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Benthic Foraminifers in Upper Quaternary Sediments of the Southern Bering Sea: Distribution and Paleoceanographic Interpretations

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Abstract—Composition and distribution of benthic foraminifers, being coupled with isotopic–geochemical data on Upper Pleistocene and Holocene sediments from the southern Bering Sea (Core GC-11; 53°31′ N, 178°51′ E, water depth 3060 m), demonstrate variations in bottom water properties during the last 54 kyr. Their abundance increased to some extent during short periods corresponding to warm Dansgaard–Oeshger interstadials 14, 12, 8, and 2 of marine isotopic stages (MIS) 3 and 2. The first and second deglaciation phases separated by the Younger Dryas cooling episode are marked by significant abundance peaks of benthic foraminifers (an order magnitude higher than in the glacial period), although their share in community of benthic and planktonic foraminifers taken together decreases. Species typical of stable high-productivity areas gain the dominant position. A significant proportion of agglutinated species in the Holocene sediments is indicative of Ca ions deficiency that accelerates dissolution of carbonate tests up to their disappearance approximately 2.5–3 ka ago.

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Key words: Benthic foraminifers, Holocene, glaciation, deglaciation, hydrological changes, Bering Sea.

INTRODUCTION

The Late Quaternary ecosystems of the Okhotsk and Bering seas and hydrological evolution of these basins attract recently a keen attention of researchers. This is linked primarily with the fact that biogenic productivity in these seas is much higher than in other oceanic regions, and investigation of their ecosystems is important from both theoretical and practical viewpoints. Owing to their huge sizes and high-latitude positions, both marginal sea basins influence significantly hydrological situation in the northern Pacific. It is shown, for example, that the Okhotsk and Bering seas played an important role in formation of intermediate water mass of the northern Pacific during the glacial period (e.g., Keigwin, 1998).

Recent studies carried out in the Okhotsk Sea showed that planktonic and benthic foraminifers experienced substantial changes by transition from glacial to interglacial conditions (Khusid and Basov, 1999; Chekhovskaya and Basov, 1999; Basov et al., 2000; Gorbarenko et al., 2000, 2002). It was established also that biological productivity in this basin during the glacial period was notably lower than in the Holocene (Gorbarenko, 1996).

The Bering Sea influence on regional hydrological processes remains poorly understood. Response of its ecosystem and different groups of planktonic and benthic organisms to different-scale climatic oscillations during the Late Quaternary has practically never been studied. Recent study of planktonic foraminifers in bottom sediments of the southern Bering Sea revealed intricate variations in their composition and abundance during the last 50 000 calendar years (MIS 1–MIS 3) under impact of short-term climatic fluctuations and the Alaska Current. The calculated mass accumulation rates (MAR) of organic carbon showed that the primary productivity of waters in the region under consideration was slightly higher during the last glacial than in the Holocene (Gorbarenko et al., 2005). This inference is consistent with data on diatoms from the last glacial and Holocene sediments of the northern Pacific, which indicate a substantial decrease of plankton biomass in Holocene surface waters as compared with glacial waters (Sancetta, 1992).

In this connection, it seems reasonable to understand how the deepwater fauna reacted to these processes, especially benthic foraminifers, which have never been studied in this region. To understand this, we analyzed composition and distribution of these microfossils through the section of Upper Quaternary sediments in the southern Bering Sea (Core GC-11). The the results of our study are discussed below.

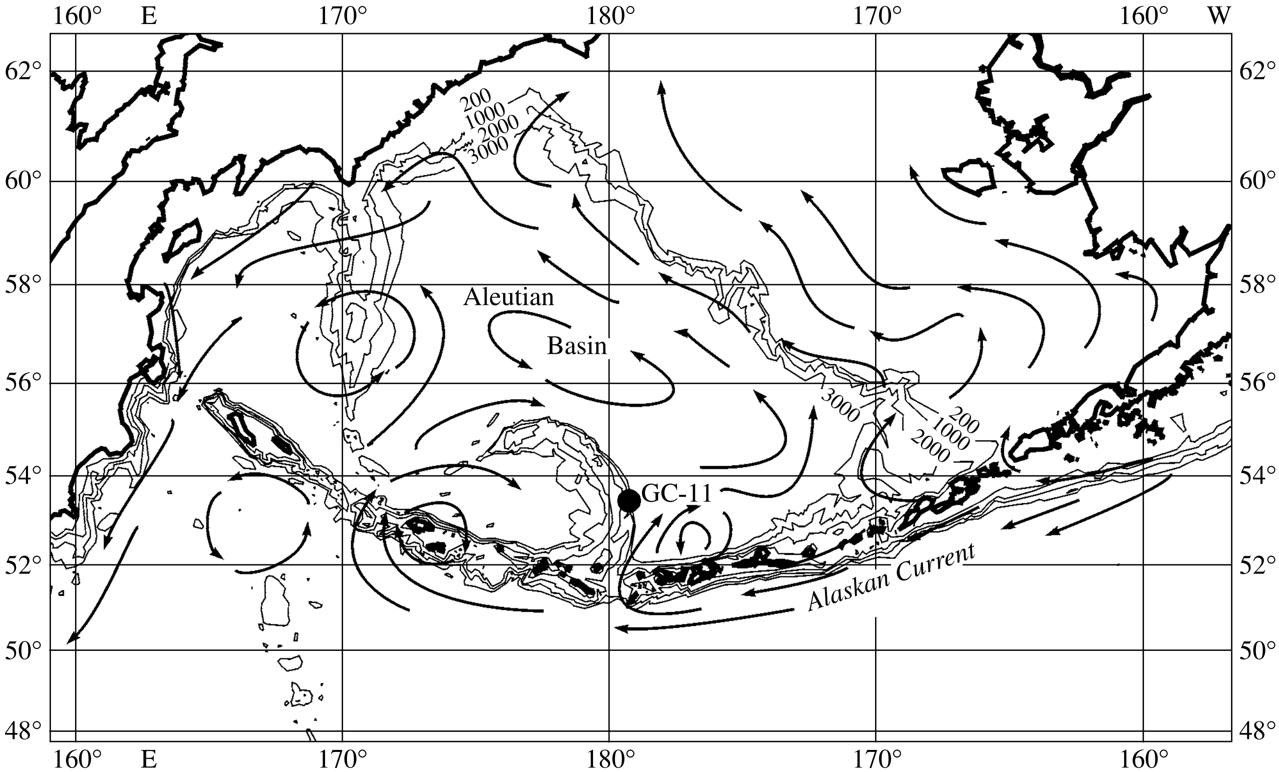

Fig. 1. The Core GC-11 site in the Bering Sea; arrows show present-day surface circulation.

MATERIAL AND METHODS

Core GC-11 660 cm long was taken at the foot western of the Bowers Ridge, the site depth 3060 m, lat. 53°31′ N, long. 178°51 E (Fig. 1). The recovered section is composed of the following sediments (from base upward): olive gray sandy clays (645–660 cm); olive gray silty clays with insignificant admixture of diatoms (530–645 cm); sandy silt (510–530 cm); slightly diatomaceous clay with admixture of sandy material in the lower part (462–510 cm); gray silt with admixture of sand (457–462 cm); dark olive gray silt with inclusions of pebbles and gravel at 263 and 340 cm and tephra at 395 and 405 cm (161–457 cm); dark grayish green silty clay with admixture of diatoms and foraminifers (123–161 cm); greenish gray silt with sand admixture (111–123 cm); olive gray silty diatomaceous mud with admixture of foraminifers and ash interbed at 95 cm (13–111 cm); grayish brown silty clay with sand admixture (0–13 cm).

Samples for the foraminiferal analysis (121 in total) were taken from 1-cm-thick slices with the step of 5 cm. Tests of benthic foraminifers were examined in the fraction of 63 μm separated from 40 to 60 g of dry sediment. Depending on abundance, they were counted in entire or partial fraction with subsequent recalculation for 1 g of dry sediment. Previously, contents of C_{org}, $CaCO_3$, and ice-rafted material (Gorbarenko, 1996), oxygen and carbon isotope composition in tests of benthic and planktonic foraminifers, composition and abundance of the foraminiferal species (Gorbarenko et al., 2005) have been determined. In the last work, all these parameters are correlated to the chronological scale of Core GC-11 in calendar years. The scale is calibrated using the results of radiocarbon AMS dating corrected for the reservoir effect of surface waters, which is equal to 1000 years, and with account for correlation of the isotope curve obtained for benthic foraminifers with the standard isotope chronostratigraphy (Martinson et al., 1987). For the lower part of the core corresponding to MIS 3 (from depth of 310 cm downward), intervals of relative climate warming (385–410, 500–520, and 600–640 cm) were defined based on the distribution of planktonic and benthic foraminifers and on proportions of thermophilic and cold-resistant diatom species. These intervals were then correlated with known and best-manifested warming episodes in the Northern Hemisphere, which correspond to Dansgaard–Oeshger (DO) interstadials 8, 12, 14, respectively (Gorbarenko et al., 2005). Ages of sediments correlative with DO interstadials 8 and 12 that, which were measured in Core GC-11 based on available chronological dates and extrapolation in the core lower part, correspond to dates of approximately 38 and 45 cal. ka, respectively. These dates are determined for relevant events recorded in Greenland ice cores (GISP 2 project, Meese et al., 1997) and in stalagmites of central China (Wang et al., 2001). The average age of the DO interstadial 14 (53.5 cal. ka), which is determined in Core C-11 by extrapolating sedimentation rates, is corrected to 52 cal. ka (Gorbarenko et al., 2005) to fit chronology of the Greenland ice core and stalagmites of China.

RESULTS AND DISCUSSION

Quantitative distribution. Abundance of benthic foraminifers in all the examined samples varies from 2–3 to 644 specimens/g of dry sediment (table, Fig. 2).

Sediments of the core lower part (155–660 cm), which accumulated during the glacial period of 54–14.9 cal. ka ago (MIS 3 and MIS 2), are usually characterized by low concentrations of foraminiferal tests (below 10 specimens/g) largely belonging to secretory species (95%). Abundance of benthic foraminifers increases up to 30–50 specimens/g in intervals of 640–600, 520–500, 410–385, and 245–230 cm corresponding to warm DO interstadials 14, 12, 8, and 2 of MIS 3 and MIS 2 (52, 45, 38, and 23 cal. ka ago, respectively; Gorbarenko et al., 2005). Abundance of planktonic foraminifers is getting higher as well (Gorbarenko et al., 2005). Sediments in these intervals with the C_{org} content up to 0.64–0.72% are slightly enriched in $CaCO_3$ (up to 1.5–2.0%). Benthic species usually represent 1–2% and less of all foraminifers occurring in these sediments, while in intervals with minimal abundance of benthic foraminifers and low concentrations of $CaCO_3$ (0.5–0.6%) and C_{org} (0.5%), their relative content increases up to 20–40%. Foraminiferal tests in sediments of MIS 3 and MIS 2 are mostly of satisfactory preservation, although tests of some species, e.g., of *Uvigerina auberiana* Orbigny and *Globobulimina auriculata* (Bailey), are strongly corroded and sometimes fragmented in certain intervals. An increased relative share of benthic forms in assemblages represented by not numerous foraminifers probably indicates a low influx of planktonic foraminifers to sediments, in addition to dissolution of carbonate tests. As is known, proportions between benthic and planktonic foraminiferal tests in assemblages is traditionally used for estimating the basin depths and chemistry of bottom waters. It is conceivable that in marginal seas this parameter reflects as well a productivity signal.

The uppermost glacial sediments in the interval of 165–155 cm demonstrate a notable increase in abundance of both the benthic and planktonic foraminifers, thus reflecting the productivity growth in the basin. This trend is consistent with increased concentrations of biogenic material and organic matter in sediments.

In the interval of 155–120 cm (14.87–12.28 cal. ka ago) corresponding to the onset of MIS 1, abundance of benthic foraminifers represented entirely by calcareous species increases sharply to reach maximum of 400–664 specimens/g in the layer of 150–140 cm (14.41–13.82 cal. ka ago). Sediments of this layer are also remarkable because of maximal $CaCO_3$ and C_{org} contents (up to 12 and 1.47%, respectively). Benthic species constitute approximately 10% in the amount of planktonic and benthic foraminifers.

Against the background of relatively high abundance of benthic foraminifers below and higher in the section, the interval of 120–110 cm (12.28–11.2 cal. ka ago) corresponding to the Younger Dryas event is distinguishable owing to low content of tests: 10–35 specimens/g. The group of calcareous forms becomes simultaneously slightly less diverse. Planktonic foraminifers in these sediments are also impoverished in diversity and quantitative respect (Gorbarenko et al., 2005). The share of benthic species in the whole foraminiferal assemblage is 30 to 50%. The $CaCO_3$ and C_{org} contents decrease down to 2–3 and 0.72–0.95%, respectively.

The interval of 110–50 cm (early–initial middle Holocene; 11.2–5.6 cal. ka ago) demonstrates increase in abundance of benthic foraminifers as compared with underlying sediments corresponding to the Younger Dryas event (up to 40–65 specimens/g). The $CaCO_3$ content is also slightly higher, varying from 5 to 7.5%, while C_{org} concentration decreases down to 0.45–0.75%. In the upper 50 cm of the core (0–5.6 cal. ka), abundance of benthic foraminifers drops to 3–7 specimens/g. Thus, variations of foraminiferal abundance in Holocene sediments are of the same magnitude as in glacial sediments. The C_{org} content irregularly ranges from 0.46 to 0.8% being comparable with that in glacial sediments. The Holocene sediments are however richer in (3–7%) than the glacial interval. The $CaCO_3$ concentration decreases to 1% only in the uppermost layer (0–5 cm) that corresponds to the last 0.44 cal. ka.

In Holocene foraminiferal assemblages, secretory species represented by intact tests and their fragments are always accompanied by agglutinated forms, the share of which progressively increases upward the section. For example, they constitute 3–4% in the early Holocene (11.2–8.0 cal. ka ago), up to 4–14% in the Middle Holocene, and are dominant (86–99%) in the uppermost 0–20 cm corresponding to the last 2.0–2.5 cal. ka ago.

The relative proportions of benthic and planktonic foraminifers in Holocene sediments are approximately similar to their percentages in most samples from glacial sediments. Benthic species represent 1–5% of all the foraminifers. In the terminal Holocene (2.5 to 2.0 cal. ka ago), the foraminiferal fauna suffered a drastic transformation: planktonic species disappeared, while benthic are represented mostly by agglutinated forms. Such cardinal and rapid faunal change reflects probably a sharp hydrological reorganization in the bottom layer of the southern Bering Sea, most likely the deficiency of Ca ions in bottom waters capable to dissolve calcium carbonate, i.e., to eliminate calcareous tests. At the same time, hydrochemical conditions and productivity of the surface water layer were relatively stable, as it is evident from the unchanged composition

Radiocarbon (bold italic) and calculated ages of sediments recovered by Core GC-11 in the southern Bering Sea

Depth, cm	Age, cal. ka	Depth, cm	Age, cal. ka	Depth, cm	Age, cal. ka
0	0.16	225	21.35	450	41.82
5	0.45	230	21.76	455	42.16
10	0.85	235	22.16	460	42.51
15	1.35	***240***	***22.16***	465	42.85
20	1.91	245	22.67	470	43.19
25	2.51	250	23.18	475	43.54
30	3.14	255	23.69	480	43.88
35	3.77	260	24.20	485	44.23
40	4.40	265	24.70	490	44.57
45	***5.01***	270	25.21	495	44.91
50	5.60	275	25.71	500	45.26
55	6.17	280	26.21	505	45.60
60	6.72	285	26.71	510	45.95
65	7.25	***290***	***26.27***	515	46.22
70	7.77	295	26.75	520	46.50
75	8.28	300	27.24	525	46.77
80	***8.79***	305	27.72	530	47.05
85	9.14	***310***	***28.21***	535	47.32
90	9.51	315	29.56	540	47.60
95	9.88	320	30.01	545	47.87
100	10.28	325	30.46	550	48.15
105	***10.71***	330	30.90	555	48.42
110	11.19	335	31.35	560	48.70
115	11.86	340	31.79	565	48.97
120	12.28	345	32.24	570	49.25
125	12.71	350	32.68	575	49.52
130	13.13	355	33.12	580	49.80
135	***13.55***	360	33.56	585	50.07
140	13.83	365	34.00	590	50.35
145	14.11	370	34.44	595	50.62
150	***14.41***	375	34.88	600	50.90
155	14.87	380	35.32	605	51.17
160	***15.34***	385	35.75	610	51.45
165	15.78	390	36.19	615	51.72
170	16.23	395	36.62	620	52.00
175	16.68	***400***	***37.06***	625	52.28
180	17.12	405	37.55	630	52.55
185	17.57	410	38.05	635	52.83
190	18.01	415	38.54	640	53.10
195	18.45	420	39.03	645	53.38
200	***18.89***	425	39.52	650	53.65
205	19.71	430	40.01	655	53.93
210	20.12	435	40.50	660	54.20
215	20.53	440	40.99		
220	20.94	445	41.47		

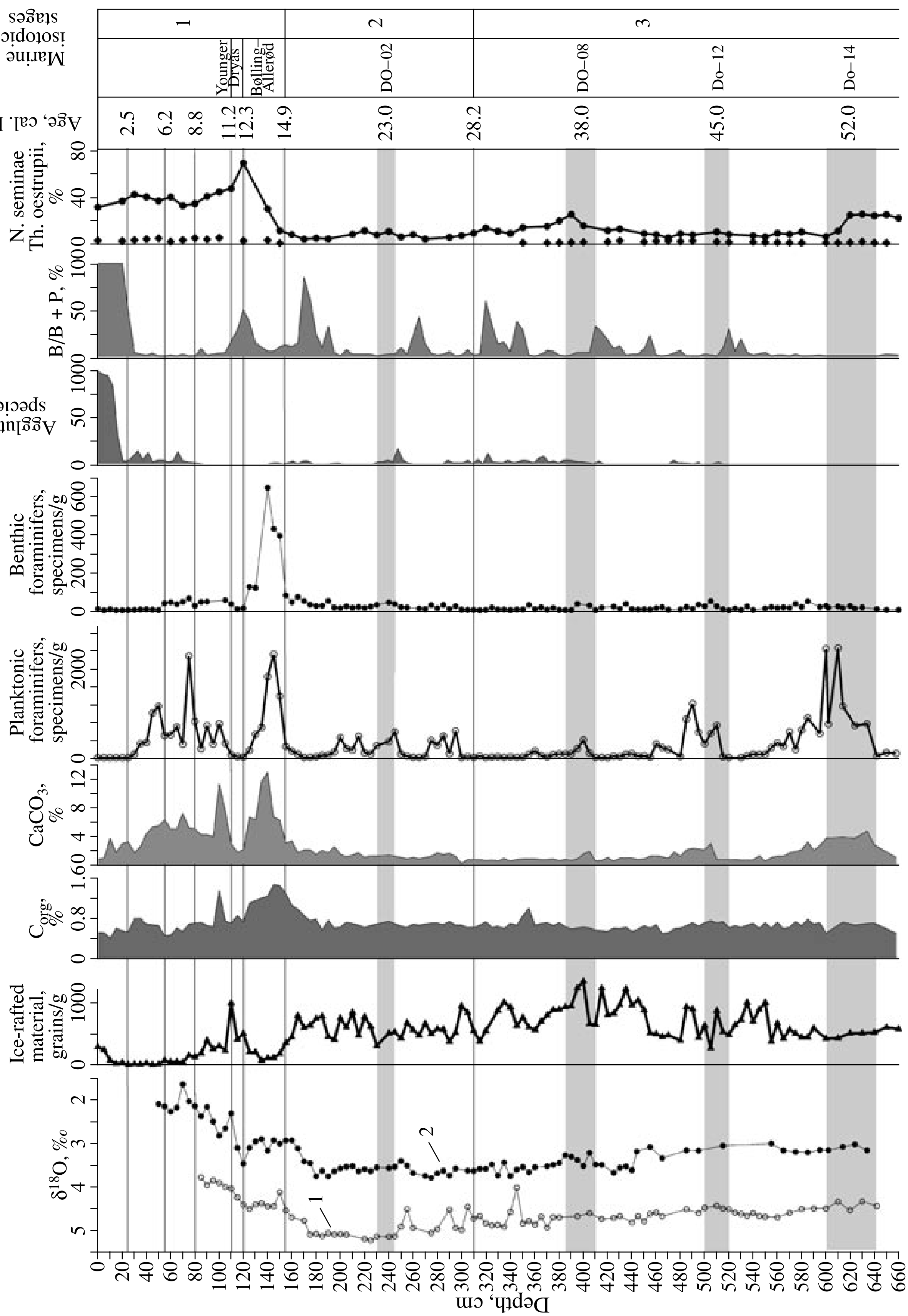

Fig. 2. Distribution of main abiotic and biotic characteristics of sediments through Core GC-11 from the southern Bering Sea; (B/B+P) ratio between benthic foraminifer and integral (benthic + planktonic) abundances; DO-02, DO-08, DO-12, and DO-14 are Dansgaard–Oeshger interstadials. (1) *Uvigerina auberiana*; (2) *Neogloboquadrina pachyderma*.

of sediments (diatom oozes) and their chemical parameters such as $CaCO_3$ and C_{org} contents.

Taxonomic composition. *Alabaminella weddellensis* (Earland) and *Uvigerina auberiana* (Orbigny) are the most representative species of the benthic assemblage almost throughout the core section, ranging in abundance from 20 to 60% and from 5 to 20%, respectively (Fig. 3). Their share is significant in sediments of the glacial period (MIS 3 and MIS 2), deglaciation, and Lower Holocene (onset of MIS 1). *A. weddelensis* and *Uvigerina auberiana* remain dominant up to 9 and 8 cal. ka ago, respectively. In younger sediments, both species are scarce. Their proportions are different, depending on total abundance of foraminifers. Being persistently abundant in foraminiferal assemblages of MIS 2 and MIS 3, species *A. weddellensis* reveals frequent and sharp variations in abundance during MIS 3, and lower percentages of this taxon correspond mostly to episodes of relative warming and habitat improvement in DO interstadials 2, 8, 12, and 14. The highest content (60–70%) of *U. auberiana* is established in the impoverished Younger Dryas assemblage, where a substantial share also belongs to *Globobulimina auriculata* (7–16%).

A. weddellensis is a so-called phytodetrital species (Gooday, 1988; Thomas et al., 1995; Okushi et al., 2000) whose development depends on seasonal influx of fresh readily decomposing phytodetritus. In the present-day Bering Sea, it populates the depth zone of 2000 to 3000 m (Saidova, 1975). *U. auberiana* is an infaunal species. It is able to penetrate into surface sediments up to depth of 3–4 cm and prefers labile organic matter and bacteria for food (Corlis, 1985, 1991; Jorisson, 1999; Bubenshchikova et al., in press). In the present-day Bering Sea, *U. auberiana* is found in the lower part of the continental slope within the depth interval of 2300 to 3000 m (Chekhovskaya, 1973). It is conceivable that the high productivity of *A. weddellensis* is favored by seasonal influx of phytoplankton, development of which is suppressed by harsh conditions during winter (for example, because of sea ice).

The most abundant and diverse foraminiferal assemblage is characteristic of sediments accumulated immediately after the glacial period between 14.9 and 12.3 cal. ka ago (MIS 1). The dominant species of relevant deglaciation assemblage is *Bulimina exilis* missing from all the other foraminiferal assemblages of the examined core.

In the present-day Bering Sea, *B. exilis* is known from continental slopes of the underwater Shirshov Ridge (Saidova, 1961), being confined here to sediments enriched in organic matter (Lisitsyn, 1966). Like the other *Bulimina* species, *B. exilis* dwells in the World Ocean areas, where primary productivity of surface waters is permanently high, providing a high flux of fresh phytoplankton and terrigenous organic matter to bottom sediments (Thomas et al., 1995; Rasmussen et al., 2002). The mass development of *Bulimina exilis* during deglaciation signifies most likely the ability of this species to assimilate terrestrial organic matter, which entered the basin in high quantities precisely in that period. Abundant populations of this taxon are reported from upwelling zones at northwestern (Caralp, 1989) and southwestern (Schmiedl and Mackensen, 1997) continental slopes of Africa and from the Gulf of Mexico near the Mississippi River mouth (Rasmussen et al., 2002). Representatives of the genus *Bulimina* survive under a sharp oxygen deficiency in bottom waters (Khusid, 1977; Basov, 1978; Sen-Gupta and Machian-Castillo, 1993).

The following species occur persistently throughout the studied core section: *Gyroidina orbicularis* (Orbigny), *G. soldanii* (Orbigny), *Cibicides kullenbergi* Parker, *C. lobatulus* (Walker et Jacob), *Melonis barleeanus* (Williamson), *M. umbilicatulum* (Montagu), *Globobulimina auriculata* (Bailey), *Elphidium batialis* Saidova, and *Pullenia sphaeroides* (Orbigny). The relative content of each species in glacial assemblages (MIS 3 and MIS 2) is usually below 10%. Some of them demonstrate certain regularity in their distribution. For example, *E. batialis* and species of the genus *Melonis* are more frequent and abundant in sediments of MIS 2, while in deglaciation assemblages their role is notably reduced.

In the Holocene sediments, share of this group substantially increases, and content of each species is variable in this interval. In the Early Holocene (11.2–8.8 cal. ka ago), *G. orbicularis* and associated *A. weddellensis* and *U. auberiana* dominate in foraminiferal assemblages. After 9.1 and to 6.2–5.6 cal. ka ago, dominant taxa are *G. orbicularis* accompanied now by *E. batialis* and *Cassidulina reniformis*, (14–20% each), and by persistently occurring *Globobulimina auriculata* and species of the genus *Cibicides.* During a relatively short period of the Middle Holocene (6.2 to 2.5 cal. ka ago), of dominant rank was *Chilostomella oolina* (20–40% of benthic foraminifers), and share of *Melonis* species increased as well at that time.

The Holocene species had similar distribution areas. All of them populate now deep basins of the Bering and Okhotsk seas being most abundant in the depth interval of 2500–3000 m (Saidova, 1961).

At the same time, ecological preferences of Holocene species are different (Corlis, 1991; Jorisson, 1999; Wang et al., 2001). Representatives of the genus *Cibicides* dwell on sediment surface and thus belong to epifauna that feeds on suspended particles of organic matter. Species of genera *Gyroidina, Elphidium, Melonis,* and *Pullenia* represent the so-called shallow infauna dwelling on the surface and within the uppermost sedimentary layer 2 to 4 cm thick and feeding largely on labile organic matter and bacteria. *Chilostomella oolina* and *Globobulimina auriculata* are species of deep infauna that penetrates into sediments below 4 cm and assimilate residual organic matter ignored by other species. These species are usually

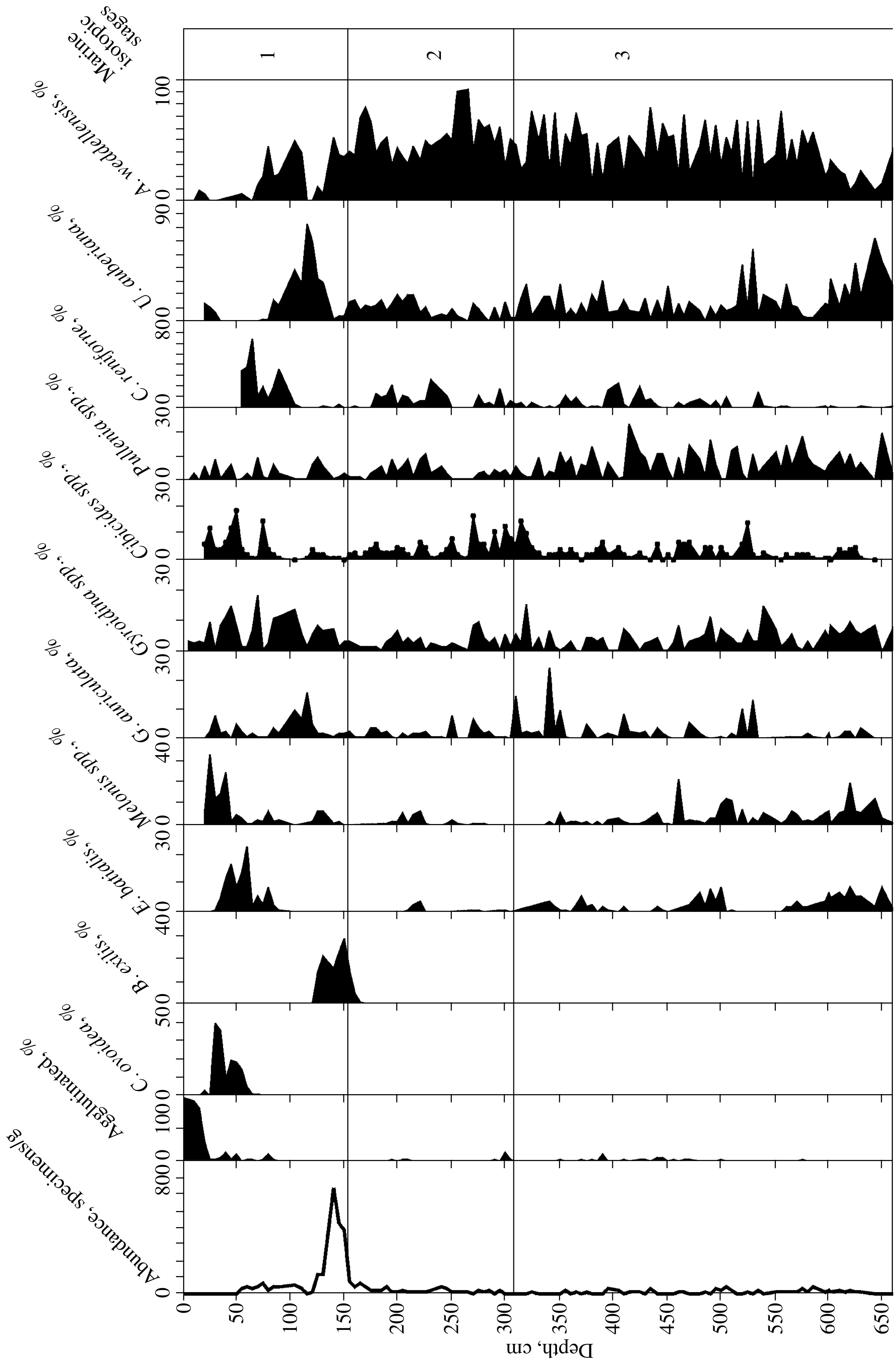

Fig. 3. Quantitative distribution of benthic foraminiferal species through Core GC-11 section in the southern Bering Sea.

attributed to the high-productivity group (Loubere and Fariduddin, 1999). *E. batialis* is reported from highly productive northern areas of the Pacific, from sites at slopes of the Aleutian and Komandor basins in the Bering Sea, near Hokkaido and Honshu islands, and in the Kurile–Kamchatka Trench (Saidova, 1961).

In the Late Holocene (the last 2 kyr or upper 20 cm of the core), foraminiferal community was dominated by agglutinated species *Rhabdammina parabyssorum* Stschedrina, *Hormosina normani* Brady, *Ammolagena clavata* (Parker et Jones, *Labrospira jeffreysi* (Williamson), *Cribrostomoides subglobosus* (Sars), *Karreriella baccata* (Schwager), and others, which represented in total up to 83–99% of all foraminifers. Some of them occur in the Lower and Middle Holocene sediments as well. *K. baccata* is present also in glacial assemblages.

Hydrological changes. Based on the analyzed composition and structure of benthic foraminiferal assemblages from the Core GC-11, it is possible to reconstruct general features of the Bering Sea paleooceanographic evolution in the last 54 kyr.

Judging from distribution of benthic foraminifers in the section, hydrological conditions near the bottom and, probably, in the surface water layer of the southern Bering Sea during the glacial period (MIS 3 and MIS 2) were stable and unfavorable for development of benthic fauna. This is evident from low abundance of benthic foraminifers in this period (Fig. 2). Their abundance was getting 3 to 4 times higher only during short-term episodes of relative warming approximately 52, 45, 38, and 23 cal. ka ago corresponding to Dansgaard–Oeshger interstadials 14, 12, 8 and 2 (Gorbarenko et al., 2005). It seems that productivity of surface waters in these periods increased as well that is evident from the following facts. First, proportion of "phytodetrital" species *Alabaminella weddellensis* feeding on continuous flux of fresh organic matter decreased in corresponding assemblages of benthic foraminifers. This was likely a result of more favorable conditions in surface waters and less expressed seasonal patterns of phytoplankton development. The infaunal detritophagous *U. auberiana* played a subordinate role during the last interstadials. Second, abundance of planktonic species was substantially higher in these periods (Gorbarenko et al., 2005), and they represented up to 98–99% of all foraminifers, more than in the other epochs of glacial period (60–90%). Third, C_{org} and $CaCO_3$ contents in corresponding sediments increased against the background of their low values throughout the entire glacial period.

The deglaciation onset approximately 14.9 cal. ka ago (beginning of MIS 1) was marked by sharp changes in basin environments, which resulted in substantial transformations of the foraminiferal community. Like in the Sea of Okhotsk and northern Pacific, the deglaciation period in the Bering Sea is marked by two peaks in the C_{org} and $CaCO_3$ contents, negative $\delta^{18}O$ excursion, and by enrichment of sediments in biogenic components, i.e., in diatoms and foraminifers (Keigwin et al., 1992; Keigwin, 1998; Kiefer et al., 2001; Gorbarenko, 1996; Gorbarenko et al., 2002, 2005). These events are correlative with the Bølling–Allerød warming at the end of the Pleistocene (14.9–12.3 cal. ka ago) and pre-Boreal warming episode at the beginning of the Holocene (11–8 cal. ka ago), which were accompanied by accelerated melting of glaciers in the Northern Hemisphere. For example, some researchers believe that Alaskan shelf near the Kadyak Island (westernmost island of the Aleutian arc) became free of ice 14.7 cal. ka ago (Mann and Peteet, 1994). The accelerated melting of glaciers during two warm episodes (glacial recession) was responsible for the so-called melt water pulses (MWP 1A and 1B; Fairbanks, 1989) and rapid sea-level rises (Mann and Hamilton, 1995; Perry and Hsu, 2000). This activated the Alaska gyre and enhanced influx of North Pacific waters to the Bering Sea via deepened straits in the Aleutian arc. Due to the sea level rise, the influx of terrestrial organic matter increased. Profiles of terrestrial vegetative n-alkanes and sedimentation rates in the Sea of Okhotsk for the last 30 kyr demonstrate maximums during deglaciation (Seki et al., 2003). The carbon/nitrogen atomic ratios in organic matter (Nuernberg and Tiedemann, 2004) and analysis of organic alkenons in sediments of the Sea of Okhotsk (Ternois et al., 2001) imply a significant growth of the surface water temperature (by 2–3°C) and elevated influx of terrestrial organic matter to this marginal basin during the MWP 1A event that happened, evidently, due to the rapid sea level rise and enhanced supply of terrigenous material. The recession of glaciers and increased influx of snow–ice melt water provoked an intense bloom of coccolithophorids, which become dominant over diatoms because of insufficient silica replenishment from subsurface water layers (Seki et al., 2004). Significant anomalies in ratios of stable carbon and nitrogen isotopes in organic matter are explained by suppressed vertical water mixing and low contents of nutrients in surface waters because of the low influx of water melted from mountainous glaciers on adjacent land (Nakatsuka et al., 1995).

Warming and productivity growth in the Bering Sea during deglaciation are recorded in a relatively thermophilic composition of planktonic foraminifers and a sharp increase in their abundance. Good preservation of their tests implies decreased aggressiveness of bottom waters with respect to carbonate tests (Gorbarenko et al., 2005). Assemblages of benthic foraminifers show a significant abundance growth (by several times as compared with the glacial period). *Bulimina exilis* characteristic of areas with permanently high productivity becomes dominant at that time. The accelerated development of *Bulimina exilis* population during the deglaciation reflects most likely the species ability to assimilate food of terrestrial origin, transported to the sea in maximal volume precisely at that time.

The deglaciation period was interrupted by a short-term cooling of the Younger Dryas event (12.3–

11.2 cal. ka ago), when abundance of benthic foraminifers decreased to the values characteristic of the glacial period (up to 12 specimens/year and lower) and their share in foraminiferal community as a whole became equal to 30–50%. The Younger Dryas was the disappearance period of *Bulimina exilis* and phytodetrital species *Alabaminella weddellensis* and the development time of foraminiferal fauna similar to that of the glacial period. In the Younger Dryas, dominant in the community was *Uvigerina auberiana* accompanied by subdominant *Globobulimina auriculata.* Thus, phytodetrital species gave way to infaunal forms capable to penetrate deep into sediments and assimilate residual organic matter buried in sediments. Such a composition of foraminiferal fauna suggests selective dissolution of carbonate tests and deceased productivity of surface waters. This is evident from the elevated share of benthic species in the integral foraminiferal assemblage, minimal abundance of planktonic forms with signs of intense dissolution of their tests (Gorbarenko et al., 2005). The significant Younger Dryas cooling is recognizable also owing to other parameters: heavy oxygen isotope composition in tests of planktonic (*Neogloboquadrina pachyderma*) and benthic (*Uvigerina auberiana*) foraminifers, low concentrations of carbonate and organic carbon, and elevated content of ice-rafted material (Gorbarenko et al., 1995, 2005).

The period of 8.8 to 2.5 cal. ka ago corresponded to transformation of the hydrological regime and biota in the Bering Sea. Judging from relatively high $CaCO_3$ and C_{org} contents (up to 7 and 0.8%, respectively) and high diatom admixture in sediments, the productivity of surface waters declined insignificantly as compared with deglaciation period. The changes affected primarily the quantitative distribution of benthic foraminifers, abundance of which dropped to 40–60 (8–6 cal. ka ago) and 3–7 specimens/g (6.0–2.5 cal. ka ago); percentage in the assemblage as a whole to 1–5%. Taxonomic composition of benthic foraminiferal community changed notably as well. Species widespread in sediments of the deglaciation period (*Alabaminella weddellensis, Uvigerina auberiana, Globobulimina auriculata*, and *Bulimina exilis*) disappeared or lost their dominant position to give way to a group of previously subordinate deepwater taxa (*Gyroidina orbicularis, G. soldanii, Elphidium batialis, Melonis barleeanus, M. umbilicatulum, Cibicides kullenbergi, C. lobatulus,* and *Chilostomella oolina.*) Species of the last group dwell in the present-day Bering and Okhotsk seas close the carbonate compensation depths occupying different levels relative to the bottom surface: some of them belong to epifauna (*Cibicides*), while the others live in sediments 2 to 4 cm below the bottom surface (*Gyroidina, Elphidium, Melonis, Pullenia*) or deeper (*Chilostomella, Globobulimina*; Corlis, 1985, 1991). The relatively high percentage of last two genera in the Middle Holocene assemblage (up to 20–40%) implies progressing carbonate dissolution in bottom waters. This is consistent with the notably increased share of agglutinated species (up to 12–14%) and declining preservation degree of planktonic foraminifers during this period (Gorbarenko et al., 2005).

Based on study of biogenic components in sediments and distribution of organic elements triads and biomarkers (alkenons, n-alkanes, calcium carbonate, biogenic opal, and others), it is shown (Gorbarenko et al., 2000, 2002; Seki et al., 2004) that during the deglaciation and Early Holocene coccolithophorids were a main components phytoplankton in the Sea of Okhotsk. Bottom sediments of that time contain abundant carbonate microfossils (coccolithophorids, planktonic and benthic foraminifers). Later on, in the Middle and Late Holocene, phytoplankton was dominated by diatoms. In opinion of Seki and his colleagues, this was a response to intensified vertical mixing of surface and subsurface waters in winter seasons and to enhanced silica influx into subsurface water layer from the North Pacific. In the Bering Sea, the situation was similar in many aspects. Nevertheless, the diatoms production rate in the sea was different, although trends in development of carbonate microorganisms and production of organic matter here and in the Northwest Pacific were comparable with relevant trends in the Sea of Okhotsk (Gorbarenko, 1995). In the Bering Sea, the diatom content, being relatively high in sediments of the first deglaciation phase (MWP 1A), is low in the interval of the Younger Dryas cooling event and high again in sediments corresponding to the episode MWP 1B. Accumulation of diatom oozes in this basin commenced already in the Early Holocene in distinction from the Sea of Okhotsk, where sediments of this kind accumulated only during the last 4–6 kyr.

The most dramatic changes in the composition of benthic foraminifers occurred during the last 2.0–2.5 kyr, when calcareous species were completely replaced by agglutinated forms and planktonic tests disappeared from sediments. These changes are explainable by a sharp deficiency of Ca ions in bottom waters. The phenomenon was characteristic of the Bering Sea, Sea of Okhotsk, and Northwestern Pacific, thus being of the regional significance. At present, foraminiferal communities dwelling at the depth of 3000 m in the above regions consist exclusively of agglutinated species (Saidova, 1961).

CONCLUSIONS

The analyzed composition and quantitative distribution of benthic foraminifers in Upper Pleistocene–Holocene sediments of the southern Bering Sea elucidate the following principal features of hydrological evolution in this part of the basin.

(1) During MIS 3 and MIS 2 (54 to 14.8 cal. ka ago), environments near the bottom were relatively stable and unfavorable for development of benthic fauna. Like in the Sea of Okhotsk during the glacial period (Khusid and Basov, 1999), productivity in the marginal basin

under consideration was of seasonal character, as it is evident from prevalence of phytodetrital species *Alabaminella weddellensis* in the foraminiferal community. The taxonomic composition, proportions of benthic and planktonic foraminifers, distribution of diatoms, and isotopic–geochemical signals suggest a slight water warming in the Bering Sea during short periods the DO interstadials 14, 12, 8, and 2 (approximately 52, 45, 38, and 23 cal. ka ago; Gorbarenko et al., 2005.

(2) In the first and second deglaciation phases separated by the Younger Dryas cooling event, abundance of benthic foraminifers was an order of magnitude higher than in first glacial phase and two–three times higher than in the second one, although their proportion relative to planktonic foraminifers was lower. *Bulimina exilis* characteristic of areas with persistently high productivity and capable to assimilate terrigenous organic matter was a dominant species during the first deglaciation phase. The obtained micropaleontological and isotopic–geochemical data indicate a notable warming and productivity increase in the Bering Sea during the warm Bølling–Allerød episode and at the beginning of the Holocene. During the Younger Dryas cooling over the entire Northern Hemisphere, environments in the Bering Sea were close to glacial ones.

(3) The progressively increasing proportion of agglutinated species in the Holocene foraminiferal community indicates growing deficiency of Ca ions in bottom waters and dissolution of carbonate tests up to their complete disappearance from sediments of this basin approximately 2.0–2.5 cal. ka ago.

(4) Judging from the quantitative distribution of benthic foraminifers through the Core GC-11 section, productivity in the Bering Sea was relatively stable during the last 54 kyr and notably increased only during the first deglaciation phase, i.e., 14.9 to 12.3 cal. ka ago.

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