Late Holocene variations in Arctic Shelf hydrology and sea-ice regime: evidence from north of the Lena Delta

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ORIGINAL PAPER

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Late Holocene variations in Arctic shelf hydrology and sea-ice regime: evidence from north of the Lena Delta

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Abstract Diatom assemblage studies are used to interpret past changes in river runoff (salinity) and sea-ice regime in the vicinity of the vast Lena River delta, southern Laptev Sea shelf. On the basis of their distribution in surface sediments, the shelf region outside the strong influence of riverine waters is characterized by a dominance in sea-ice diatoms and other marine species. Their numbers increase steeply (>20%) within the area of drifting pack ice. In contrast, the marginal zone of the delta, where exceedingly low salinities prevail, is marked by freshwater diatoms showing values higher than 70%. Using the environmental information from the surface sediments, the downcore distribution patterns of the main ecological groups of diatoms were investigated on a sediment core that covers the past 2800 cal. years BP. Although the freshwater group indicates some temporal variations in salinities, the study site north of the Lena River delta remained under a dominantly riverine influence for most of the three recognized phases. In contrast, the relative abundance of sea-ice species gives evidence that pack-ice conditions were more severe during the oldest phase (older than ~2700 cal. years BP). The most significant changes are observed in the uppermost core section (younger than ~300 cal. years BP) when the relative abundance of freshwater diatoms decreases from 80% down to below 20%. This dramatic decrease is interpreted as a major shift from a more northward-directed to the modern, dominantly eastern outflow pattern. Because the dispersal and fate of riverine waters and its role on the ice regime as well as on water mass properties is a central issue in understanding short- and longer-term climatic changes in the Arctic and beyond, it needs to be tested using more cores if this most recent change in outflow pattern from the delta is connected to climate change or simply a result of channel migration within the delta.

Keywords Arctic shelf · Siberian river runoff · Sea ice · Paleoenvironment · Micropaleontology · Diatoms

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Introduction

The Arctic region plays an important role in the global climate system through its albedo and freshwater budget, both mechanisms which are regarded responsible for past climate perturbations (e.g., Rahmstorf 1995). It is now believed that any future climate change will have a significant impact on the entire global environment; however, its effects will be first noticeable in the Arctic region probably through changes in sea-ice extent and thickness (Dickson 1999). The sea-ice cover of the Arctic Ocean has a positive feedback on the albedo in this region. It represents the frozen part of the Arctic Ocean Halocline, a low-density surface layer which is continuously fed with freshwater by the rivers draining into the Arctic Ocean (Bauch et al. 1995). Therefore, changes in this riverine freshwater system, i.e., in the amount of the runoff, may have a significant impact also on the thickness and distribution of sea ice.

Due to its unique geographical position, the Laptev Sea, which constitutes the central part of the vast Eurasian Arctic shelf (Fig. 1), is a key area to study the influence of river systems on the Arctic Ocean environment (Kassens et al. 1998). One of the two hydrologically important features of this broad and shallow shelf sea is the high annual input of freshwater of approximately 770 km^3/year from rivers draining onto

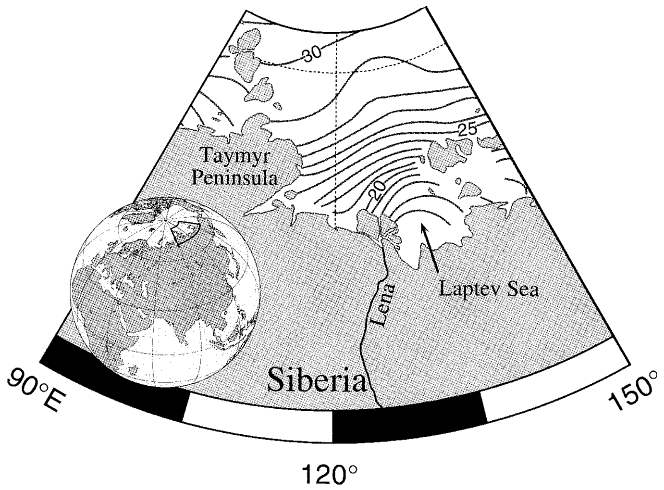


Fig. 1 Distribution of mean summer surface salinity in the Laptev Sea region (1950s–1980s) indicating the strong influence of the river water runoff from the Lena River on the southeastern Laptev sea shelf. (Data from Environmental Working Group 1998)

the Laptev Sea shelf (Aagaard and Carmack 1989). This river water is discharged mainly during the first half of the summer after the river ice breaks. The second feature is the development of a stretch of open water in winter, a so-called flaw polynya which is maintained by consistent offshore winds (Zakharov 1966; Dethleff et al. 1993). This flaw polynya is a conspicuous ice boundary that separates the fast ice from the pack ice (Fig. 2). Depending on the physical conditions, the width of the flaw polynya in the eastern Laptev Sea may range from a few meters to approximately 100 km (Zahkarov 1996). In this regard, the flaw polynya is an important production area of arctic sea ice which, together with the fluvial runoff, has a profound influence on the upper hydrography and the sea-ice regime in the Arctic Ocean (Schlosser et al. 1994; Kassens et al. 1998).

In order to investigate past variations in river runoff and sea-ice formation in the Arctic Ocean, it is necessary to understand the modern physical and biological processes on the Siberian shelves. The reconstruction of the Holocene paleoenvironment on these shelves has been hampered either by poor age control due in part to low carbonate content, limiting reliable chronologies (Dzinoridze 1978; Saidova 1994; Polyakova 1997a, 1997b; Kuptsov and Lisitzin 1996; Polyakova 1999), or by a lack of suitable and long sediment cores. But more recently, radiocarbon-dated sediment cores were obtained from the Laptev Sea offering the opportunity to study paleohydrological shelf processes on the basis of mircopaleontological methods (Bauch 1999; Bauch et al., in press). Using a shelf sediment core from near the largest riverine freshwater source in the Laptev Sea, the Lena River delta, this study makes a first attempt to investigate the temporal variability of the freshwater-ice system in the Laptev Sea during the late Holocene on the basis of diatom assemblage data.

Materials and methods

Core PM9482-2 was obtained from 27 m water depth just north of the Lena River delta using a vibro kasten corer (Kassens and Dmitrenko 1995). The total sed-

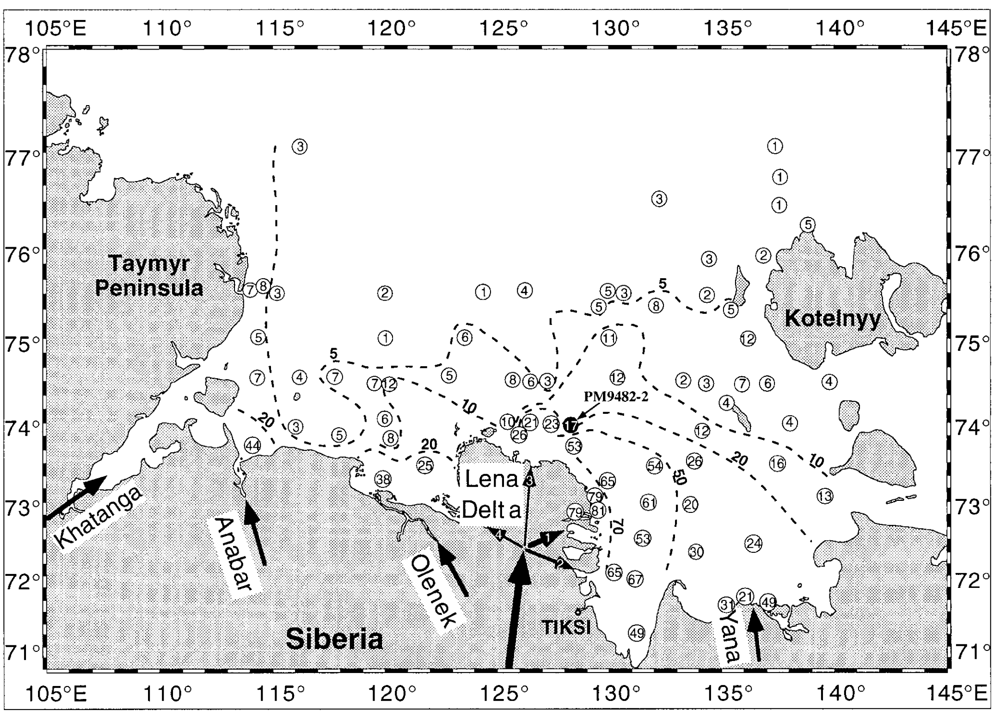


Fig. 2 Relative distribution of freshwater diatoms in surface sediments from the Laptev Sea shelf (after Bauch et al. 2000). Also shown are the main rivers draining into the Laptev Sea as well as the main channels within the Lena River delta (*1* Trofimovskaya; *2* Bykovskaya; *3* Tumatskaya; *4* Olenekskaya). *Black spot* indicates the position of core PM9482-2

Table 1 Original AMS radiocarbon dates with 1-σ error and the calculated calendar years

Lab. no	Depth (cm)	Age (^{14}C years BP)	Age (cal. years BP)
KIA-3128[a]	27	590±30	302
KIA-3129[a]	47	300±30	0
KIA-3130[a]	87	630±30	358
KIA-3131[a]	111	1190±30	823
KIA-3132[b]	161	2260±40	2326
KIA-3133[a]	241	2880±30	2739
KIA-3134[a]	273	2990±30	2839
KIA-3135[a]	325	2930±40	2766

[a]Marine bivalve
[b]Wood

iment recovery of the core was 345 cm. To analyze the physical properties of the sediment (dry bulk density), the core was sampled at 5-cm intervals using 10-ml open barrel syringes. The same samples were then used for diatom assemblage studies. For modern comparison, the undisturbed surface sediment from trigger box core PM9482-1 taken at the same location was investigated.

The AMS radiocarbon dates of the investigated sediment core were obtained from seven small bivalve shells commonly less than 1 cm in diameter (Table 1). They belong to the Arctic species *Portlandia arctica*, which is presently the dominant species on the inner eastern Laptev Sea shelf where reduced salinities prevail (Sirenko et al. 1995). One sample was dated on the basis of a piece of wood. To account for the reservoir effect, 313 years were subtracted from each of the dated marine shells (Bauch et al., in press). All radiocarbon dates were calibrated into calendar years BP using the intercept method (Stuiver et al. 1998).

The following methods were applied for preparation of diatom slides and determination of absolute diatom abundance per gram of freeze-dried sediment samples. Diatoms were concentrated by treatment with 10% HCl and 30% H_2O_2, with subsequent decantation using distilled water. Slide preparation was carried out following Battarbee (1973). The residues were mounted on glass slides with the medium Mountex (Merck, Darmstadt, Germany) which has a refraction index of 1.68. The valves were examined under a light microscope at ×1000 magnification. Generally, approximately 300–400 specimens were counted in each sample. The counts were then calculated to percent data and number of valves per gram of dry sediment.

For this study the following ecological groups among marine diatoms were distinguished: sea-ice species and other marine (planktic and sublittoral) species (see Table 1). Sea-ice diatoms are one of the main components of the Arctic marine ecosystem, producing organic matter in the Arctic marginal seas (Andersen 1989; Melnikov 1989; Poulin 1990). Their distribution in the sediments generally reflects the sea-ice conditions (Polyakova 1994, 1997b). In surface sediments of the eastern Eurasian Arctic they occur with high abundances (up to 50%). The third group of diatoms used in this study are various freshwater species which all indicate terrestrial, aquatic environment (e.g., rivers, bogs, and lakes; Table 2).

Oceanography setting

The annual discharge of the Lena River comprises approximately 70% of the total river input to the Laptev Sea (Rusanov et al. 1979). At its mouth, the Lena River forms an extensive delta with many tributaries. The largest of these channels, Trofimovskaya and Bykovskaya, are responsible for ~60 and ~25% of the total annual Lena River runoff, respectively (Fig. 2). These waters are mainly directed to the east and northeast (Ivanov and Piskun 1999). Although surface salinities within the shelf region may vary on a yearly basis (e.g., Dmitrenko et al. 1999), lowest values are always found in the southeastern part of the Laptev Sea (Fig. 1). The influence of river water in the Laptev Sea is also well manifested by chemical tracers such as dissolved SiO_3 (silicon). Because of the high content in Lena River water, silicon exhibits a distribution pattern similar to that of the surface salinity with maximum concentrations found adjacent to the mouths of the large Lena river channels (Heiskanen and Keck 1996; Pivovarov and Smagin 1995). In wintertime, the Laptev Sea shelf surface waters become relatively enriched with silicon (Pivovarov et al. 1999) probably due to low bioproductivity and remineralization processes.

The Laptev Sea flaw polynya, separating the fast ice from the pack ice, is one of the longest (ca. 2000 km) open-water areas in Arctic winter sea-ice cover. Its open areas are maintained by persistent offshore winds (Zakharov 1966; Smith et al. 1990; Dethleff et al. 1993, 1998). Investigations carried out in the Laptev Sea during recent expeditions (e.g., Kassens and Dmitrenko 1995; Kassens et al. 1997) have revealed that river runoff plays a leading role in the areal extent of the fast ice and in controlling the interannual variations in the geographical position of the flaw polynya (Dmitrenko et al. 1999).

Diatom distribution in surface sediments

The diatom assemblage in the surface sediments of the Laptev Sea is dominated by allochthonous freshwater species which account for approximately 60% of the total taxonomical diversity (Cremer 1998). The near-coastal regions, especially to the east of the Lena River delta, contain the largest portions of freshwater diatoms (Fig. 2). Although the species diversity occurring here is relatively high (~200 species), only few species (*Aulacoseira subarctica*, *Asterionella formosa*, and *Diatoma tenuis*) are dominant (Cremer 1998). The

Table 2 Ecology of marine and brackish water diatoms found in core PM9482-2; *p* planktic-neritic and planktic-panthalassic species; *s* sublittoral benthic and semi-benthic species; *s-i* sea-ice species

Species	Ecology	Species	Ecology
Actinocyclus divisus (Grun.) Hust.	p	*Navicula kryophila* Cl.	s
Amphora proteus Greg.	s	*Navicula peregrina* (Ehr.) Kutz.	s
Bacterosira concava-convexa Makarova	p	*Navicula punctulata* W.Sm.	s
Bacterosira bathyomphala (Cl.) Syvertsen and Hasle	p	*Navicula transitans* Cl.	s
Caloneis aemula Schm.	s	*Navicula transitans v. derasa* Grun.	s
Caloneis formosa (Greg.) Cl.	s	*Navicula trygonocephala* Cl.	s
Chaetoceros compressus Lauder	p	*Navicula valida* Cl.	s
Chaetoceros debilis Cl.	p	*Navicula vanhoeffenii* Gran	p, s-i
Chaetoceros diadema (Ehr.) Gran	p	*Nitzschia delicatissima* Cl.	p
Chaetoceros furcellatus Bail.	p	*Nitzschia frigida* Grun.	p
Chaetoceros ingolfianus Ostf.	p	*Nitzschia laevissima* Grun.	s, s-i
Chaetoceros mitra (Bail.) Cl.	p	*Nitzschia polaris* Grun.	p, s-i
Chaetoceros septentrionalis Oestr.	p, s-i	*Nitzschia scabra* Cl.	s
Cocconeis scutellum Ehr.	s	*Paralia sulcata* (Ehr.) Cl.	s
Coscinodiscus asteromphalus Ehr.	p	*Pinnularia quadratareae* A.S.	p
Coscinodiscus marginatus Ehr.	p	*Pleurosigma angulatum* (Queck.) W.Sm.	p
Coscinodiscus oculus-iridis Ehr.	p	*Pleurosigma stuxbergii* Cl.	p, s-i
Cyclotella striata (Kutz.) Grun.	p	*Porosira glacialis* (Grun.) Jurg.	p
Detonula confervaceae (Cl.) Grun.	p, s-i	*Pseudogomphonema arctica* Grun.	p, s-i
Diploneis smithii (Breb.) Cl.	s	*Pseudogomphonema groenlandicum* Ostr.	p
Diploneis smithii v. pumila (Grun.) Hust.	s	Rhizosolenia hebetata f. semispina	p
Diploneis subcincta (A.S.) Cl.	s	*Stenoneis inconspicua* Greg.	s
Fallacia forcipata (Grev.) Stickle and Mann	s	*Synedra tabulata* (Ag.) Kutz.	s
Fossula arctica Hasle, Syvertsen and von Quillfeldt	p, s-i	*Thalassionema nitzschioides* Grun.	p
Fragilariopsis cylindrus (Grun.) Krieger	p, s-i	*Thalasiosira antarctica* Comber	p
Fragilapiopsis oceanica (Cl.) Hasle	p, s-i	*Thalassiosira baltica* (Grun.) Ostenf.	p
Melosira arctica (Ehr.) Dickie	p, s-i	*Thalassiosira bioculata* (Grun.) Ostenf.	p, s-i
Melosira juergensii Agardh	s	*Thalassiosira constricta* Gaard.	p
Melosira nummuloides (Dillw.) Agardh	s	*Thalassiosira gravida* Cl.	p
Navicula cariana v. detersa Grun.	s	*Thalassiosira hyalina* (Grun.) Gran	p
Navicula digitoradiata (Greg.) Ralfs	s	*Thalassiosira hyperboreae* (Grun.) Hasle and Lange	s
Navicula distans Smith	s	*Thalassiosira nordenskioeldii* Cl.	p
Navicula gelida Grun.	s	*Thalassiothrix longissima* Cl. and Grun.	p
Navicula imperferta Cl.	s	*Trachineis aspers* (Ehr.) Cl.	s
Navicula kariana v. detersa Grun.	s		

good correspondence of the freshwater diatom distribution in the surface sediments with the main pattern in surface water salinity indicates a clear link to the riverine sources of the eastern Lena River delta (Fig. 1). Comparisons with detailed mapping of surface salinities show that proportions in freshwater diatoms higher than approximately 70% are associated with salinities well below 6 (Bauch et al. 2000). Away from the marginal zone of the delta, in areas with salinities larger than 10–15, the relative abundance of freshwater diatoms steeply decreases (see also Fig. 1). This strong relation between river water and distribution in freshwater species is further corroborated by a good correlation between the position of the 20% isoline with the winter mean distribution of silicon (Pivovarov et al. 1999). Northward of the 20% isoline the relative abundance of freshwater diatoms sharply decreases due to enhanced proportions of marine diatoms.

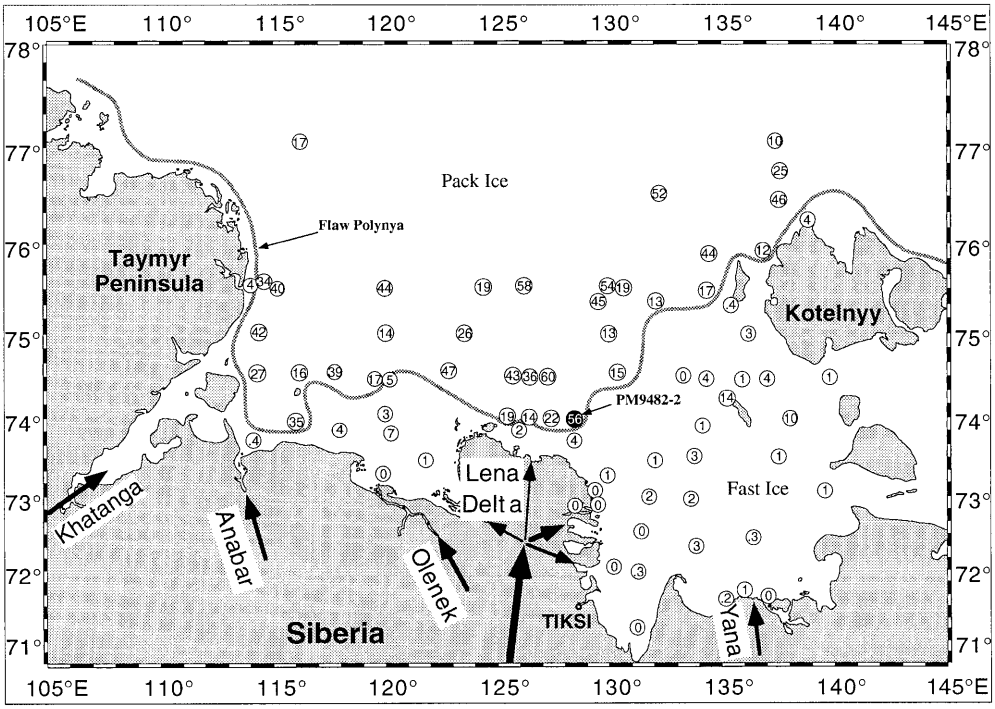
In the Laptev Sea, the sea-ice species group is dominated by *Fragilariopsis oceanica*, *F. cylindrus*, and *Fossula arctica* (Cremer 1998, 1999). The maximum relative abundance of sea-ice species in surface sediment assemblages from this region may be as high as 60% (Fig. 3). From this pattern it becomes apparent that the relative abundance of the sea-ice group is associated with the region dominated by pack ice. Notable is a significant steep increase in sea-ice diatoms (>~20%) to the north of the flaw polynya (Fig. 3).

Marine planktic diatoms of the surface assemblages are dominated by neritic species such as *Thalassiosira nordenskioeldii*, *T. gravida*, and *T. antarctica* which can comprise up to 32% north of the flaw polynya (Cremer 1999). The typically brackish water taxa of the genus *Thalassiosira* (*T. hyperborea*, *T. baltica*), along with spores of *Chaetoceros spp.*, dominate in the southeastern part of the Laptev Sea where the influence of freshwater is most pronounced (Cremer 1999).

Downcore distribution pattern in diatom groups

Approximately 300 species and varieties of diatoms have been recognized in core PM9482-2. Abundant diatoms were encountered in all samples (Fig. 4) with concentrations generally increasing downcore (up to 1.8 million valves/g). Distribution patterns of the total

Fig. 3 Relative proportions of sea-ice species in surface sediments from the Laptev Sea (compiled on the basis of Cremer 1998) and their relation to the mean position of the Laptev Sea flaw polynya which separates the fast ice from the pack ice regime (after Dmitrenko et al. 1998). *Black spot* indicates the position of core PM9482-2



concentrations of diatom valves as well as of the main ecological groups (freshwater diatoms, marine diatoms, sea-ice diatoms) are characterized by a high variability throughout the core section.

On the basis of the downcore distribution in Fig. 4 three main intervals are recognized: highest concentrations occur between 340 and 245 cm core depth and

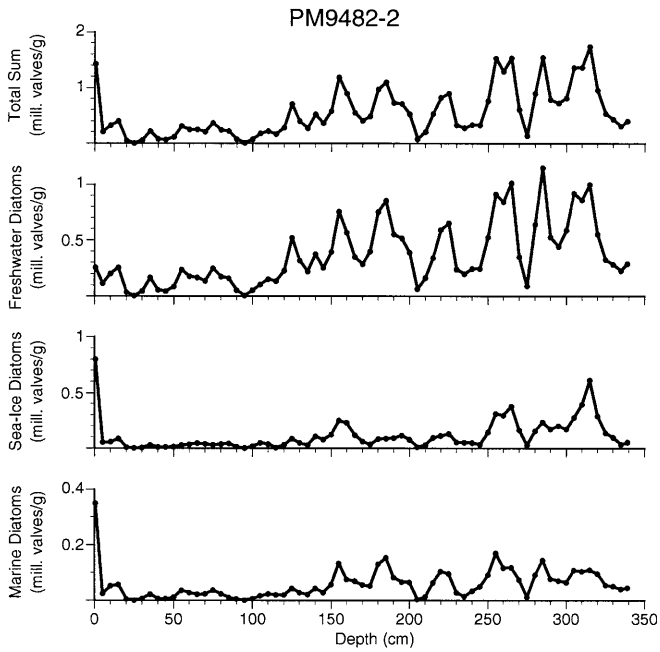


Fig. 4 Downcore distribution of diatom valve concentration for the various ecological groups (note the different vertical scales)

intermediate number of valves between depth 245 and 125 cm. Lowest abundance is observed for the remaining upper part with the exception of the surface sample which was added to the core from the trigger box corer. This surface sample reveals an unusually high number of marine diatoms and sea-ice diatoms, respectively, whereas the freshwater group remains on its relatively low abundance level. Direct comparison of all abundance records reveal that minima and maxima covary well. This may be caused by variations in productivity or a silicon deficit in sea water and/or pore water leading to diatom dissolution; however, robust as well as more delicately built taxa were found throughout the core.

Freshwater, mainly riverine, diatoms predominate both taxonomically (two-thirds of total taxonomical diversity) and quantitatively (up to 83%) in the entire core (Fig. 5). The total variability of this group varies mainly between 80 and 60% with a substantial number of samples being well above 70%. Planktic species of the genus *Aulacoseira* (*A. subarctica*, *A. italica*, *A. granulata*, *A. islandica*) are most important among the freshwater group, ranging from 12 to 43%. The lowest relative abundance of freshwater diatoms (<60%) is observed near the bottom of the core and in the uppermost few samples. This notable steep decreasing trend in freshwater species towards the sediment surface commenced at 25 cm core depth and ends in a minimum showing less than 20%.

The marine diatom assemblage in core PM9482-2 largely comprises sea-ice species (Fig. 5; Table 2). This species assemblage is composed mainly of *Fossula arctica*, *Fragilariopsis grunowii*, and *F. cylindrus*.

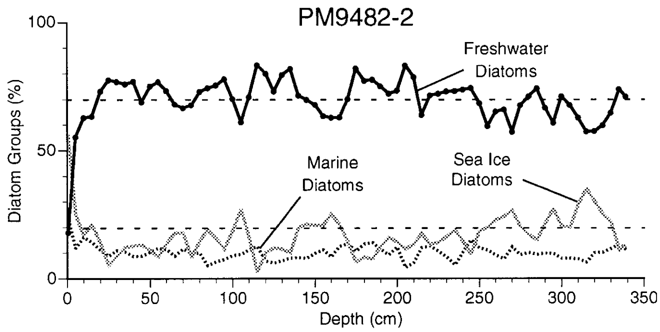


Fig. 5 Downcore distribution of the three main ecological groups of diatoms expressed in relative abundances. *Dashed lines* indicate the 70 and 20% levels, respectively

Significant proportions of this group larger than 20% are recognized within the lowermost meter of the core, around 160 and 105 cm core depth. Highest proportions of up to 56% are found in the surface sample due to the consistently low numbers in freshwater diatoms in the uppermost part of the core (see Fig. 4). The coeval increase to more than 80% in both marine diatom groups seems intriguing, particularly because of the increase in planktic and sublittoral species which otherwise remain insignificant throughout the entire core.

Chronology and downcore sediment characteristics

The marine radiocarbon dates reveal that the base of the core yields an age of approximately 2800 cal. years BP (Fig. 6). The age based on the wood fragment at 161 cm is 700 years younger, indicating rapid deposition of the lowermost ~180 cm of the core. The age reversal found at 273 cm core depth seems negligible because it is within the 1-σ error of the lowermost two dates (Table 1).

Compared with the lower part of the core, the upper 100 cm appear to be young. That the top section of the investigated site is relatively young and the bottom no older than 3000 years BP is also confirmed through analyses of both Cs^{137} on the short trigger box core from the same site (core PM9482-1) and $^{210}Pb_{supported}$ on PM9482-2, respectively (H. Erlenkeuser, unpublished data). A major change, however, becomes apparent between the wood age at 161 cm and the next youngest date at 111 cm core depth. Between these two dates, the density data indicate a clear decrease. Density values found below 823 cal. years BP are higher and, moreover, relatively constant. These higher values may suggest a lower sedimentation rate and/or a different sediment than above. This assumption of higher sedimentation rates in the lower 200 cm than above gains support from the observed higher concentration of diatom valves found in this core interval. Another explanation for the marked change in age and density values could be a hiatus. But even X-rays could not give evidence of erosional feature in this core section. Moreover, the sediment composition is fairly uniform throughout most of the core (Dehn et al. 1995).

Several factors could have additonally influenced the marine radiocarbon dates in core PM9482-2. These may be connected with the burrowing nature of the infaunal species *P. arctica*, or with the fact that we have used the intercept method instead of the interval method to calibrate calendar years (Stuiver et al. 1998). Another possibility are variations in the reservoir age due to either changes in the geographical position of the flaw polynya with its increased rate of vertical convection and/or the amount of river runoff which may have a different reservoir age due to hardwater effect. Other problems arise from the radiocarbon date obtained from the wood sample. Although it gave a reasonable age that fits between the other ages in this core section, a large uncertainty remains due to its allochthonous nature making it problematic to include into a marine-based chronology. Interesting in the context of the core chronology, however, is that the diatom valve concentrations fluctuate evenly, i.e., troughs and peaks are defined through several points (Fig. 6). This is not expected if more erratic changes in sedimentation, such as erosion, occur. Therefore, the recorded coeval variations in diatom valve concentrations are more likely the result of changes in the rate of total sediment deposition caused by a variable input of total sediments to the site.

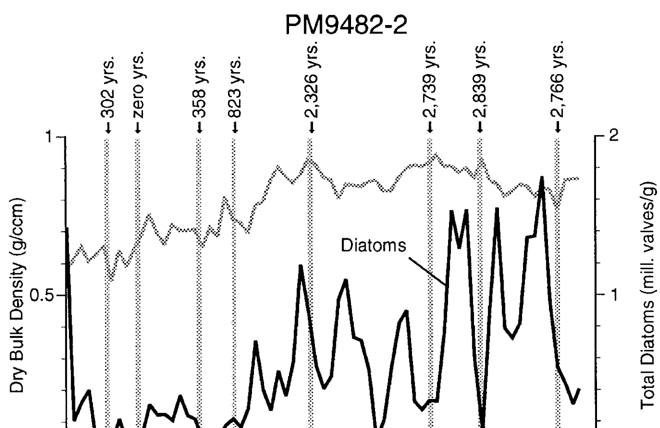


Fig. 6 Radiocarbon ages (in calendar years BP) conducted on core PM9482-2 and records of sediment density and total sum of diatom valve concentrations (per gram of dry sediment)

Late Holocene changes in freshwater runoff and sea-ice regime

The modern physical and chemical variations in hydrological conditions in the Laptev Sea are inevitably linked to the input of Lena river water (Dmitrenko et al. 1998; Pivovarov and Smagin 1995). The distribution of the main ecological groups of diatoms in surface sediments from this region shows a strong relationship to salinity, general ice conditions as well as hydrochemical features (Cremer 1999; Pivovarov et al. 1999; see also Figs. 1, 2, 3). As a consequence of that, the variations in the relative proportions of these different ecological groups recognized in core PM9482-2 during the past 2800 cal. years BP (Fig. 6) should therefore also directly reflect past changes in the environmental parameters, namely the input of riverine freshwater and the distribution of drifting pack ice, i.e., the position of the flaw polynya as the boundary to the fast-ice regime (Dethleff et al. 1998).

The data from core PM9482-2 indicate that both environmental indicator groups behave in a strong antiphased manner (Fig. 7). As shown by the distribution of diatoms in surface sediments, the freshwater group has proportions higher than 70% in close proximity of the Lena River delta where surface salinities are below 6 (Dmitrenko et al. 1999; Bauch et al. 2000; see also Fig. 2). The sea-ice diatoms, on the other hand, generally increased above the 20% level north of the flaw polynya (Fig. 3). Using these two numbers as thresholds three major phases showing significant changes in environmental parameters are recognized in core PM9482-2 (Fig. 7). The predominance of freshwater diatoms along most of the core sequence but near the surface indicates that the study area has been affected by intensive river runoff throughout the investigated time period. The fact that the variability remains above 60% implies that salinities were never higher than 10–15 (Bauch et al. 2000). However, it may well be that these high proportions in freshwater diatoms are to some extent also the result of variations in the total amount of allochthonous sediment material (including riverine and lacustrine-bog diatoms) supplied to the coastal zone through the main delta channels (Ivanov and Piskun 1999) and/or due to changes in productivity of marine diatom coenoses alone. The variations observed in the sea-ice diatoms remain mostly below the 20% level, indicating that the study site was largely under the influence of the fast ice and the flaw polynya. Only for phase 1 and the uppermost core section can the inference be made that the study area was within the area of pack ice (Fig. 7).

Appreciating some chronological uncertainties of core PM9482-2, which make a more detailed age-related interpretation speculative at present, the entire studied interval covers the time of the Subatlantic period. Palynological and oxygen isotope data from northern Yakutia and Severnaya Zemlya archipelago give evidence for a gradual climatic cooling and decrease of summer air temperatures during this time (Khotinsky 1984; Andreev and Klimanov 1990; Makeev et al. 1991; Hahne and Melles 1999). The high relative input of freshwater diatoms noted in phase 2 (Fig. 7) may therefore imply that this general trend in cooling was accompanied by a steady, north-directed water transfer from the Lena River delta. This may have been caused by a higher net river runoff or by enhanced water flow through the northern part of the delta.

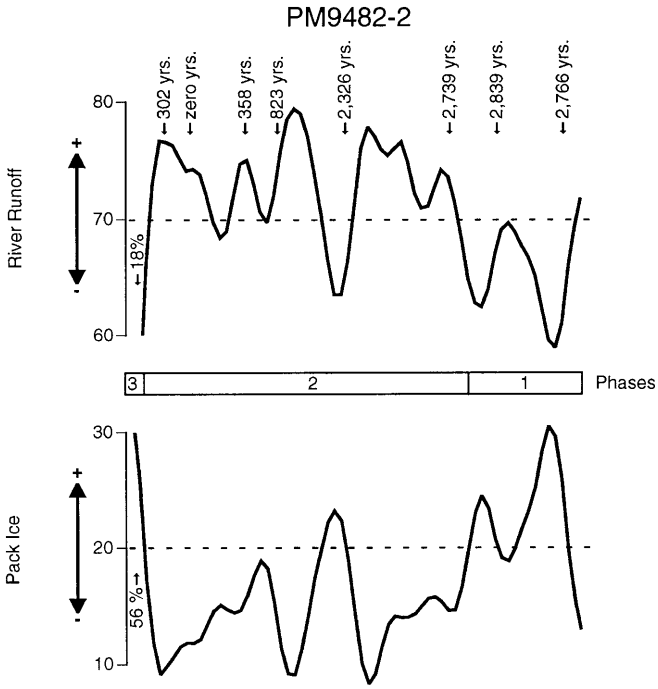


Fig. 7 Inferred variabilities in river runoff (salinity changes) and pack-ice cover north of the Lena river delta (ages in calendar years BP). Also indicated is the 70 and 20% threshold (*dashed line* in top and bottom graph, respectively). Both curves are smoothed records of the relative abundances of sea-ice and freshwater diatoms (data taken from Fig. 6)

The major change in sea-ice conditions and river runoff noted in the uppermost part of core PM9482-2, during phase 3, is certainly outstanding compared with the remaining variability in the core. The relative low number of freshwater diatoms in the surface sample is also verified in other samples (Fig. 2). Considering that these surface samples may yield an average age of several tens of years, the trend that commenced with phase 1 seems realistic (Fig. 7). It implies that the main direction of riverine outflow from the delta has changed significantly from north to east during most recent time. Whether this was indeed induced by a climate change (e.g., Little Ice Age) is a tempting hypothesis; however, it remains speculative at present due to the uncertainty in the core chronology.

Summary and conclusions

In this study we utilized a sediment core from north of the large Lena River delta and near the mean modern position of the winter flaw polynya to identify paleoenvironmental changes during the past 2800 cal. years BP. Using diatom assemblages, the temporal variability of river runoff and sea-ice conditions was the primary objective. Some of the pertinent results provide a first insight into key elements which control parts of the climate system in the Arctic presently.

The diatom assemblage in Laptev Sea surface sediments can be subdivided on the basis of their ecology into a freshwater and a marine group; the latter is further distinguished into a sea-ice group and a group comprising all other marine species. Due to strong salinity gradients caused by enhanced river runoff during summer, the distal areas of the delta are characterized by a dominance in sea-ice diatoms and other marine species. In contrast, the marginal zone of the delta, especially toward the east, reveals proportions of freshwater diatoms higher than 70% which correlate with salinities below 6. As part of the marine species group, the relative proportions of sea-ice diatoms steeply increase above 20% north of the mean position of the winter flaw polynya and within the general area of drifting pack ice.

The downcore distribution patterns of the three main ecological groups of diatoms during the investigated time interval are characterized by some significant variability, reflecting temporal changes in hydrology and sea-ice conditions north of the Lena River delta during the past 2800 cal. years BP. In general, increased pack-ice conditions correlate with enhanced salinities. Although salinities show some variations, the study site remained under a dominantly riverine influence for most phases that are recognized in the core. In contrast, the relative abundance of sea-ice species gives evidence that pack-ice conditions were more severe during the oldest phase.

The most significant changes are observed in the youngest core section when the relative abundance of freshwater diatoms decreases from 80% down to below 20%. This dramatic decrease is interpreted as a major shift from a dominantly northward-directed riverine outflow to the modern situation which is characterized by a runoff pattern toward the east. It needs to be tested, using more cores from the area around the Lena River delta, whether this most recent change in outflow pattern from the delta is connected to climate change or is simply a result of channel mirgation within the delta.

In the context of the growing concern about the response of the Arctic regions to environmental change and its impact on global climate, the Laptev Sea shelf and its Siberian hinterland are of particular interest because of the many large rivers that discharge onto this shelf, thereby constituting a key source for the freshwater budget of the halocline in the Arctic Ocean. Moreover, the shallow Laptev Sea shelf is the major sea-ice production area in the Arctic, ice which is generated in a flaw lead during the long winter season. Both sea-ice and freshwater link the Siberian shelves to the Arctic Ocean and the Nordic seas via the Transpolar Drift. Given the variability on decadal and in particular on longer timescales, the dispersal and fate of river discharge and its role on the ice regime as well as on water mass properties are a central issue in understanding long-term changes beyond the Laptev Sea region.

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