

# Planktic Foraminifera in Holocene Sediments from the Laptev Sea and the Central Arctic Ocean: Species Distribution and Paleobiogeographical Implication

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**Abstract** - Two sediment cores, one from the Siberian Laptev Sea shelf and another from the central Arctic Ocean were investigated with respect to the temporal distribution of planktic foraminifera as well as the species composition.

The assemblage in the Laptev Sea, which cover the time back to about 2.3 ka, is mainly comprised of species that can be related to a subtropical-subpolar biogeography and is dominated by the minute species *Turborotalita clarkei*. The origin of the non-polar species on the Siberian shelf remains unknown. It is suggested that these microfossils were either reworked from older sediments and/or entrained into sea-ice on other shallow Arctic shelves, transporting them eventually to the Laptev Sea.

In contrast to the Laptev Sea the glacial and Holocene sediments from the perennially ice-covered central Arctic Ocean reveal a typical monospecific record, which is entirely made up of the polar species *Neogloboquadrina pachyderma* (right and left coiling forms). The relative variability of the two coiling varieties is of the order of 5%. Although this variability does not seem to be related to climate-induced environmental changes, total test concentration shows a clear signal of increasing deposition of foraminiferal tests after 7 ka. Since sea-ice and surface water conditions seem to be stable in this region, the observed increase in plankton productivity during the Holocene must be linked to changes in water mass circulation.

## Introduction

The concept that past surface water properties can be deduced from assemblage studies of planktic foraminifera was established some time ago (Imbrie and Kipp, 1971). This finding is based on studies of sediments from the surface of the ocean floor which are thought to give a fairly good reflectance of the species composition in the overlying surface water masses. Previous faunal studies, in which a detailed mapping of the ocean's floor core-top sediments was conducted, revealed various foraminiferal assemblages (Kipp, 1976). The faunal composition could be linked to specific water mass properties such as sea surface water temperature (SST). In the modern ocean, the SST displays a latitudinal change towards the northern polar regions that is mirrored by a change in the foraminiferal assemblage from warm-water representing types to a typically subpolar or polar species dominated assemblage (Bradshaw, 1959; Kipp, 1976).

Studies of plankton tows and sediment samples of Holocene age from the Arctic Ocean indicate that the faunal assemblage is rather monospecific, consisting mainly of the polar species *Neogloboquadrina pachyderma* sinistral (Bé, 1960; Steuerwald and Clark, 1972; Vilks, 1975). In areas of the Arctic Ocean influenced today by inflowing non-Arctic waters, foraminifera of a subpolar provenance can comprise notable portions of the faunal assemblage (Carstens and Wefer, 1992). However, these species are not indigenous to the Arctic Ocean but are rather the result of water-mass advection from the south (Bauch et al., 1997).

Since planktic foraminifera are deep-ocean surface dwellers, they are commonly not present on shallow shelf areas unless they are being advected. In this paper the down-core species

composition is studied in a sediment core from a shallow Siberian shelf and from the Central Arctic Ocean. The purpose of this study is to document the occurrence of unusual species which were up to now never known to occur in Holocene sediments from this region, and to discuss various possibilities regarding the origin of these species.

### Water masses and depositional environment

The modern oceanography of the Arctic Ocean is influenced by waters from three main sources. Through Fram Strait and across the Barents and Kara seas high-salinity water of Atlantic origin enters the Eurasian basin of the Arctic Ocean within the upper 600 m of the water column (Rudels, 1995; Hanzlick, 1983). To a much lesser degree Pacific surface water flows in via the Bering Strait (Coachman et al., 1975). Besides these marine sources, the Arctic Ocean is also fed by a vast fluvial freshwater runoff. This water mainly derives from large Siberian rivers such as the Ob, Jenisey, and Lena rivers. Although the contribution of the total mass of this river water to the Arctic Ocean is relatively low in comparison to the other two sources, it is of major significance for the formation of a distinct halocline. Furthermore, increased cooling processes on the shelf areas during fall season subsequently leading to sea ice formation favours the release of brines (Aagaard and Carmack, 1989). This process is responsible for much of the water mass transformation within the Arctic Ocean circulation system.

The bulk of Siberian shelves are rather shallow on average (<50 m) whereas the continental slope exhibits a steep break at ~100 m water depth. The topography of the Laptev Sea is marked by a gently northerly dipping plain cut by various submarine valleys (Holmes and Creager, 1974). These channels are linked to the mouths of the major rivers and run along preformed tectonic structures (Drachev et al, in press). The freshwater from these rivers not only reduces the salinity at the surface, it also influences the temperature of the surface water during summer, which can reach 8-10°C or more (Baskakov et al., 1987). Farther off the shelf, temperatures within the halocline are - 1.8° C on average. Below the halocline Atlantic core water with temperatures of ~1.5° C is noted (Timokhov, 1994). The Atlantic water flows along the continental slope of the Barents and Kara seas before reaching the Laptev Sea slope. Nevertheless, the Atlantic water does not seem to flow onto the Laptev Sea shelf itself (Schauer et al., 1997). The fate of the Pacific surface water in the Arctic Ocean is not very well known. This surface water has a distinct silicate signature (Walsh et al., 1989) and may be used as a suitable tracer (Bauch et al., 1994).

Previous investigations on grain-size analyses in surface sediments from the Laptev Sea showed that sediments are generally finer in the eastern part where silty clays dominate the surface pattern (Lindemann, 1995; Rossak 1995). To some extent this pattern is due to different amounts of suspended sediment material transported onto the shelf by the main rivers (Alabyan et al., 1995). Another source for sediment supply is coastal erosion (Aré, 1988). By incorporation into sea-ice these sediments can be transported far distances across the shelf (Eicken et al., 1997). Biogenic carbonate is rare in these sediments (Bauch et al., 1995) as compared to those Eurasian shelf areas which are under the influence of Atlantic surface water (Hald and Steinsund, 1996).

### Sample processing and counting technique

The studied gravity core (IK 9373-10) from the Laptev Sea shelf was taken onboard RV *Ivan Kireyev* during the Russian-German Transdrift I expedition in 1993 (Figure 1). Core IK 9373-10 was retrieved from a water depth of 47 m and has an overall sediment recovery of 109 cm (Kassens and Karpiv, 1995). The site is located within the so-called Yana valley in the eastern

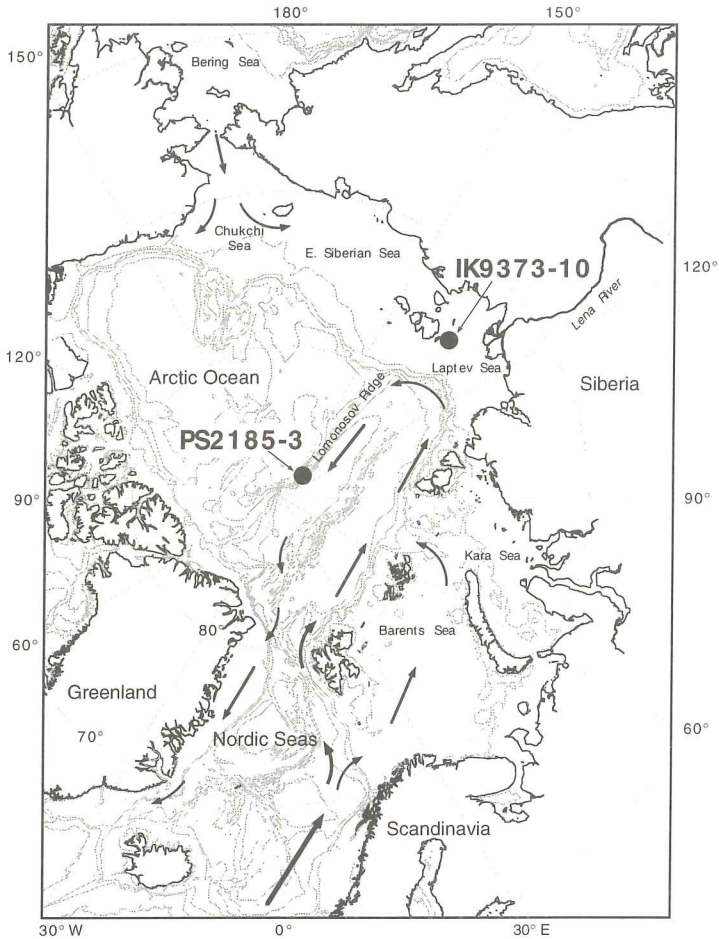


Figure 1: Map of the Arctic Ocean showing the general circulation pattern of the surface/sub-surface water mass flow into the Arctic basins (modified from Rudels, 1995). The position of the two studied cores are indicated.

Laptev Sea (75°20,8' N / 135°12,3' E). Samples were taken at 5 cm intervals as 2 cm thick slices. Prior to washing, all samples were frozen and dehydrated. In order to prevent the formation of aggregates during washing the sediments had to be treated with hydrogen peroxide. All samples were then wet-sieved over 63  $\mu\text{m}$  meshsize, and eventually dried in an oven at 50° C. It was already realized during the early part of the sample processing that faunal constituents will remain rather low in this core due to small amounts of sample residues >125  $\mu\text{m}$ . Therefore, the > 63 $\mu\text{m}$  size fraction was left unsplit in order to take into account every specimen for the qualitative and quantitative determination down to species level. Later quantifications are expressed as specimens per weight of the dried bulk sediment and as relative abundances.

The second core, PS2185-3, originates from the Lomonosov Ridge in the Central Arctic Ocean (87°32' N / 144°22.9' E) and was taken from 1051 m water depth during cruise ARCTIC '91 (Fütterer, 1992). Samples of this trigger box core were taken in 1 cm steps.

Faunal counts were carried out in two separate size-fractions (125-250  $\mu\text{m}$ , and 250-500  $\mu\text{m}$ ). In order not to miss any small-sized species, which do occur in high-latitude glacial and interglacial sediments below the lower limit of the used mesh size (Kellogg, 1984; Bauch, 1994; Hebbeln et al., 1994), the size-fraction 63-125  $\mu\text{m}$  was also carefully checked.

Table 1: List of radiocarbon measurements of core IK9373-10

Lab. No.	Depth in core (cm)	age (y BP-400y)
AAR-2253	32.5	1150 $\pm$ 75
AAR-2254	53.5	1420 $\pm$ 45
AAR-2255	62.5	1540 $\pm$ 55
AAR-2256	71.5	1760 $\pm$ 55
AAR-2257	80.5	1670 $\pm$ 70
AAR-2258	89.5	1955 $\pm$ 60
AAR-2259	100	2150 $\pm$ 60

### Age model

The age model of core IK 9373-10 is based on several radiocarbon datings. These datings were performed on bivalve shells (*Portlandia sp.*) at the AMS-laboratory of Aarhus University in Denmark (Table 1). All datings are corrected for a  $^{14}\text{C}$  reservoir effect of 400 y (original ages are between 300-500 y). This reservoir age of 400 y, which seems slightly younger than reservoir ages recently published for the Barents and Kara seas (Forman and Polyak, 1997), is based on pre-bomb mollusc shells (Bauch and Heinemeier, unpubl.) and is additionally corroborated by the method of 'supported  $^{210}\text{Pb}$ ' performed on the same core (Erlenkeuser, unpubl. data).

As is revealed by the depth/dating relation in Table 1, there is an age reversal between 80-70 cm. This age reversal is marked by two datings, and because the errors of these two datings overlap an interpolated age of the mid-depth between the two datings was calculated and used for the final age model (Figure 2). Ages between all dated samples were calculated by assuming a constant sedimentation rates between these points. From the original  $^{14}\text{C}$ -age measurements follows that the sedimentation rates above the uppermost dating steeply decreases towards the sediment surface. Because it was not possible to produce a dating for the upper section of core IK9373-10, it is assumed that either sedimentation ceased after 700 y BP or that this area became eroded after this time. Thus sediment ages in the upper- and lowermost section of the core were estimated by extrapolation. According to this modified age model, core IK9373-10 covers the time interval 2500-500y BP with sedimentation rates varying between 55-77 cm/ky.

The age model of the core from the Central Arctic Ocean is based on a series of 13 AMS  $^{14}\text{C}$  datings performed on *N. pachyderma sin.* (Spielhagen et al., 1997; Nørgaard-Pedersen et al., in press). The shown record goes back to about 34 ka BP (at 20 cm core depth). Sedimentation rates for the Holocene section above the end of the last deglaciation are of the order of 1 cm/ky.

### Faunal records

#### *Species composition*

A list with all identified planktic foraminiferal species together with the approximate time of

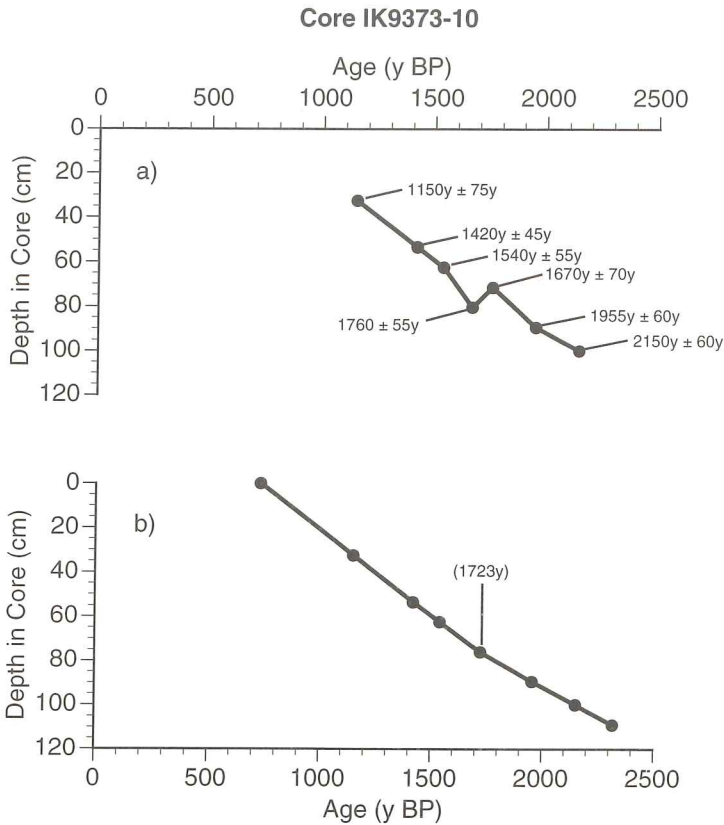


Figure 2: Age/depth relation of core IK9373-10 from the eastern Laptev Sea: a) original radiocarbon measurements (after subtracting 400 y to account for the reservoir effect) showing an age reversal; b) final age model used in this study. The grey dots at the lower and upper end of the curve are based on interpolation. The age in parentheses represents the calculated age between the two datings which marks the age reversal (see also Table 1).

their first stratigraphical occurrence as well as their presumed main latitudinal distribution is given in Table 2. From this list it follows that all species are extant. Although, individual stratigraphical records can go back to the Late Oligocene, most species first occurred some time during the Miocene or Pliocene. Apart from the polar species *N. pachyderma* and the subpolar species *G. bulloides* and *G. glutinata*, *Globoturborotalita tenella* and *Turborotalita clarkei* usually reflect much warmer water masses. All non-polar species were found on the Laptev Sea shelf. Samples from the Lomonosov Ridge only yielded the right and left coiling variety of *N. pachyderma*.

Species from core IK9373-10 are illustrated in Plate 1. Intriguing is the very small test sizes of *T. clarkei*, which range well below 100  $\mu\text{m}$  in diameter. These generally small tests have been noted before and may be the major reason why this species is so often not recognized in most sediment studies (Boltovskoy, 1991).

#### *Temporal variability on Laptev Sea Shelf*

The record of total test concentration from core IK9373-10 reveals that planktic foraminifera

occur during few specific time intervals only (Figure 3). Accordingly, highest abundances are recognized between 800-1000 a BP and between 1600-1900 a BP. Comparing the relative abundances of individual species with the record of total test concentration clearly indicates that *T. clarkei* is by far the dominant species during these intervals. All other species remain inferior to *T. clarkei* and, moreover, never reach significant numbers even during other intervals.

Table 2: List of identified species from the investigated cores. Species names according to Hemleben et al. (1989). Biogeographical distribution and stratigraphical first occurrence (FO) is based on Kipp (1976), Kennett and Srinivasan (1983), Bolli and Saunders (1984), and Boltovskoy (1991). \* biogeographical distribution strongly depending on coiling direction.

Species	FO/Biogeography
<i>Globigerina bulloides</i>	Middle Miocene/subtropical-subpolar
<i>Globigerinita glutinata</i>	Late Oligocene/tropical-subpolar
<i>Globoturborotalita tenella</i>	Late Pliocene/tropical-temperate
<i>Turborotalita clarkei</i>	Late Miocene/tropical-temperate
<i>Neogloboquadrina pachyderma</i> *	Late Miocene/subtropical-polar

#### Temporal variability on Lomonosov Ridge

The record from the Central Arctic Ocean consists essentially of a two-species assemblage with *N. pachyderma* sin. being the dominant species (Figure 4). This species makes up 94-99 % of all tests. The remainder proportion is due to *N. pachyderma* dex. A comparison of the test concentrations of the two species indicates fairly good corresponding records throughout the past 35 ka. In general, the two records show significantly reduced deposition of tests during the last glaciation. The concentration of tests only begins to increase after the end of the deglaciation, and reaches highest numbers in the later Holocene. Despite the good conformity of the two records, the relative abundances reveal a less proportional relation between both species. A comparatively strong dominance of *N. pachyderma* sin. is found between 15-20 ka, i.e., during the last glacial maximum (LGM). During the deglacial phase (15-9 ka) this dominance becomes less until relatively low values are noted between 6-8 ka. The mid-Holocene is marked by a significant shift at 3-4 ka although test concentrations steadily increase already after about 7 ka.

#### Discussion

##### *Origin of planktic foraminifera in Arctic sediments of Holocene age*

The occurrence of unusually warm-water indicating planktic foraminifera in upper Holocene sediments from the Laptev Sea shelf is intriguing in itself, but cannot be easily answered considering the modern pathway of surface water flow in the Arctic Ocean. At present it is difficult to reconcile the fact that these species from a tropical-temperate provenance can be advected to the very shallow Laptev Sea shelf or that they have lived in this region during any time of the Holocene. So far, species such as *G. tenella* or *T. clarkei* have not been reported from areas such as the Nordic seas (e.g., Kellogg, 1984; Bauch, 1994) from where the main mass of non-polar water masses is advected to the Arctic Ocean. On the other hand species such as *G. bulloides* and *G. glutinata* may more likely invade the Laptev Sea via Atlantic derived waters across the Barents Sea or along the Eurasian continental margin. A recent downcore

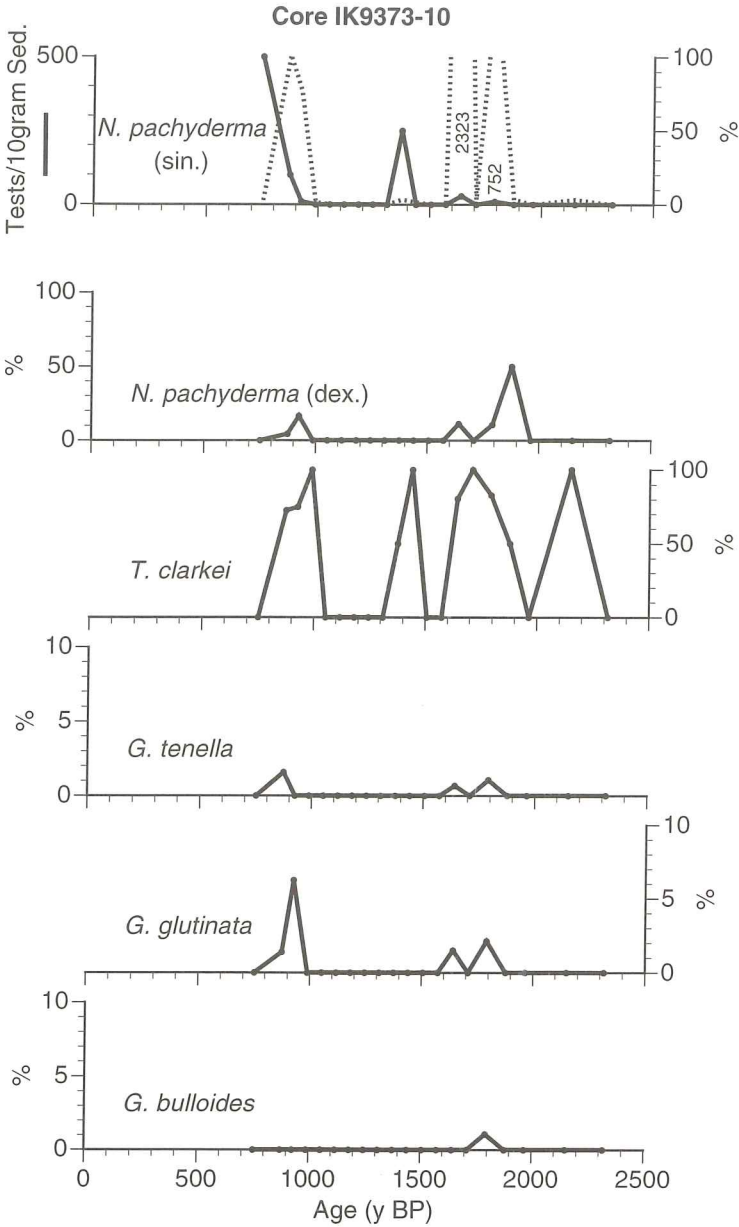


Figure 3: Variability of planktic foraminifera in core IK9373-10 from the Laptev Sea during the late Holocene.

study at the continental slope of the Laptev Sea has yielded some specimens of *G. ruber* in deglacial sediments (R.F. Spielhagen pers. com. 1997). Furthermore, ongoing investigations in this region has confirmed the presence of *G. ruber* even in surface sediments (R. Volkman pers. com. 1997) - it should be noted at this point that species such as *G. ruber*, *G. tenella*, and

*G. rubescens* are evolutionary closely linked (Kennett and Srinivasan, 1983) and are morphologically also quite similar. In Laptev Sea surface sediments only very few specimens of *G. bulloides* and *N. pachyderma* have been reported so far (Tamanova, 1971). This generally low number of specimens appears to be typical in this area and is corroborated by more recent studies (Rossak, 1995; Bude, 1997).

Because a direct water mass influence from outside the Arctic Ocean seems unlikely to be responsible for the occurrence of warm species in Holocene sediments, other processes such as coastal erosion and reworking of older sediments may be considered. Although not mapped in detail, cliffs composed of Miocene and Pliocene sediments are known to occur along the eastern shores of the Laptev Sea (Okulitch et al., 1989 Arctic Map) and are confirmed by recent field observations (A. Basilyan, G. Ivanenko, P. Nikolskiy pers. com. 1997). Previous drilling in the SE Laptev Sea yielded sediment successions down to the lower Miocene (Sudakov et al., 1991). But these sediments are shallow water sediments - like those from the terrestrial outcrops - containing typically shallow-marine and freshwater microfossils. Furthermore, detailed studies of the diatom and palynomorph assemblages in Laptev Sea surface sediments as well as in core IK9373-10 could not confirm the possibility of reworking of older sediments (Cremer, 1997; Kunz-Pirring, this volume). However, previous studies have shown that sediment transport by sea-ice is of major importance for sediment dynamics on Arctic shelves (Kempema et al., 1989; Eicken et al., 1997). Thus, sediment entrainment from shallow Arctic shelves and the later release of these sediments (Reimnitz et al., 1987) may be a possible mechanism to explain far-distance transport of recent or even much older fossil remains (Abelmann, 1992; Reimnitz et al., 1992). The mean field of sea-ice motion along the east Siberian shelves is from Bering Strait towards the Laptev Sea (Rigor, 1992). So, if the findings of warm-water foraminifera in the Laptev Sea is due to sea-ice transport then the actual source may be sought further east. But 'exotic' (mostly subtropical) planktic foraminifera have also been reported from various Holocene and glacial deposits in the Barents and Kara seas area (Gudina, 1966; Blaschishin et al., 1985; Khusid et al., 1995).

## Conclusions

With the data presently available it is not possible to decipher the origin of the warm water foraminiferal species in the Laptev Sea. It remains speculative if they had derived from sediments deposited during times when subtropical water masses are known to have reached the Arctic Ocean (Spiegler, 1996) or if they are of Holocene age. To eventually verify that the findings of warm foraminiferal species in the Laptev Sea are actually caused by water inflow during the Holocene further investigations are needed with regard to their true age. This certainly should involve large quantities of sediment sampling in the hope that these large samples may yield sufficient numbers of specimens for radiocarbon analyses.

Based on the foraminiferal record from the Lomonosov Ridge it is evident that the Arctic Ocean fauna is composed of a single genus. Although this area is marked today by a perennial coverage of sea-ice close to 100% with water temperatures in the upper 200 m well below 0° C (Rudels, 1995), foraminiferal bioproductivity has increased steadily since about 7 ka. It is therefore suggested that an inflow of non-polar water masses into the Arctic has a notable influence on planktic productivity even at remote sites such as investigated in the central Arctic Ocean. The relative changes of up to 5 % noted in the two coiling varieties of *N. pachyderma* cannot be related to variations in surface water temperatures and, thus, seems independent of major glacial-interglacial climate changes. The variability of the two coiling forms is more likely caused by unknown population dynamics. To what extent the relatively small amount of Pacific surface water inflow through Bering Strait (Coachman and Aagaard, 1988) is also influencing



the central Arctic foraminiferal productivity is not known. There are no reports regarding planktic foraminiferal species in sediments from the Chukchi and East Siberian seas which could give information on this issue. But as can be deduced from the modern sub-surface circulation in the eastern Arctic Ocean (see Figure 1), the site of PS2185-3 is under influence of Atlantic water. It is therefore suggested that the increase of planktic foraminifera after 7 ka appears to be related to circulation changes in the Nordic seas, i.e., the onset of Atlantic-derived surface water inflow to the eastern Arctic Ocean.

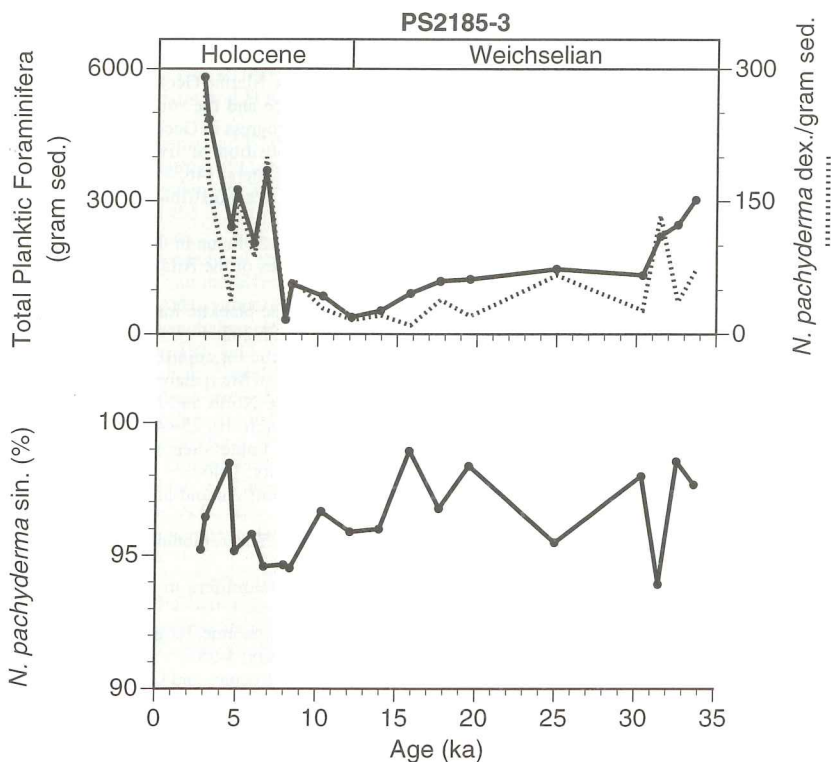


Figure 4: Variability of planktic foraminifera in the left and right coiling variety of *N. pachyderma* in core PS2185-3 from the Lomonosov Ridge during the past 35 ka. Shaded area marks the time interval after the last deglaciation when total number of test concentrations indicate enhanced foraminiferal productivity.

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## Plate I

SEM photographs of non-polar planktic foraminifera of core IK9373-10.  
Numbers in parentheses indicate magnification.

1. *Globoturborotalita tenella* (x 650)
2. *Globoturborotalita tenella* (x 250)
3. *Globoturborotalita tenella* (x 150)
4. *Globigerinita glutinata* (x 200)
5. *Globigerinita glutinata* (x 280)
6. *Globigerina bulloides* (x 100)
7. *Turborotalita clarkei* (x 360)
8. *Turborotalita clarkei* (x 380)
9. *Turborotalita clarkei* (x 360)
10. *Turborotalita clarkei* (x 310)
11. *Turborotalita clarkei* (x 350)

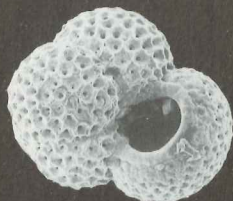
Plate 1



1



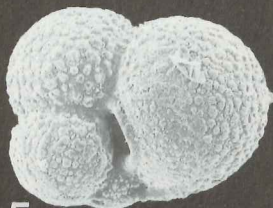
2



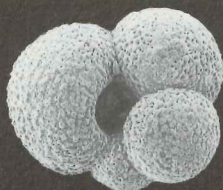
3



4



5



6



7



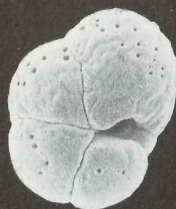
8



9



10



11