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Last postglacial environmental evolution of the Laptev Sea shelf as reflected in molluscan, ostracodal, and foraminiferal faunas

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Abstract

Temporal and spatial variations in the species composition of modern and Holocene assemblages of molluscs, ostracods, and foraminifers from the Laptev Sea shelf (Arctic Siberia) have been investigated to reconstruct palaeoenvironmental changes during the last postglacial times and associated sea-level rise. Analysis of coretop sediment samples allowed to distinguish four modern assemblages. The specific habitat preferences of these species groups, such as water depth and salinity, were then used to interpret past environmental changes on the basis of two radiocarbon-dated sediment cores from the eastern middle shelf region, i.e., obtained from the Yana (51 m water depth) and Lena (45 m water depth) palaeovalleys.

Despite the water depth difference of the two core sites, all downcore data document uniform fossil evidence for a gradual transformation of the Laptev Sea shelf from a terrestrial to a marine environment due to the southward transgressing sea. Three major phases have been recognized. These reflect: (1) a nearshore brackish-water environment of the initial stage of inundation (11.3–11.1 in the Yana and 11.2–10.8 cal. ka in the Lena palaeovalley); (2) a shallow inner-shelf, fluvially affected environment (11.1–10.3 and 10.8–8.2 cal. ka); (3) a modern-like marine environment which eventually became established since 10.8 and 8.2 cal. ka, depending on the specific water depth of each core site.

Keywords: Holocene; Laptev Sea shelf; palaeoenvironment; molluscs; ostracods; foraminifers

1. Introduction

Because of lowered global sea-level during the last glaciation the vast Laptev Sea shelf was subaerially exposed but not covered by continental ice sheets

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(Svendsen et al., 1999). At this time, the major Siberian rivers remained active, draining directly from the shelf edge into the Arctic Ocean (Kleiber and Niessen, 2000). Due to the subsequent global sea-level rise this area became rapidly inundated during late glacial and early Holocene times (Bauch et al., 1999, 2001a,b). Based on a number of proxies constrained by radiocarbon datings, it became possible to construct a chronology and some characteristic sedimentological features of this transgression (Bauch et al., 1999, 2001a,b; Peregovich et al., 1999; Mueller-Lupp et al., 2000). The palaeoenvironmental changes caused by sea-level rise and the gradual southward retreat of river mouths and the coastline were accompanied by drastic changes in water mass properties, i.e. from a fluvial–terrestrial to a dominantly marine environment, a situation which should also be expressed in downcore variations of fossil benthic assemblages.

Based on previously obtained data, the distribution of modern benthic organisms over the Laptev Sea shelf was shown to be strongly related to certain environmental parameters, notably water depth and salinity (Tamanova, 1971; Sirenko et al., 1995; Bude, 1997; Gukov, 1998; Petryashov et al., 1999; Stepanova et al., 2003). Studies of the late Pleistocene–Holocene assemblages of foraminifers, ostracods, and molluscs have been carried out on the shelves and uplifted coasts of other arctic and high-latitudinal seas (see for example Cronin, 1977; Vilks et al., 1979; Lev, 1983; McDougall et al., 1986; Brouwers, 1988; Syvitski et al., 1989; McDougall, 1994; Kupriyanova, 1999; Gordillo and Aitken, 2001). Such investigations allowed to reconstruct temporal changes in the bottom water palaeoenvironment. However, until now only little was known about the distribution of calcareous macro- (molluscs) and microfossils (ostracods and foraminifers) in Holocene sediments of the Laptev Sea (Bauch et al., 1995; Bauch, 1999). The intention of this study is, therefore, to show how benthic fossil assemblages in the Laptev Sea sediments reflect the major palaeoenvironmental changes on this shelf since the early Holocene. For this purpose, we investigated fossil assemblages of molluscs, ostracods, and foraminifers from two sediment cores recovered from the eastern Laptev Sea shelf and compared them with the recent assemblages from coretop sediment samples obtained from different parts of the Laptev Sea.

2. Modern depositional and environmental setting of the Laptev Sea shelf

The Laptev Sea is an open marginal sea of the Arctic Ocean bounded by the Taimyr Peninsula on the west and New Siberian Islands on the east (Fig. 1). Its shelf has a shallow topography, gently sloping northward down to water depths of 50–60 m. The shelf break is located around 80–100 m water depth. The shelf is cut by a number of palaeoriver valleys (Fig. 1), which were probably formed during times of glacial sea-level lowstands (Holmes and Creager, 1974). Since the early stage of the last global sea-level rise these valleys have been identified as the main areas of sediment accumulation (Bauch et al., 1999; Mueller-Lupp et al., 2000). River discharge remains one of the main factors for sediment accumulation on the Laptev Sea shelf resulting in a higher proportion of the fine sediment fraction and organic matter content in the eastern part of the sea, where outflow from the Lena River is dominant (Lindemann, 1995; Stein and Nürnberg, 1995; Stein and Fahl, 2000). Besides the input of sedimentary matter discharged by rivers, considerable amounts of terrestrial material were supplied to the Laptev Sea shelf by coastal and seabed erosion during the Holocene transgression (Bauch et al., 1999; Rachold et al., 2000).

Due to considerable river runoff in early summer and ice formation during the other seasons, salinity is the most variable feature of the Laptev Sea shelf waters which affects the spatial distribution of benthic species. In general, both surface and bottom water salinities are lower in the eastern Laptev Sea, where the average bottom salinity ranges from 18 to 20 in the shallow southeastern region to 30 to 34 at the depths exceeding 30 m (Fig. 2).

At mid-depths of the Laptev Sea, bottom water temperatures are negative nearly all year around (approx. − 1.5 °C). But on the upper continental slope, at depths exceeding 80–100 m, temperature rises up to 0.6–0.8 °C due to the influence of warmer, Atlantic waters from the north (Dobrovol’skii and Zalogin, 1982, see also Table 1). Recent investigations have

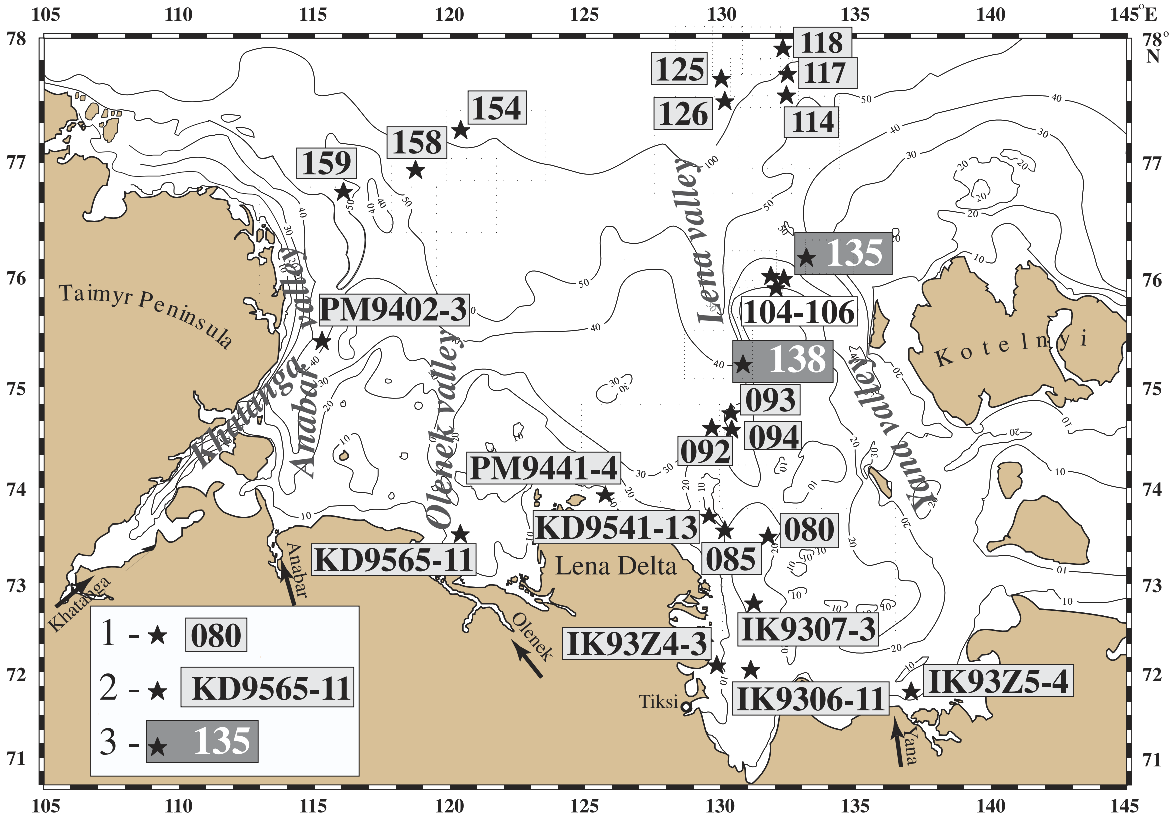

Fig. 1. Bathymetric chart of the Laptev Sea shelf (in meters) and location of the studied sites. 1—core sites from TRANSDRIFT V; 2—core sites from TRANSDRIFT I (IK93), II (PM94), and III (KD95); 3—sediment cores sampled for fossil assemblage studies.

shown that at times strong southerly winds produce bottom counter-currents that lead to a southward advection of slightly warmer and saline water masses from the north into the palaeovalleys. Therefore, the palaeovalleys are important areas of interaction between the Arctic Ocean and the Laptev Sea water masses (Dmitrenko et al., 2001a). These counter-currents also cause resuspension of bottom sediments and transport them onto the inner shelf (Wegner, 2003). In the mid-shelf region, where ice-free leads (flaw polynya) usually form in wintertime (Dmitrenko et al., 2001b) separating the fast ice from the region with drift ice, this process is pronounced all year around (Wegner, 2003). Specific hydrological, cryological, and depositional conditions in this part of the eastern Laptev Sea shelf seem to affect the distribution of both plankton and benthos (Petryashov et al., 1999; Gukov, 1999; Bauch and Polyakova, 2000).

3. Location, material, and methods

In this study we investigated two sediment cores obtained from the eastern Laptev Sea mid-shelf during the Russian–German TRANSDRIFT V expedition in 1998, also including coretop sediment samples collected from other parts of the shelf during previous TRANSDRIFT expeditions (Table 1 and Fig. 1).

Surface samples from the TRANSDRIFT V expedition were collected using a giant trigger box-corer. A total of 36 (2 samples per station) undisturbed surface samples (approximately the upper 1 cm) were taken at 18 stations covering a water depth range from 21 to 276 m (Table 1). Coretop samples from the other TRANSDRIFT expeditions were taken from both trigger box and gravity kasten cores. Both sets of samples from the TRANSDRIFT V expedition were treated differently. The first set was stained with Rose Bengal, washed over the 63-μm-mesh size sieve

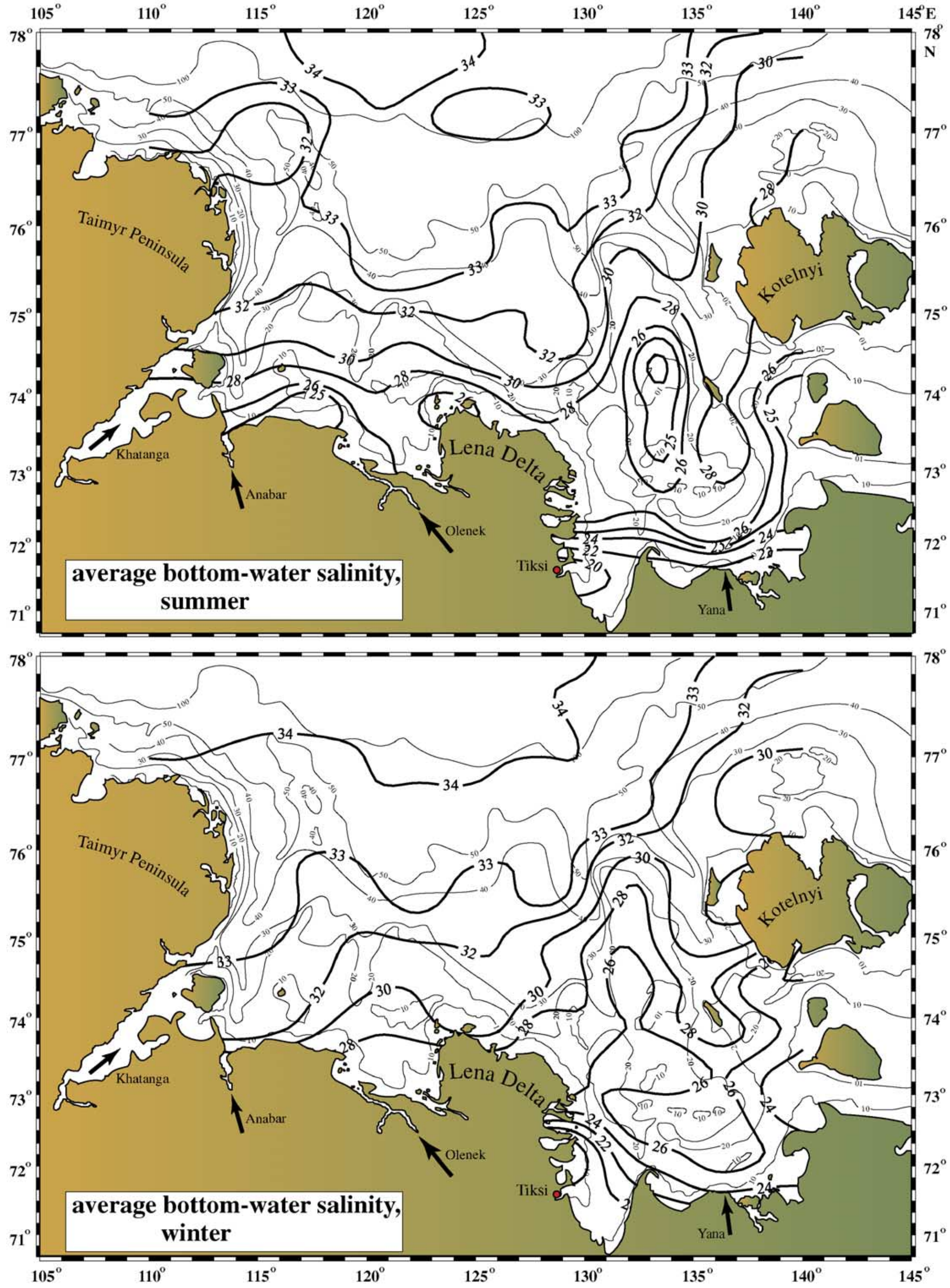

Fig. 2. Bathymetry (in meters) in comparison with average bottom salinity: A—in summer, B—in winter (from Stepanova et al., 2003).

Table 1
Location of stations, water depth, environmental data, and percentage of live ostracod specimens

Station	Water depth (m)	Latitude	Longitude	T (°C)	Salinity	Sediment	Live ostracod specimens (%)
Western Laptev Sea							
Upper continental slope							
PS-51/154-9	276.4	77°16.61N	120°36.03E	0.395	34.708	sandy silt	97
Outer shelf							
PS-51/158-8	68	76°57.49N	118°35.37E	−1.481	33.488	sandy silt	96
PS-51/159-8	61.6	76°45.99N	116°01.86E	−1.617	33.687	clayey silt	95
Middle shelf							
PM9402-3	47	75°29.44N	115°14.94E				
Central Laptev Sea							
Upper continental slope							
PS-51/125-12	127	77°36.09N	130°00.07E	−1.54		silty sand	95
PS-51/118-1	121	77°53.6N	132°12.57E	−0.7		sandy silt	80
PS-51/126-2	85	77°32.9N	130°07.9E	−1.54		silty sand	90
Outer shelf							
PS-51/117-3	76	77°49.8N	132°14.42E	−0.949	34.105	sandy silt	92
PS-51/114-13	66	77°35.52N	132°15.82E	−1.345	33.776	sandy-silty clay	99
Eastern Laptev Sea							
Middle shelf							
PS-51/135-2	51	76°09.93N	133°14.78E	−1.6		sandy silt	100
PS-51/138-10	41	75°09.18N	130°49.75E	−1.648	33.219	sandy silt	100
PS-51/104-14	34	75°57.83N	132°09.06E	−1.565	32.638	sandy silt	100
PS-51/106-1	33	75°56.97N	132°04.39E	−1.5		silty sand	90
PS-51/105-3	33	75°57.2N	132°06.13E	−1.590	32.821	sandy silt	94
Southern Laptev Sea							
Inner shelf							
PS-51/092-11	34	74°35.5N	130°08.4E	−1.584	32.427	sandy-silty clay	100
PS-51/093-1	33	74°56.74N	130°34.15E	−1.608	32.992	sandy silt	100
PS-51/094-3	31	74°33.36N	130°27.2E	−1.592	32.673	silty sand	
PS-51/085-2	22	73°33.9N	131°16.3E	−1.086	27.896	sandy-silty clay	98
PS-51/080-11	21	73°27.83N	131°39.0E	−1.062	23.407	silty clay	85
Nearshore region							
IK9307-3	20.7	72°32.97N	131°17.80E			mud	
IK9306-11	17.5	72°00.63N	130°59.23E			clay	
IK93Z4-3	14	72°01.90N	130°07.55E			silty clay	
IK93Z5-4	11	71°41.41N	137°00.40E			mud	
PM9441-4	14	74°00.00N	125°59.29E				
KD9541-13	22	73°22.80N	129°56.57E			clayey silt	
KD9565-11	21	73°50.76N	120°19.00E			sandy silt	

onboard and later used for analysis of molluscs and ostracods. The percentage of ostracod species collected alive was estimated (Table 1). The second set of sediment samples was freeze-dried, weighed, and also washed over a 63-μm-mesh size sieve. After sieving, molluscs, ostracods and foraminifers were picked, identified and counted. Abundances of molluscs were expressed as specimens per sample (~500 cm^2). Abundances of ostracods and foraminifers were calculated per 100 g of dry bulk sediment. For the second, unstained, set of samples, the percentage of different ecological groups of ostracod species was estimated, namely marine and euryhaline together with brackish-water types.

Fossil molluscs, ostracods, and foraminifers were studied in two Holocene core sections from the middle shelf area (Fig. 1). Gravity kasten core PS-51/138-12 was recovered from 45 m water depth in the eastern Lena palaeovalley (sediment recovery 530 cm), and gravity kasten core PS-51/135-4 from 51 m water depth in the Yana palaeovalley (total sediment recovery 562 cm, including core catcher). Since the upper 32 cm of sediments in core PS-51/138-12 were lost during coring, we also sampled trigger box core PS-51/138-10 (39 cm long) from the same locality. Samples from core PS-51/138-12 were taken continuously in 3-cm-thick slices, and the samples from the box core in 2-cm-thick slices. All downcore samples were freeze-dried and subsequently washed over a 63-μm-mesh size sieve to determine the percentage of sand-size fraction. The total abundance of microfossils is expressed as specimens per 100 g of the dry bulk sediment. Molluscs from core PS-51/135-4 were collected onboard, as well as later from the additional samples taken as 3-cm-thick slices at 20- to 30-cm intervals. Ostracods and foraminifers were studied from the washed samples.

The chronology of the cores is based on radiocarbon ages from marine biogenic calcite (single bivalve shells, and in one case mixed microfossils) determined by means of accelerator mass spectrometry (AMS) at the Leibniz Laboratory in Kiel (Table 2). The quality of preservation of the dated shells was good. These were either found in situ with both valves in place, or with the periostracum still preserved. While converting the AMS^{14}C dates to calendar years BP (cal. ka) using the CALIB 4.3 (Stuiver et al., 1998), the determined reservoir age of 379 ± 49 years for the modern Laptev Sea was subtracted (Bauch et al., 2001b).

4. Results

4.1. Faunal distribution in coretop samples

4.1.1. Bivalves

Although both bivalves (Table 3) and gastropods were recorded in the coretop samples, the latter were rarely found. Bivalves are of low abundance and diversity on the eastern middle shelf (30–50 m water depth) (Table 3). Their taxonomic diversity is rather uniform averaging 5–6 species per sample with the highest values recorded in the west (10 species per sample). However, species composition is quite different in the various parts of the sea

Table 2
Bivalve species, radiocarbon dates, calibrated calendar years of cores PS-51/138-12 and PS-51/135-4, eastern Laptev Sea shelf

Core/Lab #	Depth (cm)	Bivalve species	^{14}C age (years)	Calibrated age (years)
PS-51/138-12				
KIA-11040	52.5	*Nuculana lamellosa lamellosa*	2905 ± 30	2734
KIA-12929	141.5	*Nuculana* sp.	7605 ± 50	8102
KIA-12930	161.5	*Leionucula bellotii*	7745 ± 50	8213
KIA-11041	197.5	*Portlandia arctica*	9440 ± 50	10,274
KIA-11042	300	*Portlandia arctica*	9685 ± 50	10,333
KIA-11043	520	*Portlandia aestuariorum*	10,260 ± 55	11,168
PS-51/135-4				
KIA-6910	4	*Leionucula bellotii*	bomb	0
KIA-6911	8	*Macoma* cf. *calcarea*	4920 ± 40	5301
KIA-6912	40	*Yoldia amygdalea hyperborea*	6480 ± 50	7017
KIA-6913	80	*Nuculana* sp.	7100 ± 55	7610
KIA-13071	147	mixture of foraminifers and ostracods	8460 ± 70	8956
KIA-6915	266	*Macoma calcarea*	8945 ± 55	9613
KIA-6916	403	*Portlandia arctica*	9580 ± 45	10,306
KIA-6917	456	*Portlandia arctica*	10,187 ± 60	11,142
KIA-6918	562	*Portlandia arctica*	10,360 ± 55	11,339

Table 3
Bivalves in coretop samples (j—juvenile valves)

Species/Station	Eastern inner shelf region					Eastern mid-shelf region					Central Laptev Sea					Western Laptev Sea		
											Outer shelf		Upper continental slope			Upper continental slope	Outer shelf	
	080	085	092	093	094	138	104	105	106	135	114	117	118	125	126	154	158	159
Leionucula bellotii	10 2j	12j	14 3j	5 4j		5	2j	1 14j	6	4 44j				8j	2j	2j		2 16j
Nuculana lamellosa			2			1						1 1j						
Nuculana pernula				4	4j	2j												2j
Nuculana minuta						2												
Nuculana sp.											4j							
Portlandia arctica	80~350 j	46~200j	4 16j			3 4j				4 2j		2					18j	12
Yoldiella intermedia								2j			3		3		2		5	4
Yoldiella fraterna											90 12j	16 8j	37	5	32	14	18 4j	12
Yoldiella spp.								2j		2j	14j	26j	29j	2 10j	22j	15j	6j	24j
Mixture of juveniles (*Portlandia, Yoldiella)*																		~100j
Arctinula groenlandica												2 15j	6 14j	1j		2 12j	1 6j	7 20j
Dacrydium vitreum											2j	1 20j	16 10j	8j	3 12j	1 8j	5~150j	8 2j
Clinocardium ciliatum		2																2j
Astarte borealis		10 2j																
Astarte montagui	2 1j	16 24j					8	8						6j		2 2j		
Thyasira gouldi	2															1j		
Axinopsida orbiculata	4											2j						
Macoma calcarea			4															
Macoma sp.			6j	6j			4j	2j										
Lyonsia arenosa	1		3 6j		1			4j										
Lyonsia sp.													2j					
Pandora glacialis		4j																
Pandora sp.													1					
Cuspidaria cf. *arctica*																1		
Cuspidaria glacialis																2		4
Cuspidaria sp.															2j	2		2j
Lyonsiella abyssicola																2		
Total number of species per sample (*Yoldiella* spp. and a mixture of juvenile *Portlandia* and *Yoldiella* were not considered as a single species)	6	6	6	3	2	5	3	5	1	2	4	6	6	6	5	10	5	10

(Table 3). There is a clear difference between assemblages of the shallow, eastern shelf and those of the outer shelf and upper continental slope (water depths >60–70 m), which are dominated by relatively deep-water species Yoldiella, *Dacrydium vitreum*, *Arctinula groenlandica* with admixture of Cuspidaria and *Lyonsiella abyssicola*.

The distribution and abundance patterns of the two species, *Portlandia arctica* and *Leionucula bellotii*, are particularly interesting. *Portlandia arctica* is extremely abundant at two localities near the Lena Delta, at 21 and 22 m water depth, where both adult and juvenile valves are present. Another abundance peak is observed in the Khatanga submarine valley. *Portlandia arctica* is also present in the Lena and Yana submarine valleys. Thus, *P. arctica* seems to be clearly restricted to the shallow areas offshore the river mouths and submarine valleys, where fine-grained bottom sediments enriched in organic matter are dominant. Although found throughout the Laptev Sea (Richling, 2000), *P. arctica* is most common in the coastal zone affected by strong river runoff and salinity range from 18 to 30, where it is the dominant species of a homonymous macrobenthic community (Sirenko et al., 1995; Petryashov et al., 1999). *Leionucula bellotii* is especially abundant in coretop samples from the eastern mid-shelf in water depths from 30 to 50 m (Table 3). The biocoenosis dominated by *L. bellotii* (Sirenko et al., 1995; Petryashov et al., 1999) generally coincides with the position of the winter polynya in the eastern Laptev Sea, within water depths ranging from 20–25 m to about 40–50 m and a bottom salinity remaining around 30–32.

4.1.2. Ostracods

Data on modern ostracods from the Laptev Sea are already described in detail in Stepanova et al. (2003), since only a summary is presented here. The highest abundance of ostracods in coretop samples was observed in the eastern inner shelf area and in the Khatanga palaeovalley (Tables 4 and 5; Fig. 1). Like in the case with bivalves, the lowest abundance was recorded in the eastern mid-shelf region. Most ostracods were alive when collected (Table 1). Juveniles were rare and reported only from the western-central shelf area. Such an insignificant share of dead valves and low abundance of thin-shelled juveniles may point to active post-mortem transportation of valves and/or differential dissolution (Frenzel and Boomer, in press).

The ostracod fauna consists of a total of 41 species. Four different assemblages were established according to their water depth. The western-central assemblage of the outer shelf and upper continental slope relates to Atlantic waters and is taxonomically diverse (Table 4, except station PM9402). It includes the deep-water taxa *Cytheropteron biconvexa*, *Cytheropteron perlaria*, *Cytheropteron tumefactum*, *Cytheropteron nodosoalatum*, *Cytheropteron inflatum*, *Cytheropteron porterae*, *Krithe glacialis*, *Pseudocythere caudata*, and *Polycope* spp., which are usually absent in the shallow eastern and southern shelf regions (rare exceptions are *Cytheropteron nodosoalatum* and *Polycope* spp.). This assemblage exhibits a close affinity to North Atlantic and Arctic Ocean faunas (Cronin, 1996; Whatley et al., 1996, 1998; Didié, 2001). However, inner shelf species, such as *Paracyprideis pseudopunctillata*, *Heterocyprideis sorbyana*, and *Rabilimis septentrionalis* are also abundant in these areas, probably due to ice-rafting, which can affect the distribution of ostracods in the Arctic (Reimnitz et al., 1992, 1993; Cronin et al., 1994; Jones et al., 1998, 1999). The latter two species were shown to have two well-defined maxima in abundance in the Laptev Sea, one in the nearshore zone freshened by river runoff, and the other on the outer shelf and upper continental slope (Table 4), thus evidencing the impact ice-rafting might have on their spatial distribution (Stepanova et al., 2003).

The eastern mid-shelf region is occupied by the diverse *Acanthocythereis dunelmensis* assemblage (Table 5). It consists of shallow-water marine species such as *Semicytherura complanata*, *Cluthia cluthae*, *Elofsonella concinna*. The eastern inner shelf assemblage is linked to the area with reduced bottom salinity (down to 26–28) and is, therefore, dominated by the shallow-water euryhaline species *P. pseudopunctillata* together with *H. sorbyana*, *R. septentrionalis* and also includes the brackish-water species *Cytheromorpha macchesneyi*. The assemblage restricted to the most shallow nearshore zone is distinguished from the others by having the lowest taxonomic diversity (Table 5). Only in the inner-shelf and nearshore regions does the share of euryhaline

Table 4
Relative abundance of ostracod species in coretop samples, western and central Laptev Sea

Species/station	Central Laptev Sea					Western Laptev Sea			
	Outer shelf		Upper continental slope			Middle shelf	Outer shelf		Upper continental slope
	114	117	118	125	126	PM 9402-3	159	158	154
Bythocythere constricta		1.5	3					5	
Pseudocythere caudata								2	1.6
Sclerochilus sp.								8	
Jonesia acuminata								3	
Cluthia cluthae	2	14	12	4.3	8.4		4	10	8.8
Cytheropteron sulense				0.7				3	
C. arcuatum		7	10	1.4	9.6		1.6	7	2
C. porterae	0.4	5.5	11	5	3		3.2	14	3.6
C. perlaria		5	5.6	2.1	4.8			1	
C. tumefactum		2.5	7	2.8	2.4		2.4	6	12.4
C. biconvexa			3		1.8			1	
C. nodosoalatum					6.6			3	
C. champlainum		1.5							
C. discoveria								1	
C. inflatum			5.6	2.8	0.6	1.7	0.4	3	
C. cf. *nodosum*						1.7			
Semicytherura complanata			3	0.7			1.6		2
Palmenella limicola									1.6
Acanthocythereis dunelmensis	3.5	2.5					0.8		0.8
Rabilimis septentrionalis	21	2		2.8	37.6		29.6	11	7.2
Heterocyprideis sorbyana	53	4	3	8.4	4	17	8.8	3	6
H. fascis						25.6			
Heterocyprideis sp. juv.						6.4			
Sarsicytheridea punctillata	3.2	33	7	39.6	6.6		14.4	2	31.2
S. bradii	0.4			9.8			1.2		2.4
Paracyprideis pseudopunctillata	3.5	3		4.2		25	29.2	1	8.8
Krithe glacialis	6	1	12	1.4	11.6	1.7	0.4	11	1.6
Argilloecia cylindrica		3	1		1.8			1	2
Argilloecia sp.	0.8								
Elofsonella concinna	5.8					20.9	1.6		0.4
Elofsonella aff. *concinna*	0.8					16	0.4		0.4
Polycope spp. (*P. punctata*, *P. bireticulata*, *P. orbicularis*, *Polycope* sp.)		14.5	16	11.2	1.2		0.8	3	7.6
Undetermined	0.4		0.8					0.5	
Total number of species per sample	13	15	16	16	15	8	16	24	18
Total abundance, specimens per 100 grams dry sediment	228	162	172	163	347		593	211	270
Percentage of euryhaline and brackish-water species	56.5	7	3	12.6	4	74	38	4	14.8

and brackish-water species exceed that of marine species (Table 5).

4.1.3. Foraminifers

In coretop samples, abundance of foraminifers is low and varies from less than 50 tests (per 100 g dry bulk sediment) in the eastern mid-shelf area to 500–800 tests in the shallow inner shelf region and central Laptev Sea (Table 6). The abundance and species diversity of agglutinated foraminifers increases northward towards the upper continental slope. *Ammotium cassis* predominates among agglutinated foraminifers of the eastern shelf zone. In the central and western Laptev Sea it is replaced by *Cribrostomoides crassi-*

Table 5
Relative abundance of ostracod species in coretop samples, eastern and southern Laptev Sea

Species/Station	Nearshore region							Eastern inner shelf region					Eastern mid-shelf region			
	IK93 06-11	IK93 07-3	IK93 Z4-3	IK93 Z5-4	PM 94 41-4	KD 95 41-13	KD 95 65-11	080	085	092	093	104	105	106	135	138
Bythocythere constricta									3.6							
Jonesia acuminata												2.4	7.2	1.3		
Cytheromorpha macchesneyi			5						1.8					1.3		5
Cytheromorpha cf. *macchesneyi*	4															
Cluthia cluthae											2.1	2.4	31.5	15.6	16	
Cytheropteron arcuatum											1.4		3.6	28.6		
C. sulense	4								16.2	5.4	7					
C. elaeni							9	5		2.7				2.6	14	
C. suzdalskyi														1.3		47
C. montrosiense									14.4							
C. nodosoalatum													1.8			3
Semicytherura complanata		17					9		36	2.7	2.8	10.8	10.8	13	25	36
Rabilimis septentrionalis				100												
Palmenella limicola									3.2	2.7		2.4			10	
Acanthocythereis dunelmensis							28	5				53.2	21	19.5	13	
Heterocyprideis sorbyana					89			2.5		5.4	12.6					
Sarsicytheridea bradii													2.7			
Paracyprideis pseudopunctillata	88	83	95			100	18	85		81.1	60.1		4.4	10.3	20	9
Paracyprideis cf. *pseudopunctillata*					11											
Argilloecia cylindrica												13.2	0.9		2	
Elofsonella concinna							36	2.5				10.8	16.1	6.5		
Polycope spp. (*P. punctata*, *P. bireticulata*, *P. orbicularis*)	4								24.8		14	4.8				
Total number of species per sample	4	2	2	1	2	1	6	5	7	6	7	8	11	11	7	5
Total abundance, specimens per 100 grams dry sediment								600		307	671	79	55		73	113
Percentage of euryhaline and brackish-water species	92	83	100	0	100	100	18	87.5	1.8	86.5	72.7	0	4.4.	11.6	20	14

margo, *Hyperammina elongata*, and some other species (Table 6).

The distribution of calcareous benthic foraminifers influenced by the rivers is generally dependent on salinity gradients and seasonal biological productivity due to riverine outflow. In such an environment they may be subdivided into "river-proximal", "river-intermediate", and "river-distal" assemblages (cf. Polyak et al., 2002). Although our sample coverage of the Laptev Sea does not allow us to trace detailed changes in species composition (Table 6), it is still possible to distinguish two main areas. The eastern inner and middle shelf, strongly affected by river runoff, shows a predominance of "river-proximal" (*Elphidium incertum*, *Elphidium bartletti*, *Haynesina orbiculare*, *Elphidiella groenlandica*) and opportunistic (*Elphidium excavatum* forma *clavata)* species. The other parts of the Laptev Sea are taxonomically more diverse including also species from "river-intermediate" and "river-distal" habitats (*Islandiella helenae*, *Cassidulina reniforme*, *Cassidulina teretis*, *Stainforthia loeblichi*, *Pyrgo williamsoni*, *Cibicides lobatulus*, *Melonis barleeanus*). Thus, the foraminiferal assemblage from the eastern Laptev Sea is rather similar to "river-proximal" assemblages also found in other Arctic seas with high riverine runoff, e.g. the inner Kara Sea (Khusid, 1996; Korsun, 1999; Polyak et al., 2002) and the Beaufort Sea (McDougall, 1994). However, as it is the case with ostracods, shallow-water species are quite abundant also in the samples from the upper continental slope, probably as a result of ice-rafting.

Rare planktic foraminifers were found only in the samples from the upper continental slope at depths exceeding 75 m (Table 6), although Tamanova (1971) mentioned planktic foraminifers in the coastal area northwest off the Lena Delta assuming that this is a local thanatocoenosis formed due to Atlantic water advection carrying foraminifers (see also Bauch, 1999).

4.2. Sedimentary record and core chronology

The sedimentary sequence of core PS-51/138-12 mainly consists of blackish grey clayey silt, often bioturbated (Fig. 3). In the lower 200 cm of the core sediments are enriched in plant debris. Above, the abundance of plant debris decreases, becoming particularly rare in the uppermost 50 cm. Sand fraction content is low in the lower two thirds of the sedimentary sequence averaging 3–4% (Fig. 3). At 150-170 cm core depth, sand sharply increases and in the upper part of the core averages 10–12%. The sedimentary sequence of core PS-51/135-4 (Fig. 4) consists of grey to dark grey silty clay, bioturbated and enriched in organic matter.

Both cores date back to 11.2 and 11.3 cal. ka, respectively (Table 2). Sediment accumulation at each site was relatively uneven, but with a similar pattern (Fig. 5). In the Lena palaeovalley (PS-51/138-12), most parts of the core sequence (from 530 to 197 cm) accumulated very rapidly during less than a thousand years, between 11.2 cal. ka and 10.3 cal. ka. Then, an abrupt reduction in sedimentation rate occurred, and later sedimentation was slow but steady without any evident abrupt changes. In the Yana palaeovalley (PS-51/135-4), sedimentation rates were very high between c. 11.3 and 11.1 cal. ka (500 cm/kyr) but slowed down thereafter until c. 7 cal. ka. After about 5 cal. ka sedimentation rates became extremely low (Table 2), a typical feature for this particular region and water depth (Bauch et al., 1999).

4.3. Holocene faunal assemblages

4.3.1. Core PS-51/138-12, Lena palaeovalley

4.3.1.1. Molluscs. A total of 15 bivalve and 6 gastropod species were identified in the core section. Their taxonomic diversity gradually increases upcore (Fig. 3). In the lower unit (530–410 cm, c. 11.2–10.8 cal. ka), only three species were recognized, *P. arctica*, *Portlandia aestuariorum*, and *Cyrtodaria kurriana*. The two latter species are typical representatives of shallow water and estuarine environments dwelling at water depths not exceeding 10–15 m (Mosevitch, 1928; Wagner, 1977; Petryashov et al., 1999). Especially *C. kurriana* now inhabits the nearshore zone along the northern Lena delta margin (0–8 m water depths) where salinity is as low as 5 (Gukov, 2001).

Portlandia arctica becomes extremely abundant in the overlying unit (410–160 cm, c. 10.8–8.2 cal. ka) where it forms an almost monospecific assemblage

Table 6
Occurrence of planktic foraminifers, and relative abundance of benthic foraminifers in coretop samples

Species/station											Central Laptev Sea					Western Laptev Sea		
	Eastern inner-shelf region					Eastern mid-shelf region					Outer shelf		Upper continental slope			Upper continental slope	Outer shelf	
	080	085	092	093	094	138	104	105	106	135	114	117	118	125	126	154	158	159
Planktic, number of tests																		
Turborotalita quinqueloba													18					
Globigerina bulloides													2		2			
Globigerina sp.												1				4		
Benthic, relative abundance, %																		
Agglutinated																		
Ammotium cassis	3	4	30	50	82	28	8	18		57				2	10			7
Reophax curtis	12	16	2		15			12			3		2			8	7	7
Reophax sp.							3							2	5			
Cribrostomoides crassimargo							14		6	13	69	4	4	12	2	12	7	50
Recurvoides turbinatus											3							
Hyperammina elongata											15	40	2			14	7	
Spiroplectammina biformis							3							1	4			
Eggerella advena		1					1							8	3			
Textularia torquata															2			
Calcareous																		
Elphidium excavatum f. *clavata*	42	67	52	6		32		13	12	14		4	30				11	15

Elphidium incertum	8	4					16	19	64	2	1	4	6	3	23	31		7	
Elphidium bartletti		3				16	16	20	2		2			9	16			3	
Haynesina orbiculare	17		5	44			4		6	12	1	4		8	3	2		3	
Elphidiella groenlandica	7	3	9			16	7	6						15	6				7
Buccella frigida							8					4	4	10	7	2			
Buccella sp.							3							6	4				
Cyclogyra involvens	4																		
Cyclogyra foliacea													2						
Lagena gracillima	2						2									2		6	
Lagena sibirica													2						
Pseudopolymorphina novangliae	5	1				8		6	8				4						
Guttulina lactea							4							7	2				
Dentalina frobisherensis		1											2	1					
Dentalina baggi			2								2								
Islandiella helenae								6		2	4	16	16			6		14	7
Cassidulina reniforme															1				
Cassidulina teretis																2			
Nonionellina labradorica									2										7
Nonion sp.							3							5	7				
Cibicides lobatulus												20				2		18	
Pyrgo williamsoni							4							10	4				
Stainforthia loeblichi																		14	
Nodosaria sp.							1							1	1				
Oolina borealis							2												
Oolina sp.							1												
Melonis barleeanus					3							4	26			19		3	
Total number of species per sample	9	9	6	3	3	5	18	8	7	6	9	9	12	16	17	11		12	17
Total abundance, specimens per 100 g dry sediment	814		870	495	139	210	303	46		234	371	63	433	436	560	177		128	213

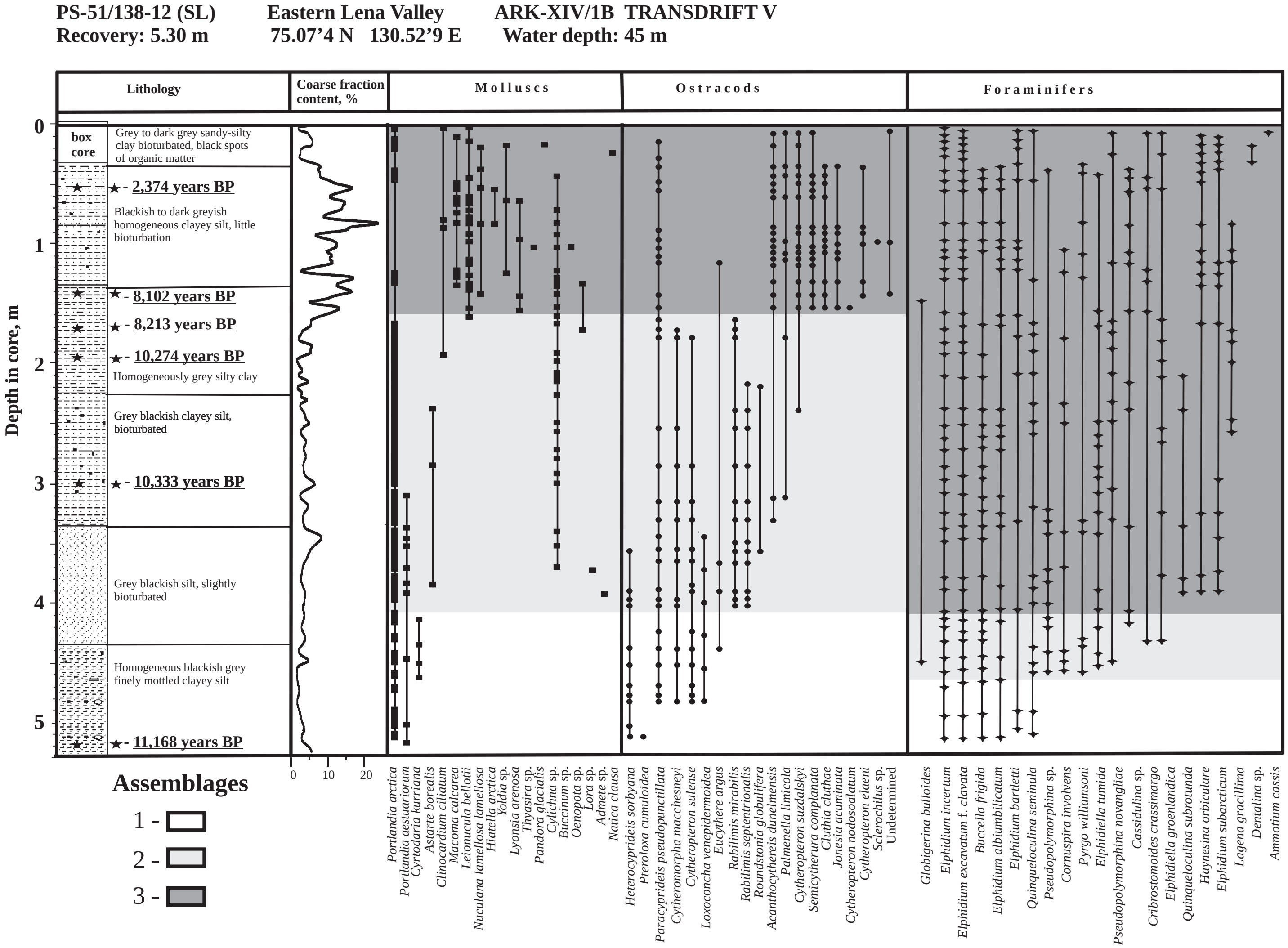

Fig. 3. Downcore results of core PS-51/138-12 in comparison with identified fossil assemblages: 1—nearshore brackish-water; 2—inner-shelf; 3—middle-shelf normal marine.

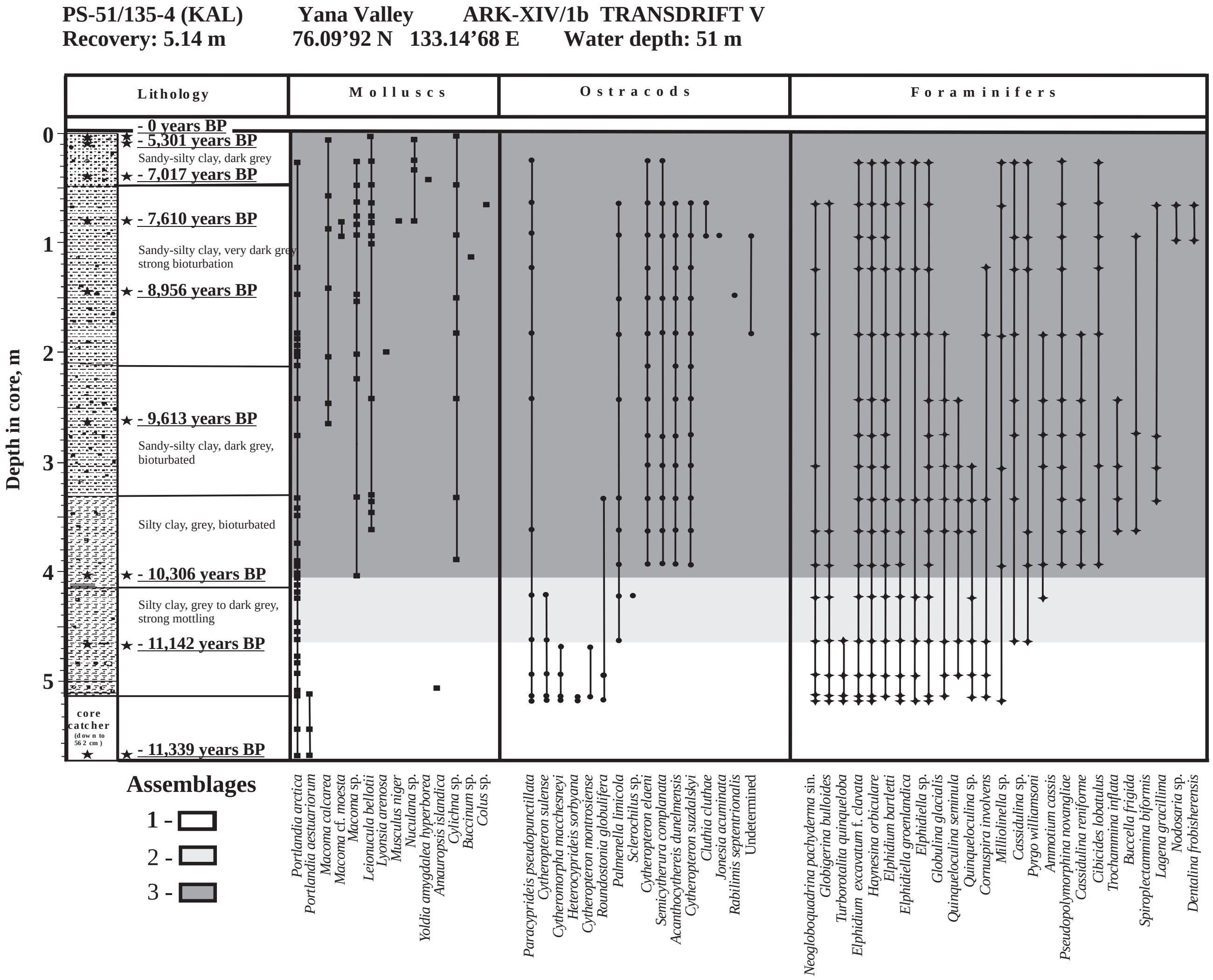

Fig. 4. Downcore results of core PS-51/135-4 in comparison with identified fossil assemblages: 1—nearshore brackish-water; 2—inner-shelf; 3—middle-shelf normal marine.

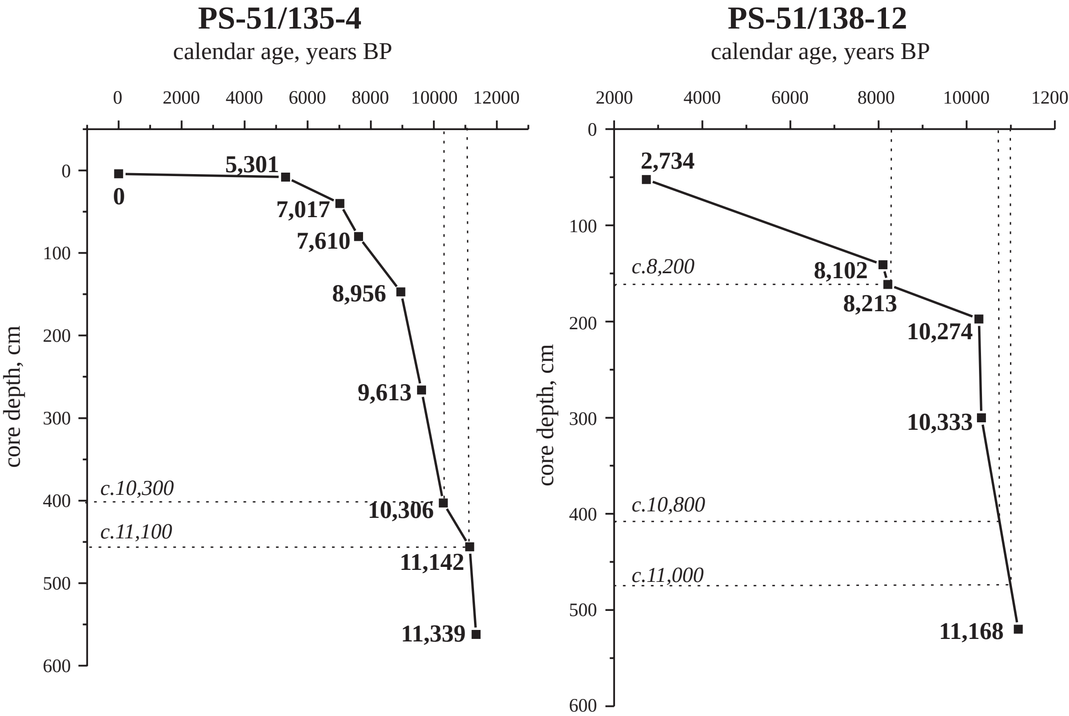

Fig. 5. Age–depth relation for cores PS-51/135-4 and PS-51/138-12. Dotted lines show core depths and ages corresponding to the main changes in fossil assemblages mentioned in the text.

being mainly accompanied by *Cylichna* sp., a small predatory gastropod probably thriving on *P. arctica*. In the unit above (160–0 cm, c. 8.2 cal. ka to recent), taxonomic diversity increases sharply from 7 to 13 species. Although *P. arctica* is still present, it becomes rare. This assemblage is dominated by *L. bellotii* accompanied by *Macoma calcarea*, *Nuculana lamellosa lamellosa*, and other species. It is similar to the modern bottom macrobenthic community in this region (Sirenko et al., 1995; Petryashov et al., 1999; this paper).

4.3.1.2. Ostracods. The total abundance of ostracods reveals certain variations along the core section, ranging from more than 80 specimens per 100 g at 400–350 cm core depth to less than 10 in its lower and middle parts (Fig. 6). This is rather low compared to their abundance in coretop sediments (Tables 4 and 5). Higher percentage of juvenile valves and carapaces in the lower part of the core reflects fast burial of these fragile valves probably due to high accumulation rates (Fig. 6).

As it is the case with molluscs, taxonomic diversity of ostracods gradually increases upcore, and changes in their composition also occur at the same core depths (Figs. 3 and 6). In the lower unit (530–410 cm, c. 11.2–10.8 cal. ka), inner neritic euryhaline species *H. sorbyana* and *P. pseudopunctillata,* tolerating freshened conditions, are dominant. They are accompanied by brackish-water species *C. macchesneyi* and *Loxoconcha venepidermoidea*. The share of euryhaline and brackish-water species reaches 100% at the core base and gradually decreases upwards (Fig. 6).

The second assemblage (410–160 cm, c. 10.8–8.2 cal. ka) consists of ostracods belonging to different ecological groups. It is dominated by inner neritic species represented by brackish-water *C. macchesneyi*, euryhaline *P. pseudopunctillata*, and normal-marine *R. septentrionalis* and *Rabilimis mirabilis*. In the upper part of this section, some normal marine middle and outer neritic species appear for the first time (*A. dunelmensis*, *Palmenella limicola*, *Cytheropteron suzdalskyi*). These latter species then become the dominant group in the uppermost core assemblage

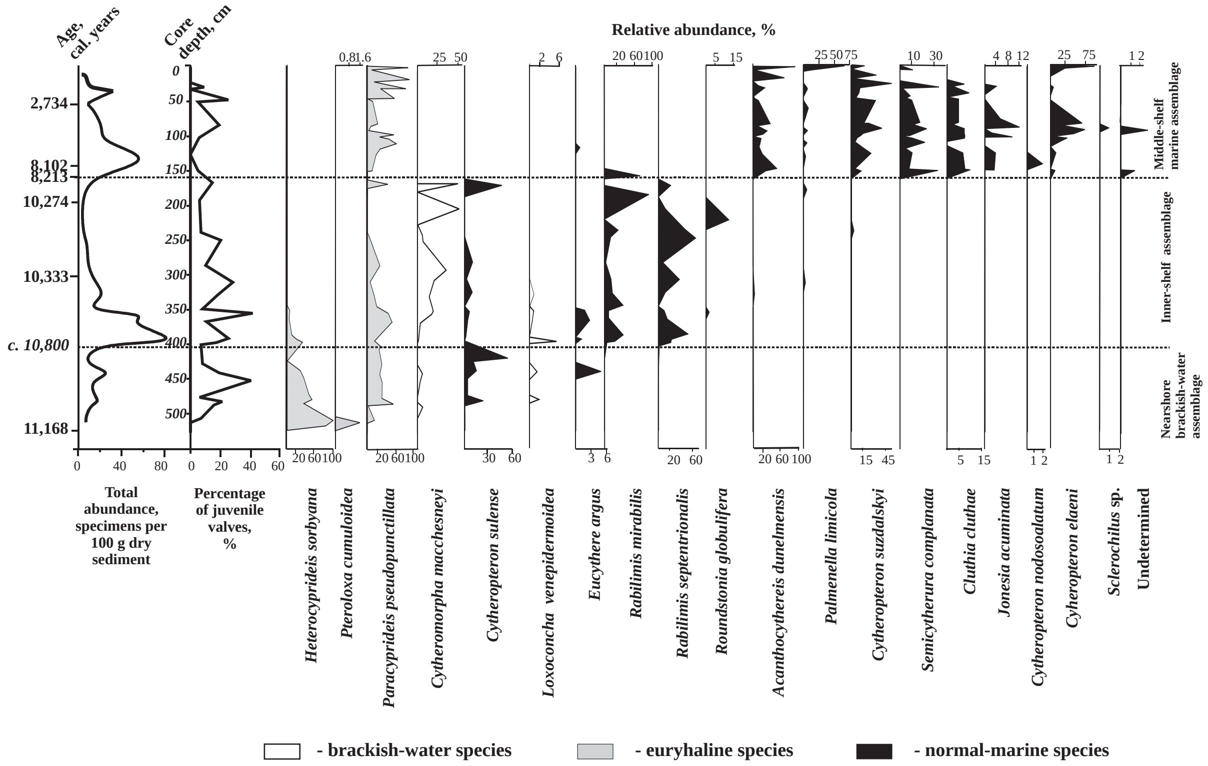

Fig. 6. Downcore variations in the relative abundance of ostracods in core PS-51/138-12.

(160–0 cm, c. 8.2 cal. ka to recent), together with numerous normal marine species which were not found in the underlying sediment units (Fig. 6). These consist of *Cytheropteron elaeni*, *S. complanata*, *C. cluthae*, *Jonesia acuminata*, *C. nodosoalatum*, and *Sclerochilus* sp. This uppermost assemblage of core PS-51/138-12 resembles the modern *A. dunelmensis* assemblage that is found in the central part of the eastern Laptev Sea shelf.

4.3.1.3. Foraminifers. Unlike molluscs and ostracods, benthic foraminifers exhibit only minor changes in their species composition in the core (Fig. 7). The whole sequence is dominated by different Elphidiids. Taxonomic diversity gradually increases upcore, although most species are present throughout the core section.

A pronounced change in species composition of foraminifers is recorded in the lower part of the core, where two assemblages are distinguished. The lowermost assemblage (530–475 cm core depth, c. 11.2–11.0 cal. ka) consists nearly entirely of the inner-shelf species *E. e. clavata*, *E. incertum*, *Elphidium albiumbilicatum*, *E. bartletti*, and *Buccella frigida*, usually restricted to “river-proximal” environments. The overlying transitional assemblage (475–410 cm, c. 11.0–10.8 cal. ka) shows an evident increase in species diversity and abundance of tests (up to nearly 1500 specimens per 100 g dry sediment) that exceeds their abundance in coretop samples (Table 6 and Fig. 7). Above 410 cm core depth (*c.* 10.8 cal. ka), taxonomic diversity increases, and a shallow-water marine assemblage is established that occurs throughout the remaining part of the core. It is dominated by *E. e. clavata, E. incertum* and *H. orbiculare*, although increasing relative abundances of *Elphidium subarcticum*, *Cassidulina* sp., and *P. williamsoni* indicate a more “river-distant” environment. In this core, changes in composition of foraminifers occurred during a considerably shorter time interval than the changes in composition of molluscs and ostracods, and already after c. 10.8 cal. ka a modern-like assemblage was established.

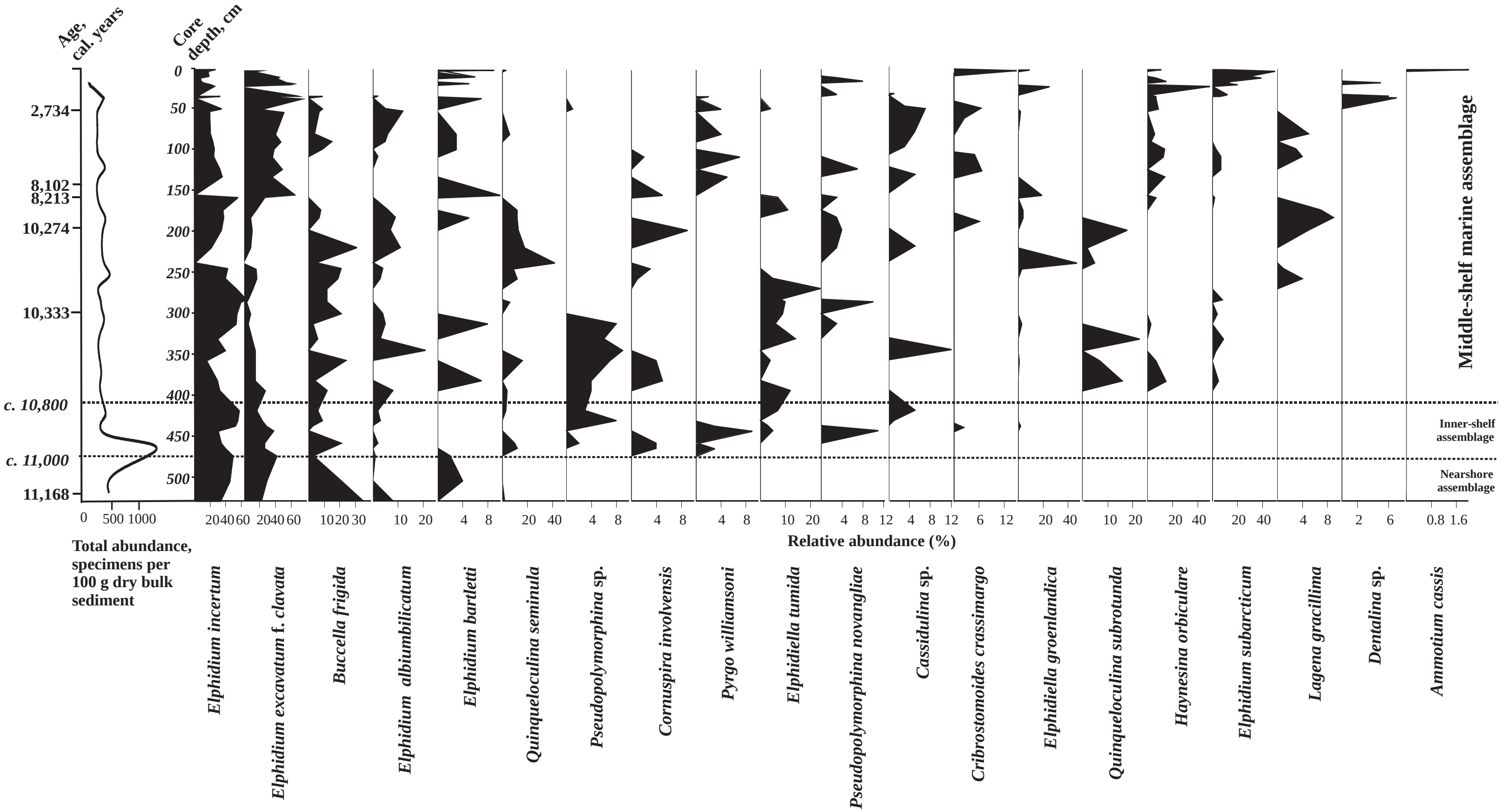

Fig. 7. Downcore variations in the relative abundance of foraminifers in core PS-51/138-12.

4.3.2. Core PS-51/135-4, Yana palaeovalley

4.3.2.1. Molluscs. The lowermost molluscan assemblage in this core (562–460 cm core depth, c. 11.3–11.1 cal. ka; Fig. 4) is taxonomically poor and consists of *P. arctica* and *P. aestuariorum* with a single specimen of the gastropod species *Amauropsis islandica.* The latter presently inhabits the nearshore freshened zone down to the water depth of 10 m (Gukov, personal communication). Upward the core (460–400 cm, c. 11.1–10.3 cal. ka), the inner-shelf *P. arctica* assemblage is observed. The uppermost assemblage (400–25 cm, c. 10.3 to recent) is the most taxonomically diverse, being dominated by *L. bellotii* and different species of the genus *Macoma*.

4.3.2.2. Ostracods. Upcore changes of ostracodal assemblages generally follow those of molluscs (Fig. 8). The lower assemblage (514–460 cm, c. 11.3—11.1 cal. ka) is nearly completely composed of inner-neritic species characteristic of nearshore estuarine environments (*H. sorbyana*, *P. pseudopunctillata*, *C. macchesneyi*, and *Roundstonia globulifera*). In the overlying inner-shelf assemblage (460–400 cm, *c.* 11.1–10.3 cal. ka) the euryhaline species *P. pseudopunctillata* is dominant. It is accompanied by three normal marine species: *C. elaeni*, *P. limicola*, and *S. complanata*. The remaining part of the core (460–25 cm, c. 10.3–6 cal. ka) contains the mid-shelf marine assemblage similar to the modern assemblage of the studied area, in which normal marine species *A. dunelmensis* and *C. elaeni* predominate.

4.3.2.3. Foraminifers. Similar to what is found in core PS-51/138-12, benthic foraminiferal assemblages are dominated by Elphidiids and show minor changes in species composition between the basal and the rest of the core (Fig. 9). In the lower assemblage (514–460 cm, c. 11.3–11.1 cal. ka) *E. e. clavata* predominates. The overlying assemblage

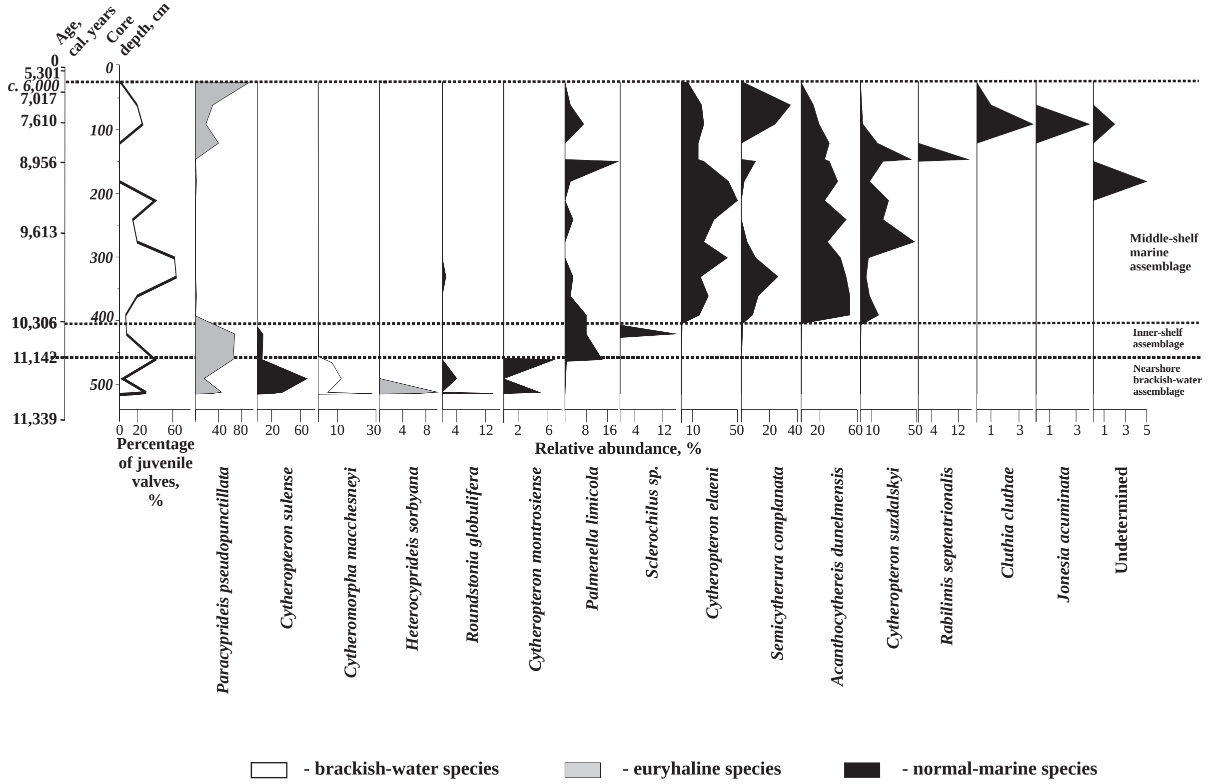

Fig. 8. Downcore variations in the relative abundance of ostracods in core PS-51/135-4.

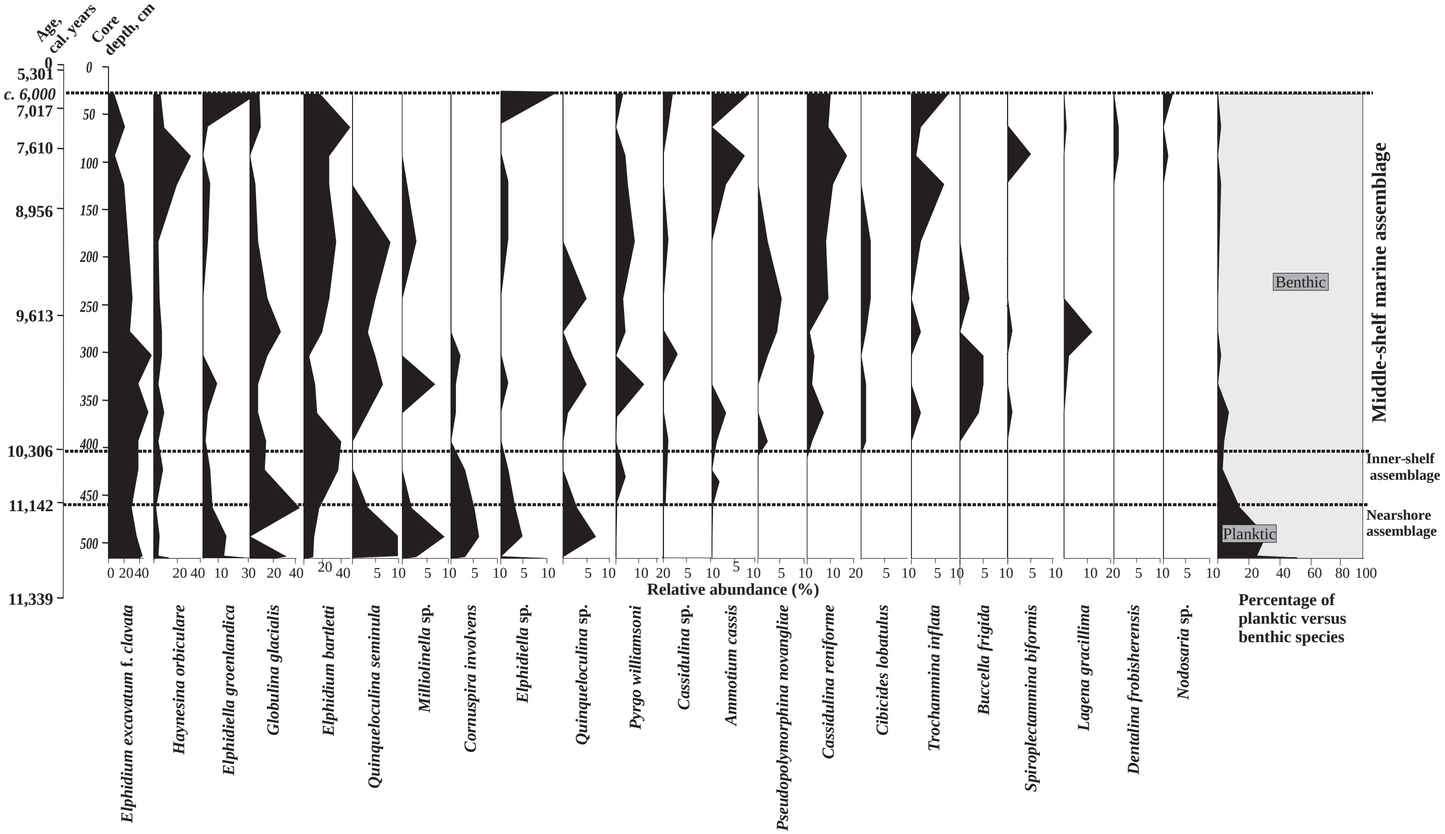

Fig. 9. Downcore variations in the relative abundance of foraminifers in core PS-51/135-4.

(460–400 cm, c. 11.1–10.3 cal. ka), regarded as an inner-shelf one, is dominated by *E. e. clavata* and *E. bartletti*. It shows a slight increase in species diversity due to the introduction of the "river-intermediate" species *P. williamsoni* and *Cassidulina* sp. The third assemblage (c. 10.3–6 cal. ka) is taxonomically the most diverse. It is distinguished by the presence of species that usually avoid shallow coastal environments, *C. reniforme* and *Cibicides lobatulus*.

An interesting feature of sediment core PS-51/135-4 is the presence of planktic foraminifers represented by *Neogloboquadrina pachyderma* sin., *Globigerina bulloides*, and *Turborotalita quinqueloba* throughout the sediment sequence (Fig. 9). They are especially abundant in the basal part of the core where their share reaches up to 50%. After 11.1 cal. ka their content decreases down to 5%, and after *c.* 9.8 cal. ka it becomes insignificant (1–2%). In core PS-51/138-12, few tests of were found in two samples. These were of the species *G. bulloides* (Fig. 3).

5. Discussion

5.1. Modern benthic assemblages as indicators of bottom environments

The modern patterns of macrobenthic communities in the Laptev Sea display a strong relationship to water depth, bottom salinity, seabed composition, and bottom hydrodynamics (Petryashov et al., 1999). Our data on the distribution of calcareous meiobenthic organisms in surface sediments provide further important environmental information in order to interpret palaeoenvironmental change of the studied territory. Although the interpretation of the factors governing the distribution of the meiofauna is somewhat limited by the low number of surface samples investigated, the clearly defined changes in species composition observed correspond to specific oceanographic characteristics of the various parts of the sea. In order to demonstrate some possible environmental preferences of ostracods (see also Stepanova et al., 2003) and foraminifers in the Laptev Sea, average frequencies of the more abundant species are shown against average summer surface salinity (Fig. 10). We used the average summer surface salinity as a factor to approximate the riverine influence on the meiobenthic community following the method applied by Polyak et al. (2002) who distinguish between benthic foraminiferal species in the Kara Sea on the basis of three environmental categories: river-proximal (<15), river-intermediate (15–25), and river-distal (>25). As seen from Fig. 10, ostracods show considerably higher dependence to the seasonal river runoff influence than foraminifers. By combining the published data and our own new results we are able to distinguish four modern benthic assemblages reflecting environmental conditions in different parts of the Laptev Sea.

The *nearshore assemblage* of the southern and southeastern Laptev Sea is confined to the brackish-water coastal zone (water depths not exceeding 10–15 m), where bottom salinity is subjected to strong seasonal variations due to river discharge. It averages 24–26 (Fig. 2), but sometimes could be as low as 5 (Petryashov et al., 1999). Although this is also the zone of highest TOC values (Stein et al., 1999; Stein and Fahl, 2000), the predominantly terrigenous organic matter deposited here shows high C/N ratios (Stein et al., 1999; Stein and Fahl, 2000). Such sediments with high C/N ratios (and lower N contents) tend to support a lower biomass of benthic invertebrates (Grebmeier et al., 1988), since refractory organic matter (woody and plant debris) consumes a lot of dissolved oxygen and releases little nutrients to the water column when it breaks down. Only few species occur in this zone with its strongly seasonally variable freshwater influence, considerable input of terrestrial organic matter, and existence of fast-ice cover during most part of the year suppressing plankton productivity. These are represented by the brackish-water bivalves *P. aestuariorum* and *C. kurriana*, along with the euryhaline (*P. pseudopunctillata* and *H. sorbyana*) and brackish-water (*C. macchesneyi*) ostracods.

Although we have not studied foraminifers from this area, tests of typical river-proximal calcareous species *H. orbiculare* (dominant), *E. incertum*, *B. frigida*, and individual tests of agglutinated foraminifers have been reported in a more recent study (Bude, 1997). This is in contrast to Tamanova (1971) who reported foraminifers to be absent in the nearshore zone down to 10 m water depth.

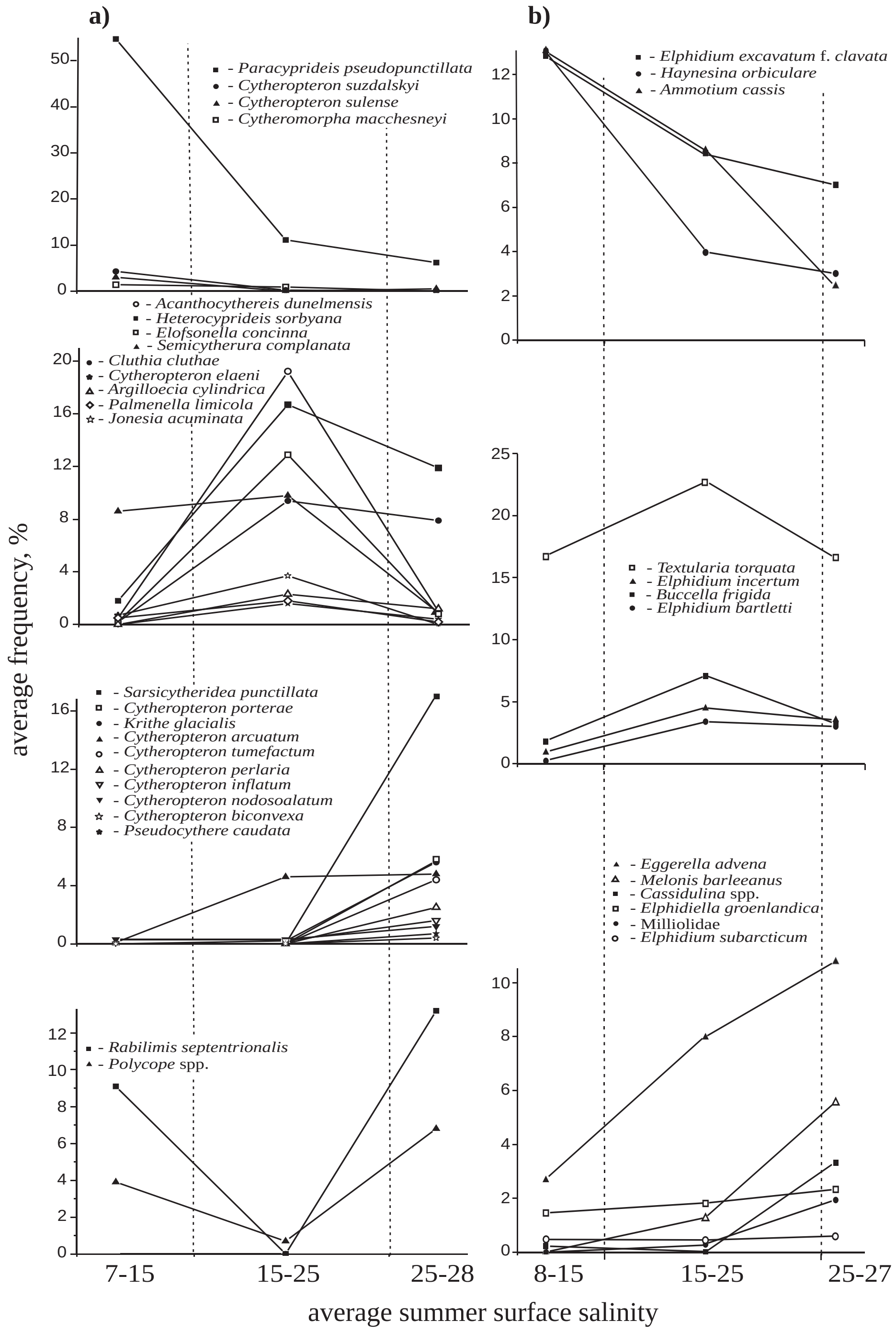

Fig. 10. Average frequencies of ostracod and foraminifer species in the Laptev Sea vs. average summer surface salinity in discrete increments. a—ostracods (Stepanova et al., 2003), b—foraminifers (combined evidence from our samples and Bude, 1997).

The *inner-shelf assemblage* occurs in the shallow eastern Laptev Sea down to 20–30 m water depth. This is the zone characterized by the highest modern sedimentation rates (Bauch et al., 2001b; Wegner, 2003). In addition, a considerable amount of terrestrial organic matter is deposited here, primarily in the submarine valleys (Stein and Nürnberg, 1995; Stein et al., 1999; Stein and Fahl, 2000). In the seasonally ice-free areas near the ice edge relatively high productivity rates were observed (Boucsein et al., 2000), thus the amount of labile marine organic matter available for benthic invertebrates increases here. This factor in combination with less seasonally variable environmental conditions and higher average bottom water salinity (26–28, Fig. 2) than in the nearshore zone probably explains the observed maximum abundances of ostracods and foraminifers. Soft organic-rich substrates favour the predominance of a deposit-feeding bivalve *P. arctica* which forms a practically monospecific assemblage. Although less than the nearshore zone, the inner eastern Laptev Sea shelf is still strongly affected by the river runoff. Generally, the calcareous meiobenthic community is dominated by the same species as in the nearshore zone, i.e., the euryhaline ostracod *P. pseudopunctillata* together with the typical river-proximal (*H. orbiculare*) and opportunistic foraminifers (*E. e. clavata*), but the total number of species is 2–3 times higher (Fig. 10).

Autumn storm events on the inner shelf correlative with the freeze-up (Wegner, 2003), a process which could be the main cause for incorporation of shallow-water ostracods, foraminifers and juvenile molluscs into newly formed sea ice. These conditions may also explain the frequent occurrence of specimens from these groups in distant offshore parts of the Laptev Sea (Petryashov et al., 1999; Stepanova et al., 2003).

In the eastern Laptev Sea, the *middle-shelf assemblage* reflects the water depth range of 30 to 50 m. Bottom sediments in this area, especially in the Lena and Yana submarine valleys, are often resuspended by reversal bottom current activity (Dmitrenko et al., 2001a; Wegner, 2003). This process not only occurs during ice-free summer months but all year due to the existence of the flaw polynya in winter. Widely affected by this active hydrodynamic regime, total abundances of ostracods and foraminifers are the lowest among those of the studied regions.

The same bottom counter-currents lead to an advection of warmer and more saline bottom waters from the north along the submarine valleys (Dmitrenko et al., 2001a). This process is indicated in the deflection of bottom water isohalines (Fig. 2). The bottom water salinity in this mid-shelf region averages 30–32. Brackish-water ostracods and bivalves are absent here, and the percentage of euryhaline ostracods sharply decreases. Normal marine species become dominant: *L. bellotii* among molluscs (*P. arctica* is restricted to the Lena and Yana submarine valleys, where bottom substrates are probably enriched in organic matter), and the middle-outer neritic species *A. dunelmensis* along with *S. complanata*, *C. cluthae*, and *E. concinna* among ostracods. Foraminifers, however, exhibit minor changes in their composition, and species characteristics of a river-proximal environment (*E. incertum*, *E. bartletti*, and *E. e. clavata*) predominate.

The *western-central deep-water assemblage* occurs on the outer shelf and upper continental slope (60–270 m water depth), where bottom salinity is 33–34. This environment is dominated by the deepest-living marine species among all studied groups. The presence of several deep-living ostracod species with clear affinities to the North Atlantic probably indicates the influence of Atlantic waters in this region (Stepanova et al., 2003).

5.2. Holocene palaeoenvironmental evolution

Our two sediment cores from the middle eastern Laptev Sea shelf clearly demonstrate similar upward changes in the taxonomic composition of their fossil assemblages. A taxonomically poor assemblage dominated by euryhaline and brackish-water species is replaced by a transitional assemblage with co-occurrence of euryhaline and marine species. Eventually, a taxonomically diverse assemblage, dominated by marine species similar to the modern benthic communities, occupies both studied areas. However, the timing of these changes was slightly different, a fact which probably results from the 6-m water depth difference that exists between the two sites.

Due to rapid sea-level rise and high sedimentation rates on the middle Laptev Sea shelf during the Early Holocene (Bauch et al., 2001b) the time interval c.

11.3–8.2 cal. ka shows the highest temporal resolution in the studied cores. The site in the Yana palaeovalley became inundated prior to 11.3 cal. ka, and the one in the Lena palaeovalley approximately some hundred years later. Shortly after inundation, both palaeovalleys became inhabited by taxonomically poor benthic assemblages. These were composed of species tolerant to reduced and seasonally variable salinities and considerable input of terrestrial material derived by river runoff and coastal erosion. The average TOC value in core PS-51/135-4 from the Yana palaeovalley is 1.2%, with the individual values ranging from 1.7% to 0.9%, and the highest values occurring in its lower part. Molluscs such as *P. aestuariorum*, *C. kurriana*, and *A. islandica*, occurring in the lower parts of the cores, presently occupy the brackish-water area off the Lena Delta and usually do not live deeper than 10–15 m water depth (Sirenko et al., 1995; Petryashov et al., 1999; Gukov, 2001). In the lower core units also brackish-water and euryhaline ostracods formed a main component of the benthic community. These nearshore brackish-water assemblages of molluscs and ostracods existed during a relatively short time period, from 11.3 until 11.1 cal. ka in the Yana palaeovalley, and from 11.2 until 10.8 cal. ka in the Lena palaeovalley. Time-coeval presence of foraminiferal assemblages dominated by Elphidiids, primarily the opportunistic species *E. e. clavata* (Corliss, 1991; Polyak et al., 2002), also gives evidence of seasonally variable nearshore conditions.

It seems as if during the initial stage of inundation only single species among all three groups were able to survive in the estuarine-like parts of the palaeovalleys with maximum water depths of about 5–10 m, and sedimentation rates of up to 300 cm/kyr (Lena palaeovalley) and 500 cm/kyr (Yana palaeovalley). Such sedimentary environments, which do not exist on the Laptev Sea shelf at present, were most likely the result of a rapid sea-level rise combined with considerable input of terrestrial sediments through river runoff and coastal erosion. Bottom water salinity during this time might be estimated to about 18–20, a value which is deduced when comparing the fossil benthic assemblages with the modern nearshore faunal community. The inference of a near-shore environment is corroborated from surface salinities calculated on the basis of freshwater diatoms, which indicate a salinity between 7 and 9, as well as the time-coeval occurrence of organic-walled freshwater algae (Polyakova et al., 2005).

In the Yana palaeovalley, the recorded high relative abundance of planktic foraminifers is unusual for a shallow, low-salinity shelf. Their occurrence in these extreme environments, therefore, might result from an advection of marine waters from the north (cf. Tamanova, 1971). Another possible explanation is reworking from older marine beds, which are known to exist on the nearby New Siberian Islands (cf. Bauch, 1999). However, findings of the well-preserved dinoflagellate cyst *Operculodinium centrocarpum* in core sediments of PS-51/135-4 correspondent to the time interval 11.2–10.5 cal. ka (Polyakova et al., 2005), support the assumption that Atlantic waters influenced this part of the Laptev Sea shelf in Early Holocene times.

The observed changes to inner-shelf benthic assemblages (11.1–10.3 cal. ka in the Yana palaeovalley and 10.8–8.2 cal. ka in the Lena palaeovalley) due to the appearance of several shallow-water normal marine species and the synchronous disappearance of brackish-water forms clearly document increasing water depth and salinity. However, the nearly monospecific *P. arctica* molluscan assemblage indicates considerable fluvial influence upon the sites and close proximity to the coastline. *Portlandia arctica* is a deposit feeder tolerant of reduced salinity that prefers soft organic-rich substrates (Semenova, 1986; Syvitski et al., 1989). This species is known to survive in high sedimentation rate environments with turbid waters (Carter et al., 1988; Syvitski et al., 1989; Aitken and Gilbert, 1996). At present, *P. arctica* dominates the inner eastern Laptev Sea shelf within water depths between 10 and 30 m and bottom summer salinities between 16 and 28 (Sirenko et al., 1995; Petryashov et al., 1999). This is similar to the ostracod fossil assemblage with its predominance of euryhaline species at this time, a community rather analogous to the modern inner-shelf assemblage.

Interestingly, the transition from a low-diverse nearshore to a more taxonomically diverse inner-shelf assemblage in the Lena palaeovalley is marked by distinct peaks in the total abundance of ostracods at c. 10.5 cal. ka and foraminifers at c.

10.9 cal. ka (Figs. 6 and 7). These observed maxima of microfossils could indicate increased surface productivity induced by the input of riverine nutrients (cf. Stein and Fahl, 2000; Boucsein et al., 2000). In the Yana palaeovalley, an evident spike in the abundance of freshwater diatoms is recorded for the time span 11.1–10.7 cal. ka (Polyakova et al., 2005), coincident with the establishment of the inner-shelf benthic assemblage. Given the earlier timing of environmental changes at site PS-51/135-4 compared to PS-51/138-12, an enhanced flux of freshwater diatoms might be assumed for the Lena palaeovalley around c. 10.9–10.5 cal. ka.

The site in the Lena palaeovalley was most likely an estuarine setting until 9.8 cal. ka, because at this time a sudden change from fluvial to marine sedimentary environment is recognized in a nearby core (Bauch et al., 2001b). Considerable fluvial influence upon the middle Laptev Sea shelf until about 7-8 cal. ka is also evident by relatively light isotopic composition of organic carbon (Mueller-Lupp et al., 2000). In a core from close to site PS-51/135-4, accumulation of TOC was up to 8 g/cm^2/ka at c. 9 cal. ka, and remained high (about 2–3 g/cm^2/ka) until approximately 7 cal. ka (Mueller-Lupp et al., 2000).

The estimated sedimentation rates for the time interval 10.8–8.2 cal. ka are about 90 cm/kyr in the Lena palaeovalley, i.e. nearly three times lower than during the preceding period. Such values are comparable to sedimentation rates in the modern depocenter of the Lena River, located between 20 and 25 m water depth (Kuptsov and Lisitzin, 1996). Recent investigations of the seasonal sediment dynamics in the eastern Laptev Sea using acoustic doppler profiling data (Wegner, 2003) revealed that such water depths within the inner shelf zone form the main accumulation area of river-transported sediments.

The abrupt transition to modern-like assemblages with the dominance of shallow-water, normal marine species occurred at about 10.3 cal. ka in the Yana palaeovalley and at about 8.2 cal. ka in the Lena palaeovalley. As this phase was accompanied by enhanced taxonomic diversity in all three groups, and the disappearance of all brackish-water and most euryhaline ostracods together with the establishment of a *L. bellotii* molluscan assemblage, it can be concluded that bottom conditions nearly similar to the present day became established on the middle shelf, i.e., within a salinity environment of about 30–32.

As indicated by the proportions of planktic foraminifers (~5%), the site in the Yana palaeovalley remained affected by subsurface inflow of Atlantic-derived waters until about 9.8 cal. ka (Fig. 9). This interpretation gains support from the presence of dinoflagellate cysts between 10.7 and 9.2 cal. ka, which are typically being associated with Atlantic water masses (Polyakova et al., 2005).

An establishment of more active near-bottom hydrodynamics in the Lena palaeovalley since 8.2 cal. ka is inferred from the complete absence of juvenile ostracod valves (Fig. 6). Such an interpretation is further supported by the increase in sand content (Fig. 3). As this part of the submarine valley is affected today by strong wind-forced bottom counter-currents (Dmitrenko et al., 2001a; Wegner, 2003), this steep increase in sand content was probably related to the initiation of such currents and the eventual establishment of full-marine conditions in our study area.

The distribution of benthic communities in shallow-water environments is usually controlled by a variety of factors, such as water mass characteristics, food supply, as well as seabed lithology. Although each individual taxon has its own environmental preferences, it is obviously advantageous to consider more than one group for a synoptic palaeoenvironmental interpretation (Peacock, 1996). The trends in benthic faunal composition, from survivor or pioneer groups to a more diverse fauna in the course of postglacial flooding, as observed by us for the Laptev Sea shelf, are typical features also recognized in other Arctic and high-latitude areas (e.g. Cronin, 1977, 1981, 1989; Syvitski et al., 1989; Dyke et al., 1996; Schoning and Wastegård, 1999; Polyak et al., 2000; Gordillo and Aitken, 2001). Our data show that fossil molluscs and ostracods document past changes in Arctic shelf environments that are related to salinity and water depth to a greater degree of accuracy than benthic foraminifers, which exhibit a minor variation in their species diversity, and then only during the early stage of the Laptev Sea shelf evolution when environmental conditions were more contrasting.

5.3. Summary

By combining the spatial distribution pattern of modern molluscs, ostracods, and foraminifers in coretop sediments from the Laptev Sea shelf, and comparing them with the temporal succession of fossil assemblages in two cores from the middle shelf (modern water depth 45–51 m), conclusions have been drawn on the Holocene changes in depositional environment and bottom water properties. Due to global sea-level rise after the last glaciation, which led to the transformation of the Laptev Sea shelf from a terrestrial to a marine environment, three major phases were recognized:

1. c. 11.3–11.1 cal. ka in the Yana palaeovalley, and c. 11.2–10.8 cal. ka in the Lena palaeovalley—existence of brackish-water estuaries with water depths less than 10 m, which were inhabited by pioneer, taxonomically poor assemblages of brackish-water and euryhaline species able to survive in a seasonally variable environment with low bottom salinity (about 18–20). The occurrence of high sedimentation rates (up to 500 cm/kyr in the Yana palaeovalley) and input of terrestrial plant debris point to intensive coast-to-shelf transfer of sediments as well as fluvial runoff;
2. c. 11.1–10.3 in the Yana palaeovalley, and c. 10.8–8.2 cal. ka in the Lena palaeovalley—this time interval describes a transitional shallow-water environment with water depths increasing up to 20–25 m towards the end of the phase. The gradual replacement of brackish-water taxa by normal marine species indicates bottom salinity increase of up to 26–28. Generally decreasing, but still high, sedimentation rates (~90 cm/kyr) with considerable amounts of plant debris still indicate active coastal erosion and considerable fluvial runoff;
3. c. 10.3 in the Yana palaeovalley, and c. 8.2 cal. ka in the Lena palaeovalley—an abrupt change marks the onset of modern marine conditions. Bottom salinity rose to about 30—32 as reflected in a short transition to a taxonomically more diverse faunal assemblages, which were dominated by normal marine species similar to the modern communities of the studied area. Low sedimentation rates and insignificant plant debris content characterize strongly reduced cross-shelf transfer of sediments from the south and a bottom waters with enhanced dynamics, altogether indicating the establishment of modern-like conditions.

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