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Sources and Pathways of Organic Carbon in the Modern Laptev Sea (Arctic Ocean): Implications from Biological, Geochemical and Geological Data

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THEME 11: Cenozoic Sedimentary Archives of the Eurasian Marginal Seas: Sampling, Coring and Drilling Programmes

Summary: During the past six years organic geochemical, micropaleontological, and sedimentological investigations were carried out within the framework of the multidisciplinary bilateral German-Russian research project „System Laptev Sea" and detailed biological investigations within the project „German-Russian Investigations of the Marginal Seas of the Eurasian Arctic". In order to understand the Laptev Sea ecosystem and to obtain information about sources and fate of organic carbon, the distribution of phyto- and zooplankton, diatoms, chlorophyll *a* benthic macrofauna, palynomorphs, grain size, total organic carbon, ∂13Corg and biomarkers (*n*-alkanes, fatty acids) were determined. In general, the influence of the major rivers draining into the Laptev Sea, is reflected in the water column as well as in the surface sediments. In both habitats three ecological provinces can be distinguished, i.e., the southeastern Laptev Sea, the central Laptev Sea, and the northern Laptev Sea. Additionally, clear differences between the western and the eastern Laptev Sea occur. The comparison of the different data sets of the water column and the surface sediments provide information about organic carbon sources and pathways in the Laptev Sea shelf and continental slope area.

INTRODUCTION

Concerning the response of the Arctic region to environmental changes and its impact on the global climate system, the Laptev Sea area is of particular interest. Riverine freshwater discharge into the Laptev Sea plays a key role in controlling the temperature and salinity structure of surface water masses, sea-ice extent, terrigenous sediment (incl. organic carbon) supply, and biological processes in the Arctic as well as intermediate/bottom water formation in the Northern Hemisphere (AAGAARD & CARMACK 1989, STEIN1998, and further references therein). With respect to sea ice, the Laptev Sea shows the highest net ice-production rates in the Arctic Ocean (KASSENS et al. 1999). The winter ice cover of the Laptev Sea is characterized by the occurrence of an approximately 1800 km long, narrow zone of open water (polynyas) on the mid-shelf (DETHLEFF et al. 1993, REIMNITZ et al. 1994). During winter the polynyas are areas of intensive sea-ice formation, salinity increase, convection, and large heat loss into the atmosphere; springtime is characterized by an accumulation of heat and rapid melting of sea ice (ZAKHAROV 1966). The location of the ice margin varies annually (e.g., TIMOKHOV 1994, EICKEN et al. 1995). The high fluvial input causes a brackish surface plume which is extending 350 km northward (LÉTOLLE et al. 1993) and forms a halocline above the intermediate and deeper Arctic water masses with salinities of about 34 to 35 (TIMOKHOV 1994). This causes a strong gradient in salinity of the surface water from the river mouths to the shelf break from 6 to 30 (DMITRENKO et al. 1995). The bottom water is well advected from the north and north-west to the northern part of the shelf, but in the south and south-east, the subhalocline waters experience a clear response to the fluviatile impact at the surface, and particular chemical environments and ecological conditions may develop in the benthic boundary zone. The accumulation of remineralization products such as CO2 was evident from stable isotopes in the dissolved inorganic carbon of the bottom waters (ERLENKEUSER et al. 1995).

During the past years, a bilateral Russian-German research project has been initiated in the Laptev Sea area to study the land-ocean interaction in the Siberian Arctic and its paleoclimatic interrelationships (KASSENS et al. 1999). In order to understand the modern processes controlling the organic-carbon cycle in the Laptev Sea and the biological, organic-geochemical, and sedimentological interrelationships, a multidisciplinary approach has been used. In this study, we present data on the abundance, community structure, and biomass of phytoplankton, zooplankton, and benthos as well as biomarker and micropaleontological tracers determined in surface sediments.

We would like to mention that additional investigations were carried out within the framework of the international program SPASIBA (MARTIN et al. 1993, HEISKANEN & KECK 1996, PEULVÉ et al. 1996, SALIOT et. al. 1996).

The material for this study was collected during several cruises listed in Table 1 and shown in Figure 1. The methods, which were used to obtain the data sets, are summarized in

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Expedition	Year	Vessel	Reference
E.S.A.R.E.*	1992	Helicopter	DETHLEFF et al. (1993)
Transdrift I	1993	RV *Ivan Kirejev*	KASSENS & KARPIY (1994)
ARK-IX/4	1993	RV *Polarstern*	FÜTTERER (1994)
Transdrift II	1994	RV *Prof. Multanovskiy*	KASSENS & DMITRENKO (1995)
Transdrift III	1995	*IB Kapitan Dranitsyn*	KASSENS (1997)
Transdrift IV	1996	Helicopter	KASSENS et al. (upubl.)

Tab. 1: List of the expeditions and relevant cruise reports. * E.S.A.R.E.: East Siberian Arctic Region Expedition

Table 2, including references containing descriptions of the methods applied.

RESULTS

Phyto- and Zooplankton

Based on measurements performed during August/September 1993 (TRANSDRIFT I, for reference see Tab. 1), chlorophyll *a* concentrations in the surface water and at 10 m depth were the highest in the southeastern Laptev Sea. Maximum values of 2.5 µg l^{-1} occurred in the vicinity of the Lena River mouth at the surface and near the Yana River. In general, chlorophyll *a* concentration in the eastern Laptev Sea decreased to the north. Very low concentrations, at some stations not traceable, were found in front of the Olenek River and off Kotelnyy Island.

64 phytoplankton taxa, most of them belonging to diatoms and dinoflagellates, were identified. In the plume of the Lena River pennate diatoms dominated, whereas in the north-east sub-arctic/temperate centric diatoms of the genus *Chaetoceros* and the species *Thalassiosira nordenskioeldii* were most abundant. In the southeast also *Chaetoceros* and the Arctic brackish water species *Thalassiosira baltica* were dominant.

Total phytoplankton biomass ranged from 2.5-200 µgC l^{-1}. The majority of samples rendered biomasses below 40 µgC l^{-1}. Higher biomasses were encountered in surface waters in and around the plumes of the Lena and Yana rivers (Fig.2).

To provide data on the zooplankton standing stock, zooplankton was collected in the shelf region and along the continental slope during the expeditions TRANSDRIFT I and ARK-IX/4 (Tab 1) in August and September 1993. On the shallow Laptev

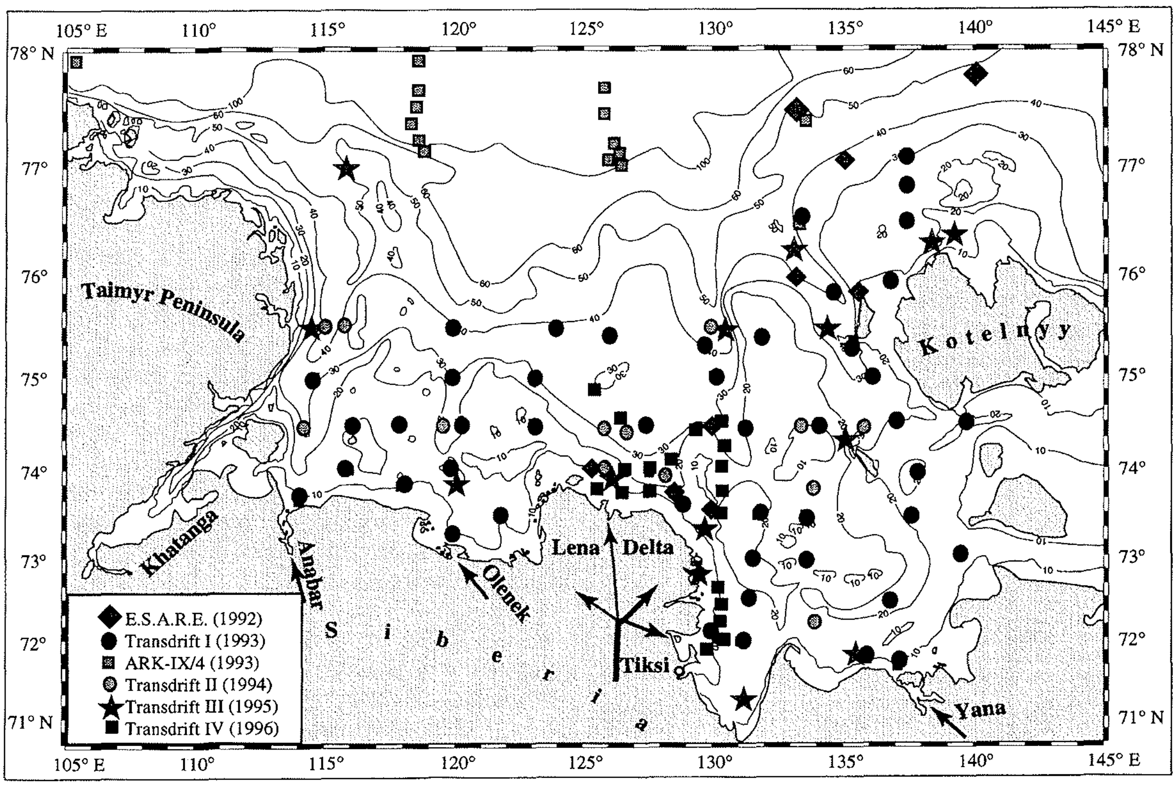

Fig. 1: Positions of samples taken in 1992 during the East Siberian Arctic Region Expedition (E.S.A.R.E, DETHLEFF et al. 1993), in 1993 during the Expedition ARK-IX/4 (FÜTTERER 1994), the expeditions Transdrift I, II, III and IV in 1993, 1994, 1995, and 1996 (KASSENS & KARPIY 1994, KASSENS & DMITRENKO 1995, KASSENS 1997).

	Parameter	Technique	Reference
Biology			
Phytoplankton	chlorophyll *a*	fluorometry	Jeffrey & Humphrey (1975),
	abundances	calculation	Smetacek (1975),
	biomass		Baltic Marine Environment Protection Commission (1989)
	taxa	microscopy	Utermöhl (1931, 1958), see Tuschling (1996)
Zooplankton	biomass*	calculation	Kosobokova et al. (1998)
	taxa	microscopy	Kosobokova et al. (1998)
Benthos	biomass	weighing	Piepenburg & Schmid (1996)
	taxa	microscopy	Piepenburg & Schmid (1996)
Organic Geochemistry			
Bulk Parameter	total organic carbonHeraeus	CHN-analyzer	Stein (1991)
	hydrogen index	Rock Eval Pyrolysis	Stein (1991), Espitalié (1977)
	carbon isotopes	mass spectrometry	Cordt & Erlenkeuser (1994)
Biomarkers	*n*-alkanes	gas chromatography	Fahl & Stein (1997, 1999)
	fatty acids	gas chromatography	Fahl & Stein (1997, 1999)
Micropaleontology			
Diatoms	taxa	microscopy	Cremer (1998a), Battarbee (1973)
Palynomorphs	taxa	microscopy	Kunz-Pirrung (1998)

Tab. 2: Material and methods, which were used to obtain the data (including references containing descriptions of the methods applied). *The total zooplankton biomass in the entire water column (g/m^2) was calculated for the shelf stations, while for the stations in the slope and deep zone the biomass of the upper 0-50 m water layer was used for comparison.

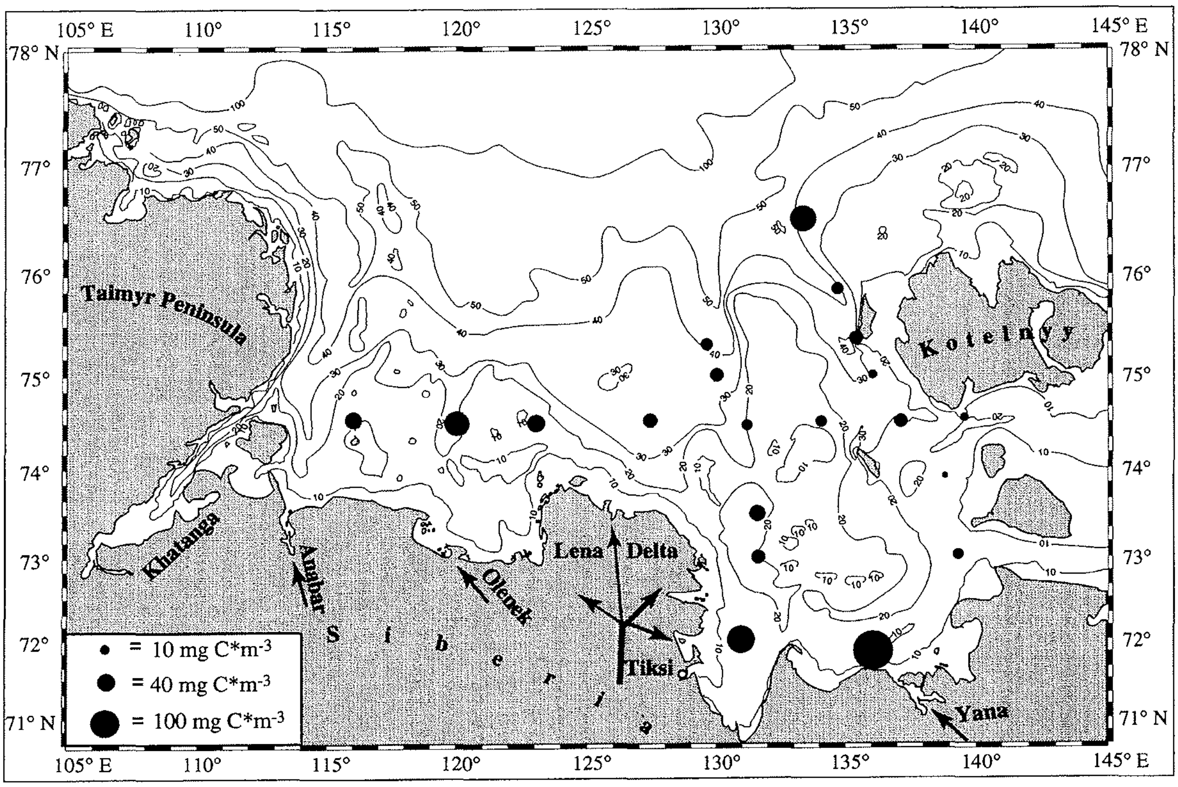

Fig. 2: Distribution of phytoplankton biomass in surface waters of the Laptev Sea during August/September 1993 (TRANSDRIFT I, Tab. 1) (diameters of circles indicate biomass in mg C m^{-3}; for comparison selected biomass data are presented at the lower left hand).

Sea shelf, about 32 zooplankton taxa were found (KOSOBOKOVA et al. 1995, PETRYASHOV et al. 1995). The species composition was dominated by Crustacea, among them 17 Copepoda. Other taxa were Hydrozoa, Appendicularia, Chaetognatha, Gastropoda, Polychaeta and juvenile stages of Echinodermata. In the outer Laptev Sea and continental slope area a more marine neritic community was found with a clear dominance of the large planktonic copepod *Calanus glacialis* (KOSOBOKOVA et al. 1998).

Zooplankton biomass differed considerably between the Laptev Sea areas. In the south-eastern and central Laptev Sea which was strongly influenced by river run-off, a brackish-water neritic zooplankton community dominated. Biomass ranged mostly between 100 and 600 mg dry mass (DM) m^{-2} (Fig. 3) with increasing values near the Lena Delta (1700 mg m^{-2}) and south of Kotelnyy Island (977 and 1591 mg m^{-2}). Highest values were found near the Yana mouth (5710 mg m^{-2}), correlating well with the pronounced high concentration of chlorophyll *a* (Fig. 2). The dominant taxa were the genus *Pseudocalanus* (>20,000 individuals m^{-3}) common for the Arctic marginal seas, and the two brackish water species *Drepanopus bungei* (>28,000 individuals m^{-3}) and *Limnocalanus grimaldii* (105 individuals m^{-3}). These taxa dominated in the eastern part of the Laptev Sea, but in the northeast these abundances were much lower. The biomass maximum of 5195 mg m^{-2} observed at a station in the central Laptev Sea (Fig. 3) was dominated by *Calanus glacialis*, followed by *Calanus finmarchicus* and other copepods.

The western part of the shallow Laptev Sea, influenced by southward directed currents from the open Arctic Ocean and the Kara Sea, hosted a marine neritic community dominated by the genera *Calanus* and *Pseudocalanus*. In this area biomass ranged from 461-2345 mg DM m^{-2} with most values higher than 1000 mg DM m^{-2} (Fig. 3). In the western central part (1634 mg DM m^{-2}) *Pseudocalanus* sp. (150 individuals m^{-3}) and *Calanus* sp. (87 individuals m^{-3}) were most abundant. For the outer Laptev Sea and continental slope area a similar community with a clear dominance of *C. glacialis* of (KOSOBOKOVA et al. 1998) was typical. The highest biomass at the marginal ice zone reached 2400 mg DM m^{-2} in the upper 50 m (Fig. 3).

Benthos

Sampling of benthos was performed during August and September 1993 (TRANSDRIFT I, Tab. 1),

Over the whole shelf, 200 macrobenthic species were found. Macrobenthic biomass was highest in the central western Laptev Sea (150 g wet weight m^{-2}; Tab. 3). Lower values occurred near the mouths of Yana and Lena rivers. Dominant species of the Laptev Sea shelf were brittle stars and isopods of the genus *Saduria*. Other main faunal groups were bivalves, gastropods, polychaetes and amphipods. Ostracods (13 species) were identified in surface sediments all over the central and eastern Laptev Sea (ERLENKEUSER & GRAFENSTEIN 1999). These species generally tolerate varying salinity and, except for *Krithe glacialis*, are adapted to shallow-water conditions. They were also known from Arctic shelf areas west

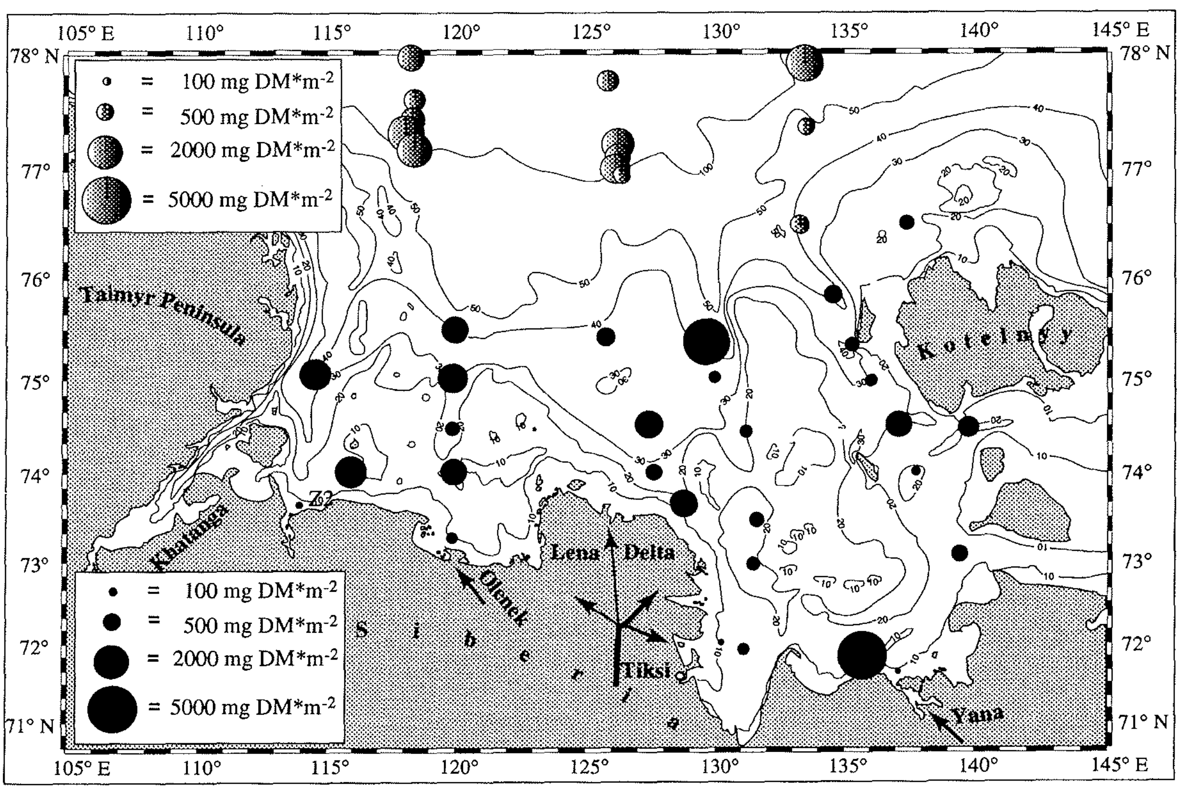

Fig. 3: Distribution of zooplankton biomass in the water column of the Laptev Sea during (black dots; TRANSDRIFT I, Tab. 1, August/ September 1993) and in the upper 50 m of the water column from the adjacent continental margin (grey dots; ARK-IX/4, Tab. 1, August/ September 1993) (in mg dry weight m^{-2}). For further explanation see Fig. 2.

Area	Biomass in g WW m-2
South-eastern Laptev Sea (Yana)	37
South-eastern Laptev Sea (Lena)	40
South-eastern Laptev Sea (Lena)	22
Southern Laptev Sea	60
Southern Laptev Sea	87
Central-western Laptev Sea	150
Central-eastern Laptev Sea	25
Central-eastern Laptev Sea	150
Central-eastern Laptev Sea	80
North-eastern Laptev Sea	38

Tab. 3: Macrobenthic biomass in the Laptev Sea (g wet weight m-2) during TRANSDRIFT I in August / September 1993.

of the Laptev Sea. In the southeastern Laptev Sea isopods of the genus *Saduria* and bivalves of the genus *Portlandia* were dominant. Both taxa were mainly found in brackish waters and were widely distributed. Bivalves (mainly *Leionucula belottii*) and polychaetes also dominated the northeastern Laptev Sea shelf. In the western and central Laptev Sea, the ophiuroid *Ophiura sarsi* and the polychaete *Maldane sarsi* were most abundant.

Organic geochemical and micropaleontological tracers in surface sediments

The distribution of total organic carbon (TOC) in the surface sediments of the Laptev Sea is shown in Figure 4. Generally, maximum TOC values (>2 %) occur in the vicinity of major rivers draining into the Laptev Sea. These maxima correlate well with low hydrogen index values (HI <100 mgHC/gC, FAHL & STEIN 1997). The same is true for the maximum TOC values, which occur at the lowermost part of the continental slope. The organic matter is characterized by light stable carbon isotope values of about -26 ‰ (Fig. 5) in the areas of maximum TOC content (Fig. 4). In general, the carbon isotope signature displays a gradient from $\delta^{13}C_{org}$ = -26.5 ‰ PDB near the coastal margin toward -23 ‰ in the northern outer shelf. The high TOC values gradually decline northward, paralleled by increasing $\delta^{13}C_{org}$ values (Fig. 5), on lateral scales.

Highest concentrations of long-chain n-alkanes ($C_{27}+C_{29}+C_{31}$) occur in areas of maximum TOC contents (Fig. 6) and light $\delta^{13}C$ values, especially off the Lena Delta. The concentration decrease toward the outer shelf and continental slope. Lowest contents were recorded in the deep-sea environment.

The 16:1(n-7) and 20:5(n-3) fatty acid distribution (Fig. 7) suggests the occurrence of marine organic carbon in the sediments, as they are supposed to be derive from phytoplankton, especially from diatoms (e.g., KATES & VOLCANI 1966, FAHL & KATTNER 1993, GILLAN et al. 1981, NICHOLS et al. 1986). Highest concentrations of the 16:1(n-7) and 20:5(n-3) compounds (0.9 mg/g TOC) were determined near the ice edge (EICKEN et al. 1995), where melting processes induce phytoplankton growth.

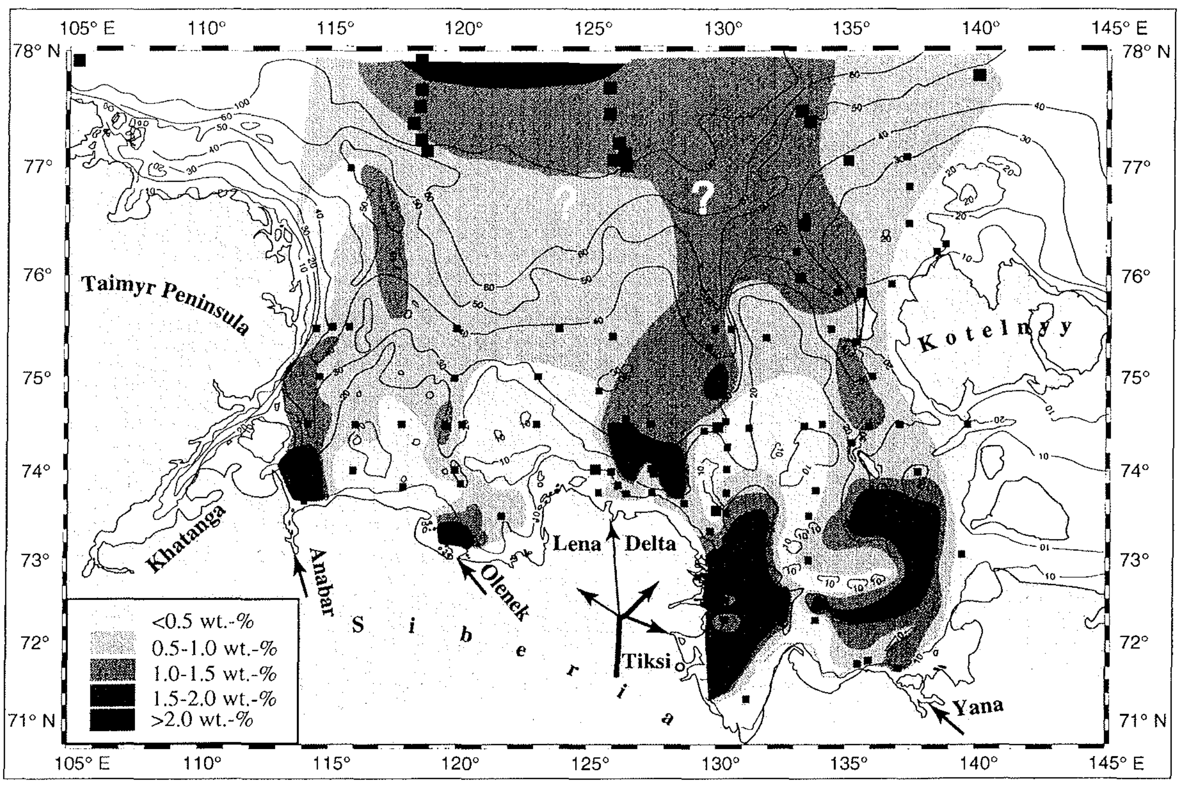

Fig.4: Distribution of the total organic carbon content (% of total carbon) in surface sediments from the Laptev Sea and the adjacent continental margin.

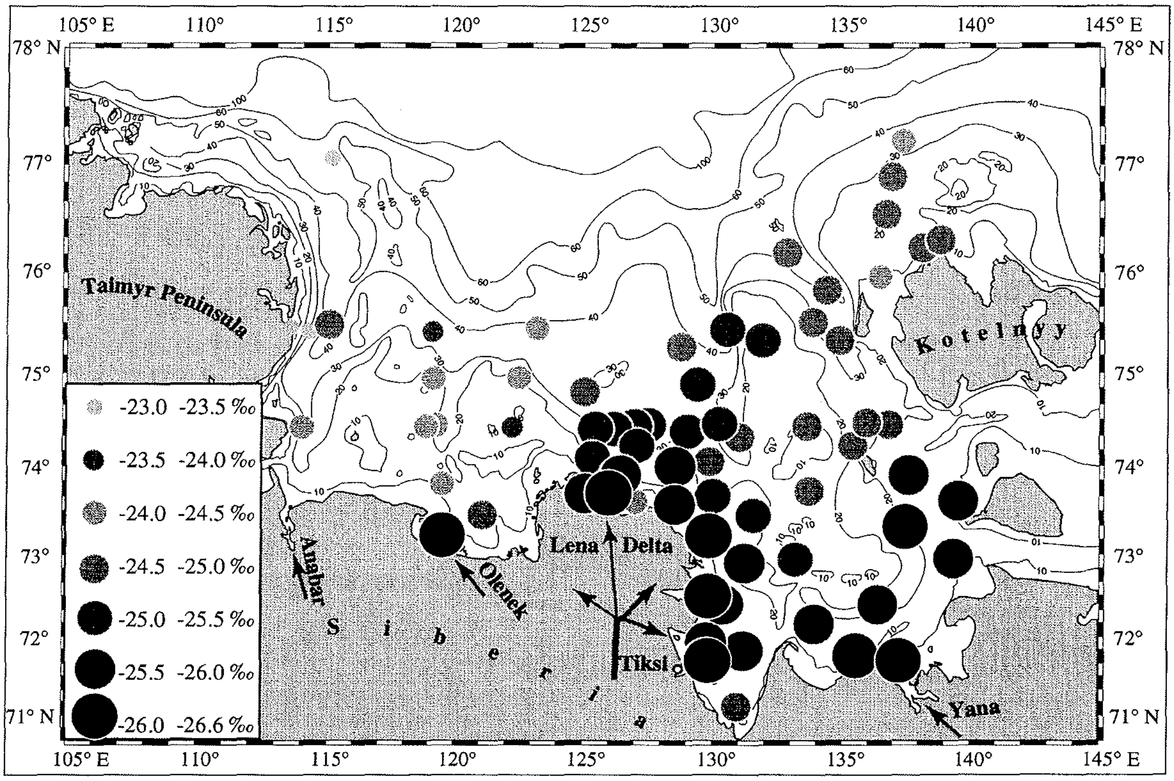

Fig. 5: Distribution of $\delta^{13}C$ in surface sediments from the Laptev Sea.

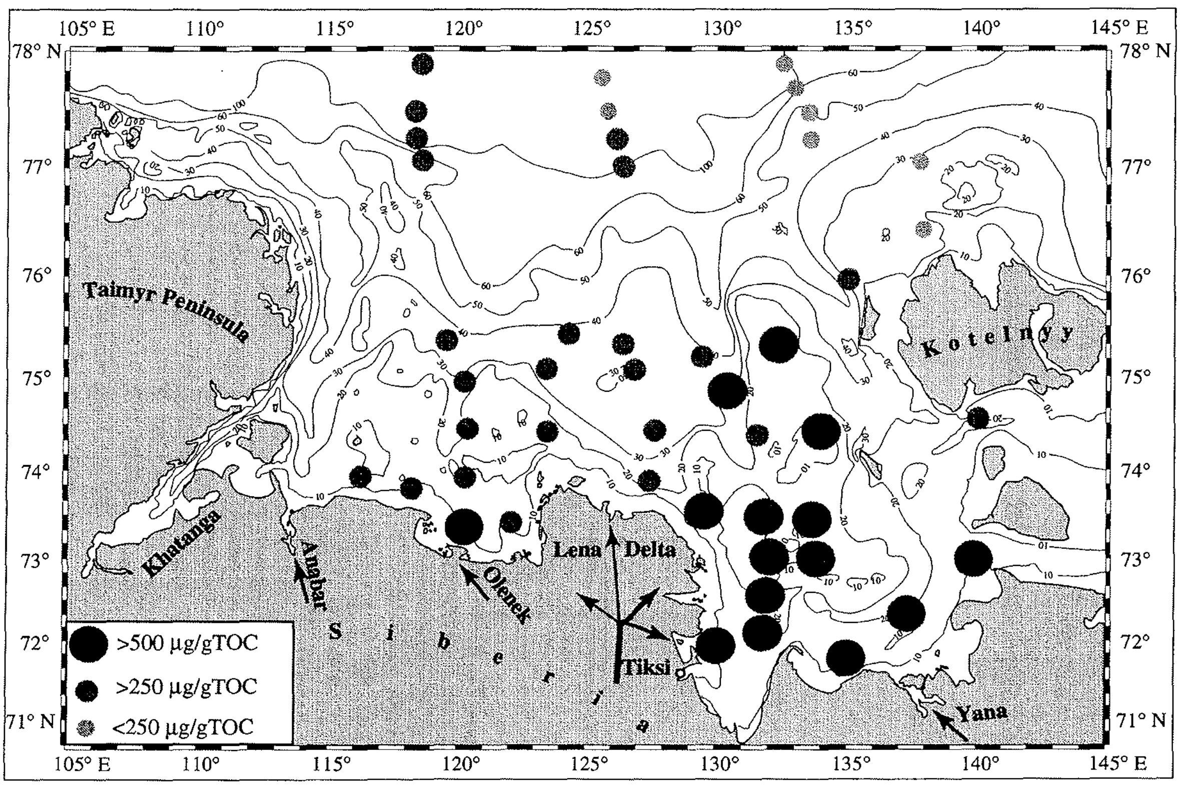

Fig. 6: Distribution of long-chain *n*-alkane (C_{27} + C_{29} + C_{31}) concentrations (µg/gTOC) in surface sediments from the Laptev Sea and the adjacent continental margin.

Diatom surface sediment assemblages of the Laptev Sea Shelf are presented in Figure 8. According to newest taxonomical concepts a total of 344 diatom taxa from 72 genera were identified from surface sediments of the Laptev Sea. The most diverse genera are *Navicula Pinnularia, Nitzschia, Cymbella, Eunotia, Fragilaria,* and *Achnanthes*, all of them being pennate diatom genera (CREMER 1998). About 60 % of all taxa are freshwater species, which originally occur in lakes and rivers of the Siberian hinterland. Planktonic diatom species of the genera *Thalassiosira, Chaetoceros, Fossula* and *Fragilariopsis,* however, are predominant in surface sediment assemblages of the Laptev Sea. Four diatom sediment assemblages could be distinguished:

The freshwater diatom assemblage (Fig. 8) predominates sediments from the river mouth regime and consists of a freshwater diatom flora rich in genera and species. Few species occur with higher abundances, e.g., *Aulacoseira subarctica, Asterionella formosa, Diatoma tenuis* (CREMER 1998, 1999). In front of the Yana and Anabar also marine and brackish water species reach higher abundances.

The *Chaetoceros* assemblage (Fig. 8) is dominated, in order, by resting spores of *Chaetoceros* spp., arctic-marine species of *Nitzschia*, and *Thalassiosira hyperborea* (brackish water species). This assemblage is mainly present in the eastern, southeastern, and northeastern parts of the Laptev Sea shelf. The regions showing a main significance of the *Chaetoceros* assemblage corresponds with regions where salinity of surface waters is reduced to brachyhaline conditions due to strong river water influx during summer. Resting spores of *Chaetoceros* are the most abundant diatoms in the surface sediments of the Laptev Sea. The chain forming vegetative forms of this genus dominate the plankton of the neritic regions of the Laptev Sea shelf (CREMER 1998).

The *Thalassiosira nordenskioeldii* assemblage (Fig. 8) is dominant in some samples of the central and northeastern parts of the Laptev Sea shelf. This assemblage consists only of the marine-neritic species *T. nordenskioeldii. T. nordenskioeldii* showing a patchy co-occurrence with the ice-algal assemblage, may point to a co-development of *T. nordenskioeldii* and the ice-algal species in the vicinity of the ice edge during spring and summer.

The ice-algal assemblage (Fig. 8) of the northern and central shelf mainly consists of *Fragilariopsis cylindrus, Fragilariopsis oceanica,* and the polar diatom *Fossula arctica.* Furtheron, the central Laptev Sea region is characterized by a patchy dominance of the marine-brackish planktonic diatom *Thalassiosira nordenskioeldii.*

Dinoflagellate cysts, chlorococcalean algae, acritarchs and several groups of zoomorphs (Fig. 9) clearly dominate the palynomorph assemblage in the Laptev Sea surface sediments (KUNZ-PIRRUNG 1999). The chlorococcalean algal assemblages mainly consist of *Pediastrum* spp. and *Botryococcus* cf. *braunii.* These groups of organic-walled mircofossils usually live in freshwater. The chlorococcalean algal concentrations were very variable on the Laptev Sea shelf (7-3800 per gram dry sediment). Highest concentrations were found in the submarine valleys and in front of the river mouths (Fig. 9).

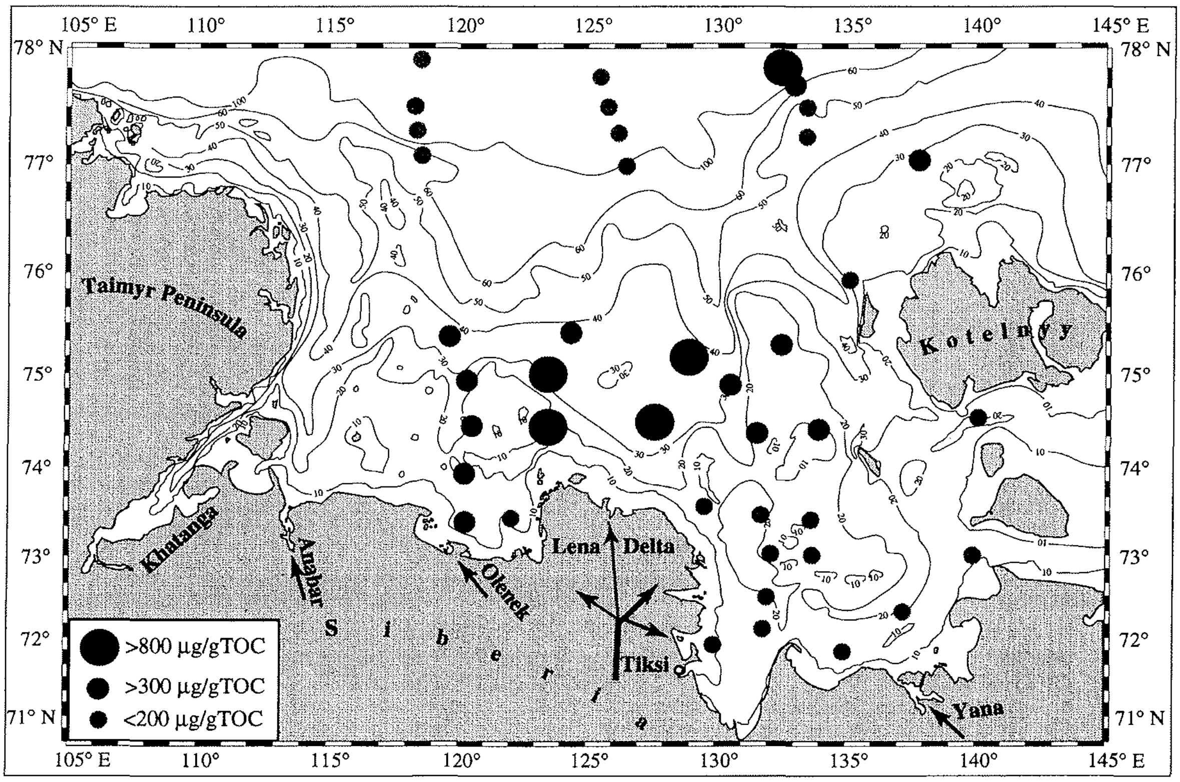

Fig. 7: Distribution of the sum of 16:1(n-7) and 20:5(n-3) fatty acids (in µg/gTOC) in surface sediments from the Laptev Sea and the adjacent continental margin.

From the inner to the outer shelf region and from the east to the west the concentrations of the chlorococcalean algae continuously decrease.

The distribution of dinoflagellate cysts in recent sediments is clearly related to hydrographic conditions of polar surface waters (KUNZ-PIRRUNG 1998). The assemblages of the Laptev Sea shelf, which are dominated by *Brigantedinium* spp., *Algidasphaeridium* cf. *minutum* and related morphotypes, reflected these polar conditions. On the continental slope *Nematosphaeropsis labyrinthus* and *Operculodinium centrocarpum* are the most dominant species. These species seem to be indicators for warmer Atlantic water masses, which influence the continental slope area.

DISCUSSION

Concerning the sources and fate of organic matter, the Laptev Sea is a complex system (e.g., FAHL & STEIN 1997, 1999). First, the strong fluvial supply provides huge amounts of organic matter of both aquatic (freshwater) and terrestrial origin. Second, due to the more or less closed sea-ice cover, phytoplankton productivity in the Arctic Ocean is generally low and represents a mixed signal of pelagic and sympagic production. Near the ice edge and due to riverine nutrient supply, however, marine primary production may be enhanced. Third, the organic matter deposited on the Laptev Sea shelf, being a mixture of terrigenous higher plant material, freshwater organic material and, to a limited extent, marine organic matter, may be incorporated into the sea ice and transported further offshore.

A pronounced predominance of diatoms, as recorded in vast regions of the Laptev Sea shelf, has also been reported from other Arctic regions (HEIMDAL 1983, SMITH JR. et al. 1995). As many of the pennate diatoms near the Lena Delta are freshwater or brackish-water species (HEISKANEN & KECK 1996), they seem to be transported seawards by the Lena River. Many species of *Chaetoceros* and *Thalassiosira,* which were common on the Laptev Sea shelf, were typical Arctic polar diatoms (MEDLIN & PRIDDLE 1990, HEISKANEN & KECK 1996, CREMER 1998).

The predominance of diatoms is also documented in the surface sediments where the distribution of freshwater diatoms again reflects the intensity of riverine freshwater supply, directly by the rivers on the one hand and by the mixing of river water with brackish-marine water masses from the shelf on the other hand. The occurrence of freshwater diatoms in high quantities is most likely related to the strong riverine freshwater supply in the vicinity of river mouths and river deltas. High abundances of *Chaetoceros* resting spores as found in the surface sediments of the Laptev Sea, have been reported from other polar regions, e.g., for the North Pacific (SANCETTA 1981) and the Greenland-Iceland-Norwegian-Sea (SCHRADER & KOÇ KARPUZ 1990). High relative concentrations of *Chaetoceros* resting spores were assumed to be an indication for high productivity (e.g., SCHUETTE & SCHRADER 1979, WILLIAMS 1986). Species of *Chaetoceros* were obviously able to use the short, ice-free summer period for an intense growth. If growth conditions deteriorate *Chaetoceros* forms resting spores which may retain their vitality and form the seed for the next growth period (SMETACEK 1985, MCQUOID & HOBSON 1995). *T. hyperborea* is a brackish water species being typical for the vicinity

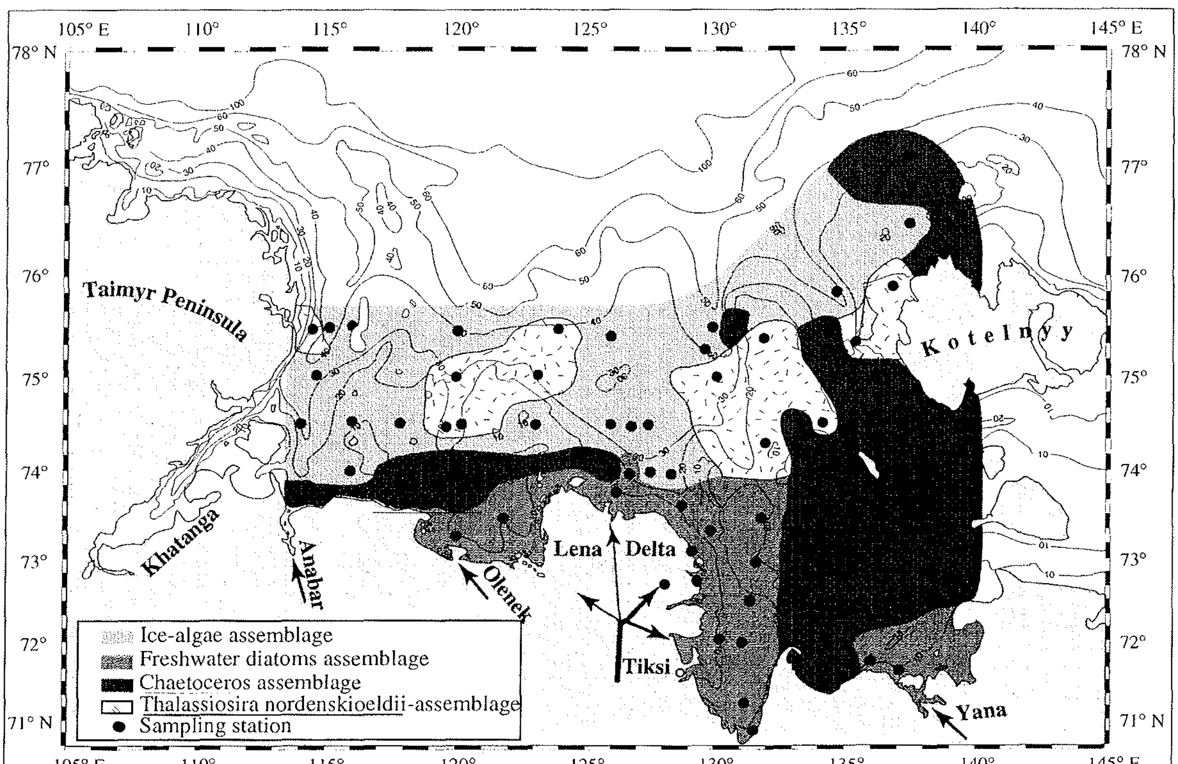

Fig. 8: Distribution of diatom surface sediment assemblages in the Laptev Sea.

of river mouths and river deltas of the Arctic Ocean (HASLE & LANGE 1989). According to PANKOW (1990) *T. hyperborea* is a mesohalobous-euryhaline species and prefers salinities between 2-30. Highest abundances of this species occur in the eastern part of the Laptev Sea shelf where brackish conditions exist. *T. hyperborea* was also reported to be a typical under-ice species, which grows under the melting ice during spring, and summer (SYVERTSEN 1990). Thus, the *Chaetoceros* assemblage may be related to occasionally ice covered shelf regions with reduced salinity and highly productive surface waters during summer.

A similar pattern is reflected by the palynomorph assemblage (Fig. 9). Dinoflagellate cysts, chlorococcalean algae, acritarchs and several groups of zoomorphs clearly dominate this assemblage (KUNZ-PIRRUNG 1999). In order to reconstruct the specific environmental conditions of the Laptev Sea in detail, it was necessary to use both marine dinoflagellate cysts and chlorococcalean algae, which again reflect the freshwater discharge into the Laptev Sea. The distribution of chlorococcalean algae and the change in the composition of the dinoflagellate cyst assemblages occur in response to the strong salinity gradient of surface water masses from the inner to the outer shelf region. For further details concerning the oceanographic situation in the Laptev Sea see PIVOVAROV (1994).

The strong connection between the primary and secondary producers is reflected in the distribution of the zooplankton whereas the results of the biomass and species composition indicate again a relation to the major hydrographic features. HIRCHE & MUMM (1992) and VINOGRADOV et al. (1994) have reported the close relationship between zooplankton distribution and hydrography for the arctic waters. Zooplankton communities of the Laptev Sea were shaped by two major hydrographic factors: the outflow of the large rivers in the central and eastern area and the advection of cold and saline waters of the Kara Sea and Arctic Ocean in the west and north.

The strong dominance of small-sized brackish-water species in the central, eastern and especially south-eastern Laptev Sea influenced by freshwater input, has already been observed since earlier investigations (VIRKETISS 1932, JASCHNOV 1940). SOROKIN & SOROKIN (1996) have found brackish-water *Cladocera* (*Bosmina* sp.), cyclopoids, copepods *Limnocalanus grimaldii, Drepanopus bungei, Pseudocalanus major, Eurytemora raboti* in the south-eastern part of the Laptev Sea during the SPASIBA-Expedition in 1991. PAVSHTIKS (1990) has found *Pseudocalanus* sp., *D. bungei* and *Jaschnovia tolli* as dominant taxa in near the New Siberian Islands in 1973. ABRAMOVA (1996) has shown that brackish water organisms were dominant at all stations in the area near the New Siberian Shoals in the spring 1993. In autumn species of marine origin prevailed by the species number, but at most stations brackish water organisms still dominated in abundance and biomass.

The plankton community of the western Laptev Sea was dominated by larger herbivorous marine species *Calanus glacialis, C. finmarchicus* and *Pseudocalanus.* (JASCHNOV 1940, KOSOBOKOVA et al. 1998). The occurrence of subarctic species *C. finmarchicus* in this area was attributed to the advection within water masses of Atlantic origin (JASCHNOV 1940).

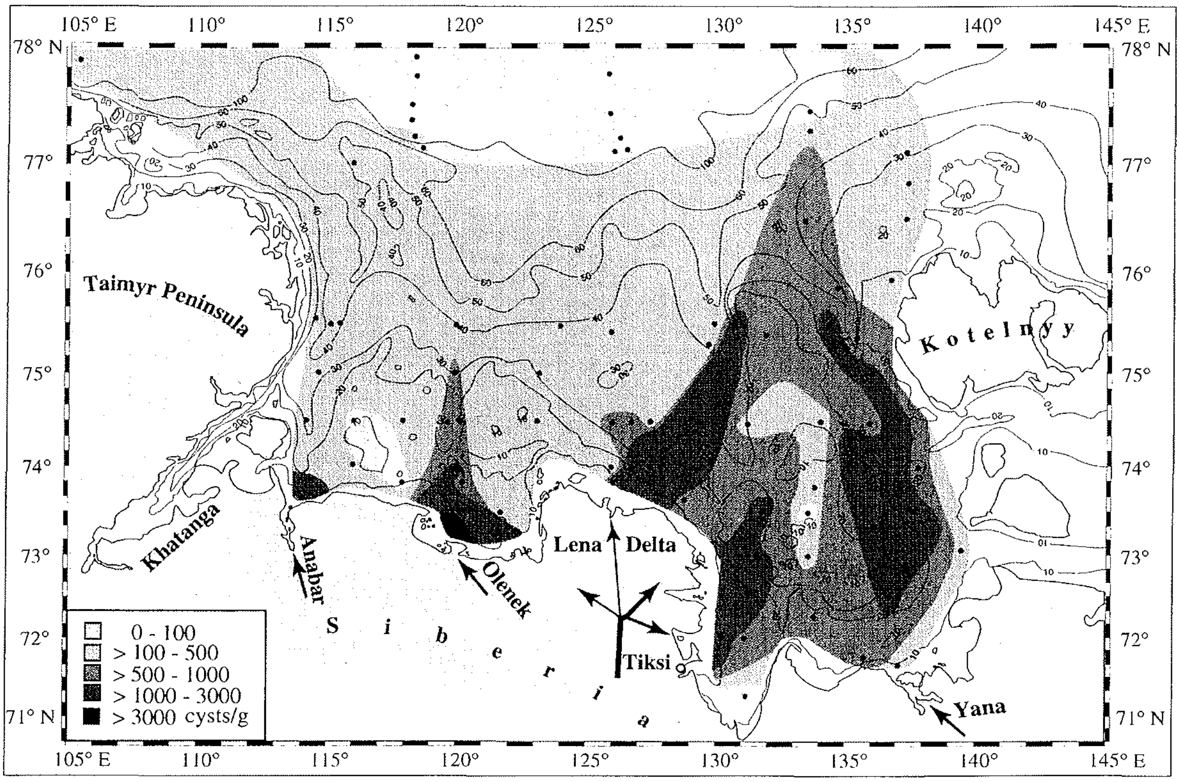

Fig. 9: Concentration (per gram dry sediment) of chlorococcalean in surface sediments from the Laptev Sea and the adjacent continental margin. The sample locations are marked by black dots.

The different composition of the zooplankton communities in the western and central/eastern Laptev Sea explained the different patterns of the zooplankton biomass distribution and suggested different extent of utilization of the organic mater in the water column resulting in different composition of the sinking material. In the eastern Laptev Sea, the primary and allochtonous organic material undergoes deeper utilization in the pelagic due to its multiple circulation through the food web dominated by small detritophagous brackish-water copepods (VINOGRADOV et al. 1994). Contrary, in the Calanus-dominated system of the western sea, primary production passed straight through the diatoms/*Calanus* trophic food chain resulting in a sink of just slightly modified plant material to the bottom (CONOVER 1966). The domination of lipid-rich copepods *Calanus/Pseudocalanus* in the water column of the western sea is reflected by high amounts of fatty alcohols in the surface sediments. These alcohols derived from the wax esters synthesized by the herbivorous plankters as storage lipids to survive the high seasonality in the polar regions (HAGEN et al. 1993)

In the marginal ice zone the primary production and grazing seem to be even less balanced than in the open water of the western sea. Only a small proportion of primary production was consumed in this area by zooplankton, resulting in the direct sedimentation of the phytoplankton and enrichment of the bottom sediments with plant material (BOETIUS & DAMM 1998). Due to the relatively stable position of the ice edge during summer, repeated phytoplankton blooms provide the permanent flux of the organic matter, reflected in the surface sediments as a belt with a high content of the organic carbon and marine fatty acids (Fig. 7; FAHL & STEIN 1997). Such a pronounced correlation between the ice edge and enhanced productivity was also reported from the Bering Sea by MCROY & GOERING (1974) and from the Weddell Sea by NELSON et al. (1989).

The comparison of phytoplankton, zooplankton and benthos biomass distribution suggests that different processes control the communities in the water column and at the sea floor. In general, benthic distribution seems to be structured by the fluvial input and meso-scale current systems rather than by large-scale biogeographical or oceanographic features. Abundance and biomass of dominant macrobenthic species can be as high or even higher (PIEPENBURG & SCHMID 1997) than those found off Northeast-Greenland (PIEPENBURG et al. 1997) and in the Barents Sea (PIEPENBURG & SCHMID 1996), indicating that the fauna in the Laptev Sea was not impoverished compared to other Arctic areas. A detailed bioenvironmental analysis of benthic community patterns indicates that the most important factors controlling the distribution of epibenthic organisms are water depth and bottom water salinity (PETRYASHOV et al. 1999). The influence of the sediment structure, commonly invoked as a prime benthic community determinant (SNELGROVE & BUTMAN 1994), is apparently less important, as grain-size distribution is rather homogenous in the Laptev Sea (Fig. 10). The high sediment load and freshwater inflow near the Lena River obviously limit the benthic colonization.

The high input of nutrients by the Lena sustains a relatively high phytoplankton biomass (see Fig. 2) near the delta in comparison to the remaining Laptev Sea shelf. No correlation between nutrients and related food supply, and biomass of

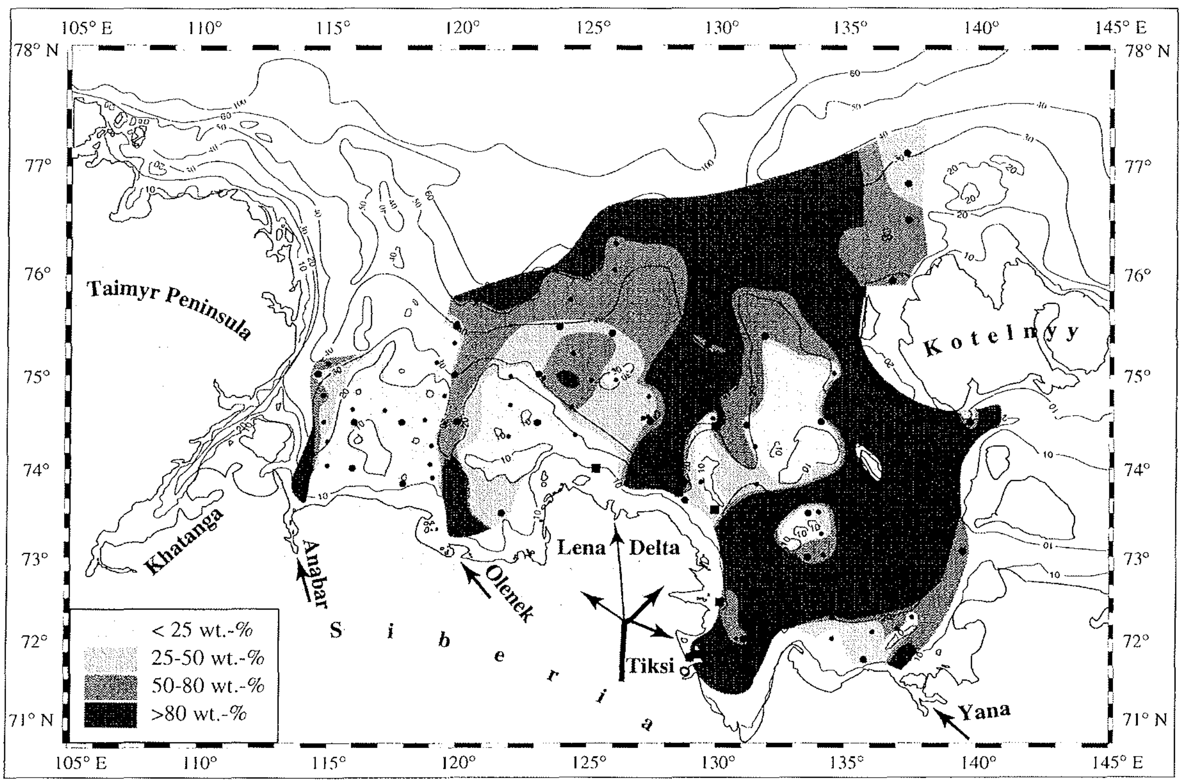

Fig. 10: Distribution of silt and clay (<63 µm) in surface sediments from the Laptev Sea (wt.-%).

benthic organisms, however, can be found. This situation is different to that in the Chukchi Sea where GREBMEIER & BARRY (1991) explained the high benthic biomass by high primary production of 300 gC $m^{-2}a^{-1}$, caused by nutrient discharge of the Anadyr River.

Despite the marine biological activities mentioned above, up to 99 % of the organisms and the organic carbon in the coastal-near surface sediments is of terrigenous/aquatic (freshwater) origin, as suggested from micropaleontological and geochemical parameters. The maxima of total organic carbon off the major Laptev Sea rivers correlate well with low hydrogen index values (HI <100 mgHC/gC) indicating the dominance of terrigenous organic matter (STEIN & NÜRNBERG 1995, STEIN 1996, STEIN & FAHL 2000). The same is true for the maximum TOC values occurring at the lowermost part of the continental slope, which may be related to the inflow of Atlantic water masses laterally transporting (organic-carbon-enriched) suspended matter (FAHL & STEIN 1997).

The terrigenous predominance of the organic carbon is also supported by the stable carbon isotopes, which are often used as organic matter source indicator in hemipelagic and deep sea sedimentary deposits (e.g., NEWMAN et al 1973). Light stable carbon isotopes of $\delta^{13}C$ = -26.5 ‰ in surface sediments, correlating with the TOC maxima, indicate the terrigenous origin of the organic matter. This is also supported by the distribution of the terrigenous biomarkers (long-chain *n*-alkanes, Fig. 6). The highest concentrations of long-chain *n*-alkanes, which are generally accepted being of terrigenous origin (YUNKER et al. 1995, PEULVÉ et al. 1996), occur in areas of maximum TOC contents (Fig. 4) and light $\delta^{13}C$ values (Fig. 5), especially off the Lena Delta. The concentration of the long-chain *n*-alkanes decreases whereas $\delta^{13}C$ values become heavier towards the continental slope. Lowest contents of long-chain *n*-alkanes and heaviest $\delta^{13}C$ values were measured in the deep-sea environment, which is explained by a decreasing terrigenous flux towards the open ocean.

Organic carbon is an inherent component of the suspension load of rivers, amounting to several percent by weight (GORDEEV & SHEVCHENKO 1995, RACHOLD & HUBBERTEN 1999). Isotopically this matter is characterized by a mean $\delta^{12}C$ of -27 ‰ for the Lena (sampled 1994 and 1995) and -25.8 ‰ (1995) for the Yana River (RACHOLD & HUBBERTEN 1999). KUPTSOV & LISITSIN (1996) have identified, by radiocarbon analyses, apparently old organic components in the deposits of the mixing zone of the Lena water and further north, as reflected by radiocarbon ages grouping around 7000 years BP in surface sediments in the eastern Laptev Sea. This old fraction likely reflects organic matter eroded from the catchment area. These isotopic characteristics identify the Siberian rivers as the most prominent source of the organic matter deposited in the Laptev Sea. In addition, coastal erosion may be regarded a further process supplying terrigenous organic matter (ARE 1994, STEIN & FAHL 2000).

Maceral composition (i.e. the dominance of huminite/textinite, vitrinite, and terrigenous liptinites), hydrogen index values, and biomarkers determined in surface sediments from the Laptev Sea continental slope indicate a dominance of terrigenous organic matter. Based on analyses of maceral data, a maximum of 70-90 % of the organic matter was reported to be of terrigenous origin (BOUCSEIN & STEIN 2000). The heavy $\delta^{13}C$ values of -23 ‰, on the other hand, point to a higher marine proportion. However, the occurrence of C4 plants may also result in heavierd $\delta^{13}C$ values (ROUNICK & WINTERBOURN 1986). This discrepancy has to be solved by further studies.

CONCLUSIONS

Spatial patterns in composition and biomass of phytoplankton, zooplankton and macrozoobenthos were related to the biogeographic and oceanographic features of the Laptev Sea. Three ecological provinces can be distinguished: the southeastern Laptev Sea (highly influenced by the Lena and Yana rivers), the central Laptev Sea, and the northern Laptev Sea. Furthermore, clear differences between the western and the eastern Laptev occur.

In general, all biological, mircopaleontological, and organic-geochemical parameters (TOC, low HI values, light $\delta^{13}C$ values, and high amounts of long-chain *n*-alkanes and aquatic (freshwater) algae) indicate the strong influence of river discharge, decreasing towards the outer shelf / continental slope.

Enhanced proportions of marine-derived organic carbon, characterized by high HI and heavier $\delta^{13}C$ values, high amounts of short-chain *n*-alkanes ($C_{17}+C_{19}$), fatty acids, and high biomass of phyto- and zooplankton, were related to productive regimes such as open-water areas on the Laptev Sea shelf and the marginal ice zone at the continental margin.

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