previous projects:
We have some preliminary results about distribution pattern of paleo-river valleys on the Kara Sea floor. Nevertheless, some important problems, for example, position of the Yenisei River mouth during the last deglaciation are still unresolved.
We have got a number of data on grain-size composition; heavy, light and clay minerals; lithology of recent sediments in estuaries of OB and Yenisey Rivers, in mixing zones of fresh and sea water, and in northern

facies zones. But changes of all these parameters in time are still poorly known.

According to results of sediment core DM4397 studies, there was an event of strong river discharge in the middle of Boreal period but we need in a number of additional data about it.

Timing of the project (beginning/end):
03/1998 - 02/2000

Cooperation with other institutions:
- VNIIOkeangeologiya, St.Petersburg
- Alfred-Wegener-Institute, Bremerhaven
- Byrd Polar Research Centre, Columbus OH

Title:
Paleorivers of the Kara Sea

Institutions:
- P.P.Shirshov Institute of Oceanology, 117851 Moscow,.Nakhimovsky Prospekt, 36
- Moscow State University, 119899, Moscow, Vorob'evy Gory

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Objectives:
1. High-resolution reconstruction of Late Quaternary paleo-river runoff of Ob and Jenisey from the Kara Sea hinterland, its correlation with the terrestrial paleoclimatic history;
2. Revealing of largest sedimentary basins according to geophysical anomalies and their preliminary mapping.
3. Revealing and mapping of position of old deltas and estuaries during different stages of transgression and regression of sea level (according to Fairbanks curves).

Material:
- Long and short sediment cores from the Kara Sea continental margin as well as the modern deltas and estuaries
- Drilling from "Bovenit"
- Parasound and Multibeam records
- Geological and geomorphological maps

Methods:
- Mapping by Multibeam, Parasound, high-resolution seismic, magnetometric and gravimetry studies
- AMS ^{14}C dating, radio-isotope stratigraphy
- Stable carbon and oxygen isotope measurements of planktic and benthic foraminifers
- Grain size measurements
- Lithology of ice-rafted debris
- Coarse fraction composition
- Studies of S, Be and Pb isotopes

Work consists of several stages:
- Analysis of altimetric, gravimetric, satellite data and comparison with modern sea-floor relief, determination of largest sedimentary basins by anomalies and their mapping (already done).
- Marine expeditions with maximal use of remote methods and differential navigation. Carring out series of cross- and lengthwise sections on ancient river channels from modern deltas to shelf edge and continental slope. Task of this research: revealing and mapping positions of ancient

deltas and estuaries on different stages of transgresion and regression of sea level (accordingly to Fairbridge curve etc.).
- Mapping of the permafrost and gas hydrate layers. Both accumulative forms (ancient lakes, deltas, large marshes with layer of loose sediments etc.) and erosive forms will be mapped as well as ancient shore lines with their typical deposits and levels from the marine side of the river system.
- Polygons for detailed researches are fixed in the shelf zone after revealing of large sedimentary bodies connected with sea level changes and with migration of rivers mouths. Detailed mapping will be done using all geophysical and seismoacustical, magnetometric and gravimetric methods.
- Sites for long and superlong (10 - 20 m) cores (obtained by heavy and superheavy (to 10 t) gears) will be selected based on detailed site survey.
- Sediment cores are to be studied by all accessible methods for elaboration of a detailed stratigraphy of Quaternary (especially Late Quaternary) and comparison with sections on adjacent land. For these purposes it is necessary to drill bottom sediments in lakes and marshes; the cores are to be studied by the same methods as marine bottom sediments.
- Detailed stratigraphy will be the base for all following reconstructions using methods of geomorphology, cryology, geophysics, viscous magnetization of bottom sediments studies.
- To study more ancient stages of development of the Kara Sea paleorivers it is necessary to use drilling (e.g. from vessel „Bovenit") with sampling of cores at selected sites, and detailed study of continental slope near possible river mouths. For this purpose it is possible to use submercibels „Pices" and „Mir".
- Obtained data has to be compared with studied ice cores of Novaya Zemlya and other arctic islands glaciers and with data from Arctic Ocean and North Atlantic bottom sediments.

Selected results from previous project:
In 1991, the Lena River area has been studied during the SPASIBA-91 expedition [Kuptsov, Lisitsin - Marine Chemistry, 1996, v.53, p.301-311]:

(1) 84 determinations of radiocarbon age of organic matter in soils and Quaternary deposits in the catchment area of the Lena were made, at the mouth of Its affluent. Bottom sediments of the Lena itself and of the Laptev Sea were sampled along the 130°E profile from the delta to a distance of some hundreds of kilometers seawards.

(2) The organic matter of the upper (0-3 cm) layer of the Laptev Sea bottom deposits is inherited from soils and Quaternary deposits of the river's catchment area. The average radiocarbon age of this organic matter is ca. 7,000 yrs BP.

(3) The particulate matter of the river runoff moves northwards along surface freshwater lenses and accumulates at the present-day depocenter of the Lena, 200-250 km north of the delta. The sedimentation rates for the stations investigated vary from 170 cm/kyr in the depocenter to a few centimeters per thousend years.

(4) The distribution of solid particle riverine runoff over the Laptev Sea basin in the Late Quaternary and Holocene is determined by the position of the Lena's paleodelta, and is related to the height of sea level. The position of the depocenter is shifting with time.

(5) The most ancient sediments that could be retrieved by gravity corer have an age of 16,000 yrs BP.

(6) The distribution of magnetic susceptibility with depth in 6 sediment cores allows temporal correlations within the interval from recent to 16,000 yr B.P.

Timing of the project (beginning/end):
two years (?/1998-?/2000)

Cooperation with other institutions:
- Alfred-Wegener-Institute, Bremerhaven
- GEOMAR, Kiel University
- Department of Geosciences, Bremen University
- VNIIOkeangeologiya, St.Petersburg
- Heidelberg Academy of Sciences
- AARI, St.Petersburg
- Vernadsky Institute of Geochemistry and Analitical Chemistry, Moscow
- MMBI, Murmansk
- St.Petersburg University
- AMIGE, Murmansk

Title:
Paleoclimate history of Canadian Arctic margins and ocean basins

Institution:
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Steven Solomon
Kate Moran
Steven Blasco

Collaborators:
Anne de Vernal (GEOTOP, U. Quebec a Montreal)
David B. Scott (Dalhousie U., Halifax)

(Contact: Peta Mudie, ph. 902-426-8720, Fax -4104,
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Objectives:

1. High resolution quantitative reconstruction of physical and biological oceanographic conditions at 1000 year time-slices over the past 14-18,000 years and, at decadal to centennial scales for the past 2,000 years. Physical properties include sea surface temperature (summer & winter), seasonality, salinity (summer & winter), sea ice cover (months/year with >50% cover). Net primary production is based on abundances of planktonic and benthic micro-flora and fauna relative to terrigenous particulate organic matter (POM).
2. Reconstruction of sediment sources using magnetic susceptibility and palynology as proxies for clastic and organic POM, respectively.
3. Reconstruction of icesheet advances and retreat by measurement of sediment physical properties and lithofacies analysis.
4. Incorporation of results in regional and global paleoclimatic models.

Material:
Box cores (proxy-data calibration) and gravity/piston cores from:
-Canadian Arctic Island channels and adjoining seas
-Canadian Polar Margin
-Beaufort Sea and Mackenzie Delta (Richards Island)

Industry and research boreholes in Mackenzie Delta and Beaufort Sea

Methods:
- AMS dating of molluscs and foraminifera; radiocarbon dating of wood and peat
- Grain size measurement & coarse fraction composition
- Litho- and seismostratigraphic correlation

- Planktic foram oxygen and carbon isotope stratigraphy
- Micropaleontology of benthic foraminifera and thecamoebians
- Palynology studies of Quaternary pollen-spore assemblages, dinoflagellates and acritarchs, provenance of pre-Quaternary palynomorphs
- Whole-core magnetic susceptibility
- Acoustic velocity, bulk density and shear strength records

Results from previous studies

Canadian Arctic Channels and Polar Margin

1. A paper has been submitted describing the results of a new regional synthesis of proxy-climate data for the 6 Ka time-slice in the central and eastern Canadian Arctic. In contrast to earlier results of Dyke et al. (1996, 1997) based on mollusc, whalebone & driftwood from raised beaches, the planktic and benthic marine microfossils in marine sediment cores indicate greater influx of warm North Atlantic water and less extensive sea ice at the time of the Holocene thermal maximum onshore. These results have important implications for the transport of Mackenzie Basin runoff and sea ice out of the Arctic Ocean during global warming.

2. New transfer functions for dinoflagellates (de Vernal et al., 1994) are being applied to a core from Nares Strait and show that sea surface temperature (SST) was at least 1oC warmer and sea ice cover was lower prior to ca. 5 Ka, with the past 2 Ka being marked by very large oscillations in SST and salinity (de Vernal & Rochon, pers comm., 1997).

3. New methods have been developed for extraction of foraminifera and thecamoebians from marine sediment core samples (e.g. Collins et al., 1990). Application to new cores from Arctic channels and Beaufort Sea has allowed recovery of large numbers of calcareous benthic forams that can now be used for quantitative paleosalinity measurements.

Mackenzie Delta and Beaufort Sea

1. Cores from thermokarst lakes on Richards Island east of the modern Delta (Solomon et al., in prep.) show that late Holocene (<5 Ka) lacustrine sediments are overlain by laminated marine/brackish deposits which probably record incursions of the Mackenzie River plume during mega-discharge and storm events over the past 2-3 Ka. The mega-discharge events may be recorded in cores of Holocene sediment (up to 9 Ka) in thermokarst embayments near Kay Point, west of the Delta. Work is in progress (Mudie & Davies, in prep.) using palynological tracers to determine the sources of POC.

2. Boreholes adjacent to the modern Delta contain >100m of Holocene delta-front muds and fluvial sediments. Detailed

sediment and microfossil studies may provide a record of variations in flow regimes.

Timing

Project began 1993, to terminate 1999/2000. In 1998, it is hoped to obtain new cores from Canada Basin and Beaufort Slope for study of slope stability that may be correlated with the borehole discharge events.

Title:
Late Cenozoic Paleogeography and Recent tectonics of the Barents, Kara and Laptev Seas Shelves.

Institution:
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Objectives:
1. Investigation of Cenozoic history of the Russian Arctic continental margin during sinocenic stage of its evolution.
2. Compling of maps of thicknesses of Quatenary and Holocene veneer, bathymetric and geomorphic maps.
3. Reconstruction of amplitudes of neotectonic and/or glacial isostatic movements.
4. Implementation of result into paleogeographic models.

Material:
Single channel seismic acoustic data; long and short sediment cores from the Barents, Kara and Laptev Seas Shelves.

Methods:
Seismic stratigraphic analyses;
Grain size studies;
Mineralogical studies;
Studies of foraminiferas and mollusks
Bathymetric and geomorphological mapping of Quaternary deposits.

Selected results from previous project:
To determine amplitudes of vertical Cenozoic movements on the Barents-Kara Seas Shelves several tens thousands Sparker records and single channel seismic acoustic data were interpreted. Modern position of the top of pre-Cenozoic rocks as well as volumes of eroded rocks were restored. Cenozoic sea Level changes and glacial isostatic movements were taken into account. Maps of Cenozoic and recent movements of the Earths crust were compiled. Amplitudes of these movements are +100 to +1500 m in shields and folded - basement inliers, +200 to +2500 m within revived orogens, 0 to +200 in ancient platforms, -250 to +250 m in young intracontinental plates, -500 to +100 m in continental-margin plates -400 to -750 m in uncompensated riftogenous grabens, 0 to +1000 m in activated peripheral shelf slopes. The dominating neotectonic process on the Barents-Kara plate was successive degradation of an Land-

Severnaya Zemlya Zone, which served as a terrigenic source area for sedimentary basins of southern and central parts of continental margin. The map of neotectonic prospectivity for oil and goes resources of the Western Arctic Russian Shelf was compiled. The highest prospective zones are recognized in continental parts of intracontinental and continental-margin plates, i. e. Barents-Kara megadepression, on slopes of relics of subsidence and local positive structures of anticline and non-anticline type. Based on sparker records and single channel seismic data maps of river volley exited on Barents and Kara Seas Shelves during regressions of the Late Miocene, Mid Pleistocene and Late Pleistocene/Holocene time were also compiled.

Timing of the project (beginning/end):
01/1997 - 12/1999

Cooperation with other institutions:
Alfred-Wegener-Insitute, Bremerhaven
GEOMAR Research Center, Kiel
Institute for Geology and Geochemistry, Stokholm University
Norwegian Polar Institute, Tromso
P.P Shirshov Institute of Oceanology, Moscow
Polar Marine Geological Expedition, Murmansk
Central Arctic Geological Expedition, Norilsk
State Research Center of Russian Federation, Arctic and Antarctic Research Institute, St. Petersburg

Title:
Transport mechanisms for radioactive substances in the Arctic Ocean and Experimetal investigations on the transport of radionuclides in the Arctic Ocean

Institution:
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Objectives
1. To investigate the transport mechanisms for anthropogenic radioactive substances in the Arctic Ocean
2. To assess the current levels of radionuclides in water and sediment of the Arctic and the Nordic Seas
3. To analyse and interpret the sediment content in Arctic sea ice
4. To simulate the hypothetical release of radionuclides from the dumping areas of radioactive waste in the Kara Sea in water and contaminated sea-ice sediments on different spatial scales
5. To simulate the spreading of anthropogenic radionuclides from other sources for the Arctic Ocean like the west European reprocessing plants in Sellafield and La Hague

Methods
- Measurements of radionuclide concentrations in water and sediment
- Probing and analysis of cores and sediment content of sea ice
- Numerical modeling with coupled ice-ocean general circulation models of:
  - the fjords and bays at the east coast of Nowaja Semlja
  - the Kara Sea
  - the Arctic ocean and the Nordic Seas
- Simulation of tracer dispersion and advection with Eularian and Lagrangian methods

Timing of the project (beginning/end):
01/1995 - 05/1999

Cooperation with other institutions:
- Institute for Marine Reasearch, University of Hamburg
- GEOMAR, Kiel

Support by
- German Climate Reasearch Center (DKRZ), Hamburg
- Murmansk Marine Biological Institue (MMBI), Murmansk
- Arctic and Antarctic Research Institute (AARI), St.Petersburg

Title:
Holocene environmental change in the Barents and Kara seas

Institution:
Byrd Polar Research Center, Ohio State University, Columbus, OH 43210, USA

Principal investigator:
Leonid Polyak (polyak.1@osu.edu)

Objectives:
1. Reconstruction of the Late-glacial and Holocene paleoceanographic environments in the Barents and Kara seas on a sub-millennial time scale;
2. Understanding of long-term variations in riverine discharge, Atlantic-water fluxes, and sea-ice conditions in the western Eurasian Arctic.

Material:
Sediment cores (gravity and box cores) from the Barents and Kara seas and accompanying hydrographic and sea-bottom geophysical data.

Methods:
Core logging, grain size, mineralogy, AMS 14-C dating, micropaleontology (foraminifers, diatoms, dinoflagellates), stable isotopes, seismostratigraphy.

Summary of results from previous and on-going projects:
The study of sediment cores/boreholes and seismic records revealed that the entire Barents Sea and at least part of the Kara Sea were covered by a grounded ice sheet during the Late Weichselian glacial maximum. The deglaciation of the eastern Barents Sea has largely been accomplished by ~13 ka and completed by ~10 ka. Fluctuations in the composition of foraminiferal associations and stable isotopes indicate significant variations in oceanographic environments during deglaciation and throughout the Holocene. These variations are related to changes in the discharge of Siberian rivers, Atlantic water inflow, sea-ice conditions, and glacier ice distribution in the Barents and Kara seas and adjacent regions. Further studies are aimed at understanding these processes and reconstructing their variations on a sub-millennial time scale.

<u>Publications:</u>

Polyak, L. and Solheim, A., 1994, Late- and post-glacial environments in the northern Barents Sea west of Franz Josef Land. Polar Research, 13: 197-207.

Polyak, L., Lehman, S.J., Gataullin, V. and Jull, A.J.T., 1995, Two-step deglaciation of the southeastern Barents Sea. Geology, 23: 567-571 and 767.

Polyak, L. and Mikhailov, V., 1996, Post-glacial environments of the southeastern Barents Sea: foraminiferal evidence. In: Andrews, J.T. et al. (Eds.), Late Quaternary paleoceanography of the North Atlantic margins. Geol. Soc. Sp. Publ. 111: 323-337.

Lubinski, D.J., Korsun, S., Polyak, L., Forman, S.L., Lehman, S.J., Herlihy, F.A. and Miller, G.H., 1996, The last deglaciation of the Franz Victoria Trough, northern Barents Sea, from piston core evidence. Boreas, 25: 89-100.

Forman, S.L. and Polyak, L., 1997, Radiocarbon content of pre-bomb marine mollusks and variations in the 14C reservoir age for coastal areas of the Barents and Kara seas, Russia. Geophys. Res. Letters, 24: 885-888.

Polyak, L., Forman, S.L., Herlihy, F.A., Ivanov, G. and Krinitsky, P., 1997, Late Weichselian deglacial history of the Svyataya (Saint) Anna Trough, northern Kara Sea, Arctic Russia. Marine Geology, 143: 169-188.

Timing of the project:
09/1996 - 03/2000.

Collaborating researchers and institutions:
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M. Hald, Inst. Biology & Geology, Univ. Troms¨, Norway
Vogt, Dept. of Geosciences, Bremen University, Germany
W.B. Bryant, Texas A&M Univ., College Station, TX, USA
VNII Okeangeologia, St.Petersburg, Russia
P.P. Shirshov Institute of Oceanology, Moscow, Russia

Title:
Sea-level changes, coastal erosion and deposition in the Western sector of the Russian Arctic during the Holocene: Quantification of processes and implications for the future

Institution:
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Background:
Coastal erosion and deposition are highly variable parametres, which influence drastically sediment dynamics and sedimentary budget of the Arctic Ocean. These processes modify significantly sedimentary input from rivers and should be taken into account when estimating sedimentary budget of the coastal zone. Sea-level changes stand among the major factors in variability of sedimentary input. The role of sedimentary input is especially important for the Arctic. In this area, retreat of coastal slopes and depositional forms intensified much during the last deglacial cycle. The Holocene represents an important example of changes in coastal erosion and deposition under the relatively small-scale (several meters) sea-level changes valuable for possible correlation with anticipating future changes. Extensive but slightly comparable data exists for sea-level changes, coastal erosion/deposition during the specific periods of this epoch. These data should be verified, supplemented and combined with the instrumental data on the present century to create the uniform data base. The project touches western, i.e. European, sector of the Russian Arctic, namely the Pechora Sea, the Barentz Sea and the White Sea.

Objectives:
1. To reconstruct Holocene sea-level changes in the western (European) sector of the Russian Arctic on the basis of the existing coastal data and short-term field studies in the key areas (the Pechora Sea, the White Sea).

2. To evaluate sedimentary input from coastal erosion/deposition for the western Arctic seas of Russia during the several periods of the Holocene (Termination 1b, Middle Holocene climate optimum, Subatlantic climate optimum, Little Holocene ice age of 16-19th centuries).

3. To qualitatively estimate changes in sedimentary input from coastal erosion/deposition in the area during the past century.

4. To correlate sea-level and sedimentary input changes from coastal

erosion/deposition in order to elaborate the principles of prediction of sedimentary input changes from those processes under the anticipating sea-level changes.

Material:

- existing Holocene sediment sections from the coastal areas of the Pechora Sea, BarentsSea and White Sea;

- additional sediment sections obtained during the field studies in key areas on the coasts of the White Sea and Pechora Sea;

- existing drilling cores in coastal stretches of the area under study;

- air photographs and medium-scaled topographic maps of coastal areasdated from various years of the present century;

- sailing directions, bathymetric maps and other sources of information on coastal changes during the present century.

Methods:

- lithofacial analysis of geological data;

- grain-size analysis;

- diatom analysis;

- 14C dating;

- stereophotogrammetric method;

- method of representation of spatial images of coastal changes from the inadequate information (elaborated by the Geography Department, Lomonosov Moscow State University).

Results from previous studies

1.Curves of Holocene (10 - 0 Ka) sea-level changes for several coastal stretches of the Pechora Sea, Barentz Sea and White Sea with a time resolution of 500 years.

2.Maps of coastal retreat/advance rates in the whole area for various periods of the Holocene.

3.Qualitative estimates of sedimentary input from coastalerosion/deposition for all Russian Arctic seas with a time resolution of 1 Ka.

4.Curves of sedimentary input from coastal processes during the last decades with a time resolution of 10 years.

5.Scenarios of possible changes in sedimentary input from coastal processes under the variety of anticipating global and regional environmental changes.

Timing of the project (beginning/end):
09/1998 - 08/2000

Cooperation with other institutions:
- GEOMAR, Kiel
- Alfred-Wegener-Institute for Polar and Marine Research, Bremerhaven
- Russian Foundation for Basic Research
- St.Petersburg University of Ways of Communication

Title

Palaeohydrology and landscape evolution in the Russian Plain during the last 18000 years.

Investigator(s):

Sidorchuk, Aleksey,(PI)
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Panin, Andrey
Chernov, Aleksey
(Contact: A.Sidorchuk, email sidor@yas.geogr.msu.su)

Objectives

1. Investigations of river channel metamorphosis in the basins of Northern Dvina, Don and Dnieper Rivers due to climatic and hydrological changes during the Holocene and Late Glacial.
2. Reconstruction of the main stages of channel evolution in the Late Pleistocene and Holocene. Dating of these stages with relative and absolute geochronology.
3. Reconstruction of the paleolandscapes of the basins of Northern Dvina, Donand Dnieper for these stages with paleobotanical analyses.
4. Calculation of paleodischarges of the Rivers of Northern Dvina, Don and Dnieper basins from paleochannel morphology and by analogy of the hydrological parameters of present-day rivers.

Materials

1. Space photoes of 1:200000 scale
2. Geological maps .
3. Geological information from existing cores (not available for all key sites).
4. Shallow coring in the paleochannels.

Methods

-14C and TL dating
- Grain size measurements
- pollen analysis
- hydraulic and hydro-morphological calculations

Selected results from the works of 1997

The methodological and informatic basis of the project has been developed. The method of the paleohydrological reconstructions was supplied with the procedure of paleodischarges calculation by 2D hydraulical model and with regime equations for channel width and meander length. An electronic maps collection was created for the ranges of the modern plants, the hydrological data base was compiled, and a system of programmes for PC to calculate paleohydrological parameters was developed.
The field work in the lower Vychegda and Viled' valleys has been conducted. 15 boreholes were cored within the Vychegda paleochannels, 274 sediment samples were collected for the granulometrical analysis, 230 samples for pollen analysis, 62 samples for radiocarbon dating and 1 sample for the TL dating. 31 14C dates were obtained. Field interpretation of the aerophotoes has been done

and the geomorphological map was compiled for the lower 40 km section of the Vychegda River valley (scale 1:25000).

During the maximum stage of the Last Glacial the valley of the Northern Dvina and Vychegda Rivers was dammed by the ice. Fine lacustrine aleurites with the age 34,200 years BP (KI-6410) found at the lower 40 km of the. Vychegda River valley mark this stage. The lacustrine sediments are overlain by fine sands, which form a high Late Glacial alluvial- deltaic terrace of the dammed Vychegda River. After the ice retreat about 12,000-13,000 years ago the river incised into alluvial-deltaic deposits. Up to 12 steps of erosional - accumulative terraces and three main systems of paleochannels can be identified. The old meandering - braided paleochannel is mainly situated at the altitudes 12-14 m above the low water level, its width is 1,100 m and meander length is 7,000 m. The channel was abandoned due to river incision about 9,000- 10,000 years ago (according to radiocarbon dates MSU-1454, KI-6404, 6405, 6406, 6407). The second system of meandering paleochannels is situated at the altitudes 9-11 m above the low water level, its width is 500 m and meander length is 3500 m. The channel was abandoned due to river incision about 6000 years ago (KI-6408). The lowest system of meandering paleochannels is situated at the altitudes up to 7 m above the low water level within the river floodplain, its width is 700 m and meander length is 4,500 m. The omega-shaped meanders of this channel were developed during the period 4,500 - 2,500 years ago (KI-6401, 6402, 6409, 6393, 6394). After 2,000 years ago the most curved meanders were cut off, and the modern-type sinuous channel, 800 m wide with meander length 6,000 m was formed.
The paleohydrology of the Vychegda River for the last 34,000 years was reconstructed from the grain size of channel deposits, paleochannel morphology and paleolandscape features. The river flow reached its maximum 9,000 - 12,000 years ago, when mean annual discharge was 1,300 m3/s. The major part of the flow (75%) passed within the spring flood. According to the calculations for such a flow annual precipitation not less than 400 mm is necessary, including 270 mm of winter precipitation. In the Holocene, 7,000 - 8,000 years ago, the river flow reached its minimum (mean annual discharge was only 570 m3/s) due to the annual precipitation decline till 350 mm (only 110 mm for the winter). During the time interval 2,500 - 4,500 years ago the mean annual discharge increased to 960 m3/s when annual precipitation was 580 mm (180 mm during the winter). The stage of the humidity increase lasts till recent time: the present day precipitation is 700 mm (230 mm for the winter) and mean annual discharge is 1,160 m3/s.

Timing of the project (beginning/end):
03/1997 - 12/1999

Cooperation with other institutions:
Institute of Geography, Russian Academy of Science
Kazan University
Voronezh Agricultural University
Ukranian State Center of Radioecology
The Nordic Laboratory for Luminescence Dating, Aarhus University, Denmark

Title:
Terrigenous sediment and particulate organic carbon fluxes in the Kara Sea: Sources, pathways, and sinks

(Subproject of the Russian-German Project "The nature of continental run-off from the Siberian rivers and its behavior in the adjacent Arctic basins" coordinated by Dieter K. Fütterer, AWI Bremerhaven, and Eric Galimov, Vernadsky Institute Moscow)

Institution:
Alfred-Wegener-Institute for Polar and Marine Research, Columbusstrasse,
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Investigators:
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Hefter, Jens
Matthiessen, Jens
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Objectives:

Stratigraphical investigations
As basis for all further reconstructions of paleoenvironmental changes, a high-resolution stratigraphic framework has to be established for the Kara Sea continental margin and deep-sea areas. This work will include absolute AMS ^{14}C age dating, oxygen and carbon stable isotopes, natural radionuclides, amino acids, microfossils, magnetic susceptibility, and the correlation to other existing (dated) Arctic Ocean records.

Terrigenous sediment input and shelf-to-basin transport
The large amounts of suspension transported by the major Arctic rivers onto the Kara Sea shelf and further transported by different mechanisms onto the open ocean, may contribute in major proportions to the entire Arctic Ocean sedimentary and chemical budgets.

Investigations of terrigenous matter input will include

** the quantification (i.e., calculation of flux rates) and characterization (mineralogy, grain size) of riverine components on transects from the river mouth to the shelf-slope-deepsea environment;
** estimates of the importance of riverine input for the Arctic Ocean sedimentary and chemical budget;
** redeposition processes of riverine material by sea ice, oceanic currents, turbidity currents, and debris flows.

Determinations of mineral assemblages (bulk, clay, and heavy mineralogy) and geochemical tracer (e.g., Sr-isotopes) in combination with continuous down-core logging of magnetic susceptibility, gamma-ray absorbtion and p-wave velocity of whole cores will allow to quantify and characterize the terrigenous (fluvial) sediment input and its change through time.

High-resolution acoustics (PARASOUND, CHIRP) survey will allow

** to give information from sub-bottom reflectors for the selection of sediment sampling sites,
** to provide a two- or even three-dimensional stratigraphic framework for lateral linking of sediment cores based on sub-bottom refection pattern and calculation of sediment budgets, and,
** to characterize shelf, slope and deep-sea facies with respect to fluvial sediment input and their changes between glacial and interglacial stages.

Organic-carbon flux: Sources, pathways, and sinks

Main emphasis will be laid on

** the quantification of the marine and terrigenous organic carbon flux (accumulation rates) in the Kara Sea shelf, slope and adjacent deep-sea environments;
** its spatial and temporal change and its relationship to changes in sea ice distribution, river run-off and paleoclimate;
** the role of the Eurasian continental margin areas in the global carbon budget.

A major attempt will be made to distinguish between the different factors controlling organic carbon deposition (high productivity caused by fluvial nutrient supply; ice-edge blooms; fluvial supply of terrigenous material), using specific biomarker. Biomarkers such as long-chain n-alkanes and wax esters, are important indicators for terrigenous input. Phytoplankton-specific biomolecules (such as alkenones, fatty acids, dinosterol, etc.), on the other hand, will be used to optain more detailed informations on surface-water productivity and its importance for the carbon budget.

In addition to geochemical parameters, micropaleontological parameters will be used. Palynology is a useful tool for showing changes in marine plankton activity (e.g., dinoflagellate cysts) and influx of particulate terrigenous (riverine) carbon (e.g., freshwater algae, pollen, spores).

Material:
Long and short sediment cores from transects from the Ob/Yenesei estuaries across the shelf to the slope and adjacent deep sea off the Kara Sea

Methods:
- AMS 14C datings
- oxygen and carbon stable isotopes of foraminifers
- bulk, light, heavy, and clay mineralogy (XRD, microscopy)
- inorganic geochemistry (major and minor elements)
- organic geochemistry (elemental analysis, Rock-Eval pyrolysis, gas

chromatography, gas chromatography/mass spectrometry, stable carbon isotopes of specific biomarkers, maceral analysis)
- micropaleontology (palynomorphs, diatoms
- core logging (physical properties, magnetic susceptibility)
- evaluation of Parasound records

Selected results from previous studies:
Terrigenous sediment supply

The composition of the terrigenous sediment fraction in the Central Arctic Ocean and the Eurasian shelf areas (clay minerals, heavy minerals) allow to identify source areas and transport pathways of the terrigenous material in the Arctic Ocean. Main clay minerals in Arctic Ocean sediments are illite and chlorite. Smectite and kaolinite occur in minor amounts in Central Arctic sediments, but show strong variations in the different shelf areas. Therefore, these two minerals are the most reliable for reconstructions of source areas of Central Arctic sediments. The Kara Sea and the western part of the Laptev Sea are enriched in smectite with highest values up to 70% in the delta zone of the Ob and Yenisei rivers. Illite is the dominant clay mineral in nearly all investigated sediments, except for parts of the Kara Sea. Highest concentrations with more than 70% illite occur in the East Siberian Sea and around Svalbard. Chlorite represents the clay mineral with lowest concentration changes in the Eastern Arctic, ranging between 10 and 25%. The main source area for kaolinite in the Eurasian Arctic are Mesozoic sedimentary rocks on Franz-Josef-Land islands. Based on clay-mineral data, transport of clay fraction via sea ice is only of minor importance for the modern sedimentary budget in the Arctic basins.

Different heavy-mineral assemblages are also caused by different source areas. The western part of the Laptev Sea is dominated by high amounts of clinopyroxene which are interpreted as erosion products of Severnaya Zemlya and of the sheet basalt complexes of the Taymyr peninsula, transported by the river Khatanga. Transport vehicel of particels in the area of Severnaya Zemlya are icebergs whereas on the shelf sea ice is controlling the sediment transport into the Arctic Ocean. The eastern part of the Laptev Sea is characterized by amphiboles that are delivered by the rivers Lena and Yana from the Siberian hinterland. An additional source could be erosion products from the New Siberian Islands.

For further details on the results of sedimentological/mineralogical studies dealing with the terrigenous sediment supply in the Arctic see:

Behrends, M., Hoops, E., and Peregovich, B., 1998. Distribution patterns of heavy minerals in the Arctic Ocean: An approach to identify sources, transport, and pathways of terrigenous matter. Lect. Notes in earth Sciences, Springer Verlag Heidelberg, in press.

Stein, R. and Korolev, S., 1994. Shelf-to-basin sediment transport in the eastern Arctic Ocean. Berichte zur Polarforschung, 144: 87-100.

Stein, R., Ivanov, G., Levitan, M., and Fahl, K. (Eds.), 1996.Surface-sediment com-position and sedimentary processes in the central Arctic Ocean and adjacent Eurasian continental margin, Berichte zur Polarforschung, 212, 324 pp.

Spielhagen, R.F., Bonani, G., Eisenhauer, A., Frank, M., Frederichs, T., Kassens, H., Kubik, P.W., Mangini, A., Nörgaard-Pedersen, N.,

Nowaczyk, N.R., Schäper, S., Stein, R., Thiede, J., Tiedemann, R., and Wahsner, M., 1997. Arctic Ocean evidence for Late Quaternary initiation of northern Eurasian ice sheets. Geology, 25: 783-786.
Wahsner, M., Müller, C., Stein, R., Ivanov, G., Levitan, M., Shelekova, E., and Tarasov, G., 1998. Clay mineral distributions in surface sediments from the Central Arctic Ocean and the Eurasian continental margin as indicator for source areas and transport pathways: A synthesis. Boreas, subm.

Composition and flux of organic carbon

In order to understand the processes controlling organic carbon deposition (i.e., primary productivity vs. terrigenous supply) and their paleoceanographic significance, surface sediments and sediment cores from the Laptev Sea continental margin and adjeacent deep sea were investigated for their content and composition of organic carbon. The characterization of organic matter includes the determination of bulk parameters (hydrogen index values and C/N ratios) and the analysis of specific biomarkers (*n*-alkanes, fatty acids, alkenones, and pigments). At the Laptev Sea continental margin mean accumulation rates of organic carbon may reach high values up to about 0.3 gC cm^{-2} ky^{-1} during Holocene times. Maximum accumulation of 10-15 gC cm^{-2} ky^{-1} were recorded on the shelf between about 9,000 and 10,000 Calender Years BP, i.e., during times when the shelf seas became widely flooded at the end of the post-glacial sea-level rise, probably resulting in enhanced sea-floor/coastal erosion and/or increased Siberian river discharge. The organic matter is predominantly of terrigenous origin, however, minor but significant amounts of marine organic matter is preserved in the sediments too.

For further details on the results of the performed organic-geochemical studies in the Laptev Sea continental margin area see:

Fahl, K. and Stein, R., 1997. Modern organic-carbon-deposition in the Laptev Sea and the adjacent continental slope: Surface-water productivity vs. terrigenous input. Org. Geochem., 26: 379-390.
Fahl, K. and Stein, R., 1998. Biomarkers as organic-carbon-source and environmental indicators in the Late Quaternary Arctic Ocean: Problems and perspectives. Mar. Chem., subm.
Stein, R., 1996. Organic carbon and carbonate distribution in surface sediments from the eastern central Arctic Ocean and the Eurasian continental margin: Sources and pathways. In: Stein, R., Ivanov, G., Levitan, M, and Fahl, K. (Eds.), Surface-sediment composition and sedimentary processes in the central Arctic Ocean and adjacent Eurasian continental margin, Berichte zur Polarforschung, 212, 243-266.
Stein, R. and Fahl, K., 1998. Holocene Accumulation of Organic Carbon along the Eurasian Continental Margin (Arctic Ocean) and its Paleoenvironmental Significance. Geology, subm.
Stein, R., Fahl, K., Niessen, F., and Siebold, M., 1998. Late Quaternary Organic Carbon and Biomarker Records from the Laptev Sea Continental Margin: Implications for organic carbon flux and composition. Lecture Notes in Earth Sciences, Springer Verlag, in press.

Timing of the project:
07/1997 - 07/2001

Cooperation:
GEOMAR Kiel
Heidelberg University
Göttingen University
Shirshov Institute Moscow
VNIIOkeangeologia St. Petersburg
MMBI Murmansk

Title :
Modeling the Sediment Discharge of Large Arctic Rivers (Ob', Yenisei, Lena, Indigirka, Yana, Kolyma, Mackenzie) under Past, Modern and Predicted Cimates

Institution:
Institute of Arctic and Alpine Research, University of Colorado, Boulder, CO, USA 80309-0450
State Hydrological Institite, St. Petersburg, Russia

Investigators:
Syvitski, James (PI)
Meade, Robert H.
Bobrovitskaya, Nelya N.
Zubkova, Claudiya
Kokorev, Alexander
Yakovleva, Tatyana

Objectives:
Quantitatively evaluate the sediment load delivered to the mouths of the world's largest Arctic rivers, the Ob', Yenisei, Lena, Indigirka, Yana, Kolyma, Mackenzie, based on data of hydrological observations of water and sediment discharge and verify numerical models design to provide a direct response to climate variability.

Specific objectives include:
* Digitize daily data of Q, Cs, Qs, Y with full quality assessment and assurance for 15 selected gauging stations;
* Estimate errors and correct data across all periods of study;
* Make hydrological analysis of Q, Cs, Qs, Y through periods of historical climate change and periods of anthropogenic perturbation;
* Compare methods used in Russia and in North America for determining the daily record of Q, Cs, Qs, Y parameters;
* Make analyses and comparisons between theoretical approaches, methods, empirical formulae being used in USA and Russia;
* Develop hydrological model for determining sediment concentration and load for large Siberian rivers;
* Apply newly developed approaches to study the regime and properties of ungauged Arctic rivers

Material:
Gauging records, numerical models

Methods:
* Method of daily sediment discharge calculation
* Calculation of daily Cs for every cross-section and gauging station with correlation between measured data in one permanent cross-section station with other stations;
* Determination of Qs from direct measurements and as the function of Q, with extrapolation of the rating curve for extreme values of Q.
* Estimation of data reliability and accuracy using established statistical methods developed both in Russia and in North America;

* Connection between landscape characteristics and hydrological parameters (Q, Cs, Qs and Y) using the geographical (GIS) method;
* Calculation of the river's transporting capabilities using the hydrodynamic method to establish the connection between Q and Qs, and Q and Y;
* Application of the morphological method to estimate key hydrological parameters for input to the climatic-hydrologic model;
* Prediction of rating coefficients for Arctic rivers;
* Application of the above methods to provide estimates of Q, Cs, Qs and Y in ungauged river basins in the Arctic, including the effects of geographical conditions (climate, geology, relief, vegetation, etc.) and anthropogenic impact (deforestation, mining, river damming, etc.).

Selected Results from Previous Projects:
A new phase of Russian hydrological studies was started in 1994 when a joint team of American (USGS) and Russian (LSE/SHI) scientists studied the hydrological regime of the Ob' and Yenisei rivers. A database with monthly characteristics (Q, Cs, Qs, granulometry and water chemistry) was created for the period of 1960 - 1988. Field measurements were carried out on the Ob' river during which the new field data were evaluated (quality assessment, quality control) using both American and Russian hydrological techniques. Agreement and or methods of comparison were established between the methodologies used by the two teams on the following parameters (water discharge, sediment concentration and granulometric data). Differences between the two federal agencies included sampling approaches for the main water properties (Q, Cs, Qs, Y), standard laboratory methods, data extrapolation techniques, and numerical modeling approaches.

Timing of Project:
Aug. 1, 1998 to Dec. 31, 2001

Cooperation with other institutes:
Moscow State University
USGS

Title:
Palaeoclimatic variability in the Arctic - Causes and impact

Institution:
GEOMAR Research Center for Marine Geosciences
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email: rspielhagen@geomar.de)

Objectives

1. High-resolution reconstruction of Late Quaternary paleo-river run-off from the Laptev Sea hinterland, its correlation with the terrestrial paleoclimatic history, and its impact on ice formation and water masses in the Arctic Ocean.
2. Reconstruction changes in water mass parameters (temperature, salinity, stratification) and density and composition of the Arctic Ocean ice cover.
3. Reconstruction of the variability of circum-Arctic ice sheets during the Pleistocene.
4. Implementation of results into paleoclimatic models.

Materials

Long and short sediment cores from
- the Laptev Sea continental margin and the adjacent Eastern Arctic Ocean
- the central Arctic Ocean
- Fram Strait and the Yermak and Morris Jesup plateaus

Methods

- AMS 14C dating, oxygen isotope stratigraphy, radio-isotope stratigraphy
- Stable carbon and oxygen isotope maeasurements of planktic and benthic foraminifers
- Grain size measurements
- Lithology of ice-rafted debris
- Coarse fraction composition

Selected results from previous project (abstract)

To determine the freshwater export from the Lena River across the Laptev Sea to the Arctic Ocean, the 8 m long sediment core PS2458 from the eastern Laptev Sea continental margin has been analyzed for the stable isotope records of planktic foraminifers. The core site is situated just off the river mouth during the time of glacial lowered sea level. Foraminifers are very rare in the fine-grained, mostly terrigenous sediments and stratigraphy is based on ^{14}C-AMS datings on small bivalves. Closely spaced, they allow a detailed reconstruction of paleo-environmental changes. Apparently, sedimentation rates were extremely high during the last deglaciation and in youngest times (last 200 yr). While the stable carbon isotope record of PS2458 shows a trend from low values (-0.4‰ vs. PDB) to moderate high values (0.7‰) throughout the core, the oxygen isotope ($d^{18}O$) record of *Neogloboquadrina pachyderma* (sin.) shows a strong variability in planktic $d^{18}O$ during the last deglaciation, which reflects more than only global changes in ice volume. A significant influence of temperatures is not likely, since summer surface water temperatures were probably not much different from the present (-0.5°C). Thus much of the $d^{18}O$ variability in PS2458 must be ascribed to changes in the freshwater output from the Lena River into the Arctic Ocean. According the data, freshwater output was approximately similar to present during the Middle Holocene (~8-9 cal-ka) and the Preboreal period (11-12 cal-ka), and somewhat lower during the cool Boreal period. In the Bølling/Allerød (~14.5-13 cal-ka), freshwater output was probably higher than at present. A short-term event (<500 yr) of maximum outflow occurred at 13.0 cal-ka, just before the onset of the cold Younger Dryas period.

Timing of the project (beginning/end):
03/1998 - 02/2000

Cooperation with other institutions:
- Alfred-Wegener-Institute, Bremerhaven
- Geological Institute, Kiel University
- Department of Geosciences, Bremen University
- P.P. Shirshov Institute of Oceanology, Moscow
- VNIIOkeangeologiya, St. Petersburg
- Institute of Oceanography, Goeteborg University
- Heidelberg Academy of Sciences

Title:
Russian-German Cooperation: Laptev Sea System 2000

Scientific Coordination:
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Objectives:
The multidisciplinary research project 'System Laptev Sea 2000' was launched by Russia and Germany to study the environment of Siberian Arctic and its present and past role in global climate. The overall research objectives of the program can be summarized as follows:
• Seasonal changes in permafrost:
- Sources and sinks of greenhouse gases.
- Microbial communities and carbon flux.
• Effects of environmental changes:
- Biogeochemical dynamics: processes and interactions.
- Atmospheric input of natural tracers.
- Response of Arctic marine ecosystems.
• Terrestrial/marine interactions in coastal zones:
- Environmental and depositional history of the Lena Delta.
- Particle transport in a delta system
• Climatic trends in the central Siberian Arctic - causes and impacts:
- Subsea permafrost: feedbacks and evolution.
- Short (past 100 years) and long term (past 5 million years) environmental changes.

Materials:
- Meteorological data.
- Aerosol samples
- Hydographic data.
- Microbiological and gas samples from permafrost soils.

- Sediment and ice samples from late Pleistocene permafrost sequences.
- Suspended matter samples from sea and river water.
- Plancton and Benthos samples.
- Long and short sediment cores from the Laptev Sea Shelf.
- Geophysical data.

Methods:

- AMS measurements of ^{10}Be in aerosols.
- Gas Chromatography (CH_4 and CO_2 from soils).
- Micobiological characterization of soil microbes.
- Primary production (^{14}C) and in-situ respiration measurements of marine organisms.
- All-year observation of the hydrographic regime by means of two automatic ADCP/CTD bottom mounts
- Measurements of the concentration of suspended matter by means of optical backscatter.
- Voltammetric analysis of dissolved trace elements (concentration / chemical speciation).
- Micropalaeonological and sedimentological investigations.
- Geochemical analysis of sediments (ICP-OES, GF-AAS, CNS-analyzer).
- AMS ^{14}C datings and stable isotope measurements ($d^{18}0$, dD, $d^{13}C$).
- Optical Stimulated Luminiescence (OSL) datings.
- Seismic investigations of the seafloor (Parasound 4 kHz & Geochirp 1-11 kHz).
- Numerical modelling of permafrost, the hydrographic system and biogeochemical cycles.

Selected results from previous project:

The Arctic, in particular the large Siberian sector comprise some of the most sensitive elements of the global environment, which are considered to respond rapidly to global climate change. Various records and processes are presently studied and monitored to decipher the mechanisms which controlled past climate variations as well as ongoing environmental changes. Climate models and paleoclimatic reconstructions indicate that differences in, e.g., size of continental ice caps and in sea-ice distribution influence the global ocean circulation. However, our knowledge of the climate system in the Arctic is until now very limited making it difficult to predict possible global environmental changes.

The Siberian hinterland of the Laptev Sea is of particular interest, because it is (i) an important fresh water source for the Arctic Ocean, and (ii) large amounts of sea ice are formed on the Laptev Sea shelf, thus providing an important link to the earth's global climate system. A detailed evaluation of marine and terrestrial paleoclimate records from this region offer important information for the better understanding of the causes, impacts, and feedback mechanisms which determine the Arctic climate system today.

In 1994 the multidisciplinary research project 'Laptev Sea System' was launched by Russia and Germany to study the environment of Siberian Arctic and its present and past role in global climate. These bilateral research activities included land and marine expeditions to the Laptev

Sea area during different seasons of the year as well as to the Siberian hinterland and the Taymyr Peninsula.
In general our investigations have shown that Lena River run-off is controlling the environmental system and the depositional regime of the Laptev Sea. During summer river water spreads over the Laptev Sea as a low-salinity surface layer carrying much of the river's suspended load. During the period of ice formation the low-salinity surface layer is controlling the fast-ice edge and consequently the position of the Laptev Sea Polynya. The most changeable time of the year is during spring river break-up, when the interaction between the Lena river and the Laptev Sea is most dynamic. The sudden influx of the relatively warm riverine freshwater and high amounts of dissolved and particulate matter into the cold marine ice covered Laptev Sea results in drastic environmental changes. This short season (less than a month) seems to be also of great importance for the formation of dirty sea ice.
Short-term climate fluctuations, such as changes of the intensity in river run-off, as they are observed during the last years, may also reflect those depositional changes documented in sedimentary records of the eastern Laptev Sea for most of the Holocene. This variability not only influence the Arctic environment alone, but through the Transpolar Drift directly affects the global climate.

Timing of the project:
01/1998 - 06/2001

Cooperation Partners in Germany and Russia :
- Alfred-Wegener-Institute for Polar and Marine Research, Bremerhaven.
- Alfred-Wegener-Institute for Polar and Marine Research, Potsdam.
- All-Russia Research Institute for Geology and Mineral Resources of the World Ocean, St. Petersburg.
- Freiberg University of Mining and Technology, Freiberg.
- Geomar Research Center for Marine Geosciences, Kiel.
- Institute for Polar Ecology, Kiel University, Kiel.
- Institute for Soil Science, Hamburg University, Hamburg.
- Institute of Environmental Physics HeidelbergUniversity, Heidelberg
- Institute of Oceanology of the Russian Academy of Sciences, Moscow
- Institute of Soil Science and Photosynthesis of the Russian Academy of Sciences, Pushchino.
- Komarov Botanical Institute, St. Petersburg.
- Krylov Shipbuilding Research Institute, St. Petersburg.
- Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research, Kiel University, Kiel
- Lena Delta Reserve, Tiksi.
- Lomonosov University, Moscow.
- Permafrost Institute, Yakutsk.
- St. Petersburg State University of Means of Commuication, St. Peterburg.
- State Research Center - Arctic and Antarctic Research Institute, St. Petersburg.
- University of Fairbanks, Fairbanks
- Zoological Institute of the Russian Academy of Sciences, St. Petersburg.

Title:
Biodiversity and fluxes in glacial arctic fjords (BIODAFF)

Institutions:
Institute of Oceanology, Sopot, Poland
Norsk Polarinstitutt, Tromso, Norway

Investigators:
Falk Petersen , Stig
Weslawaki, Jan-Marcin
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Objectives:
1) To provide analytical interpretation of the influence of freshwater glacial discharge effects on the biodiversity and productivity of coastal Arctic ecosystem
2) To provide descriptive and statistical models of the influence of physical disturbance (in particular freshwater and sediment discharge) on faunal uccession and diversity
3) To analyse the impact of physical disturbance on lipid and energy flows through food webs in glacial fjords

Material:
Interdisciplinary oceanographic- ecological surveys in Kongsfjorden, along the physical gradients. Cruises of research vessels r/v "Oceania" 1995,1996, 1997, 1998, and r/v "Lance" and "Jan Mayen" in 1997 and 1998.

Methods
Standard oceanographic methodology employed for hydrography, hydroacoustics, sedimentology, plankton, benthos, higher trophic levels studies

Selected results from the first phase of the project:
Glaciers in Kongsfjorden (Spitsbergen, 79 o N) were found to discharge close to 1km3 of freshwater annually, with large load of fine mineral particles. Most of the mineral material sinks within the fjord, sedimentation ranges 1000g dw/m2/day. Fjord circulation creates hydrographic trap which keeps large concentrations of plankton (mainly euphausiids) in the innermost fjord basin. Benthic fauna counts more than 400 species, some of them of high biomass and productivity. Pelago- benthic coupling is apparently important process within the fjord.

Cooperation with other institutions:
AKVAPLAN NIVA, Tromso, Norway
SEAS LAboratory, Oban, UK
Plymouth Marine Laboratory, Plymouth , UK
University of Stirling, Stirling, UK
Alfred Wegener Institute of Polar Research, Bremerhaven, Germany
Institute for Polar Ecology, Kiel, Germany

7. List of participants of the APARD-1 and APARD-2 Workshops

APARD-1 Workshop
Alfred-Wegener-Institute for Polar and Marine Research (AWI)
Bremerhaven, Germany, October 20-22, 1996

List of participants

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APARD-2 Workshop
Institute for Arctic and Alpine Research (INSTAAR)
Boulder, Colorado, USA, November 09-12, 1997

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