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GEOLOGY

Paleoceanographic Conditions in the Western Bering Sea as a Response to Global Sea Level Changes and Remote Climatic Signals during the Last 180 Kyr

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Abstract—We present results from the sediment core SO201-2-85KL retrieved from the western Bering Sea that recovered the past 180 000 years. For the first time, the intense dissolution of calcareous microfossils has been established when the Bering Strait was open during the glacioeustatic sea level rise. Possible mechanisms of climatic teleconnections between remote regions are considered.

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Detailed reconstructions of past climatic conditions are substantiated by the necessity to develop reliable forecasts for future climate change. Abrupt changes in the environmental conditions are most reliably identified from the paleoclimate archives collected in ocean regions with high sedimentation rates and seasonal ice cover that immediately (on the geological time scale) reacts even to slight climatic oscillations. The Bering Sea fully meets these requirements. In modern paleoceanographic studies, great emphasis is focused on detection and comparison of events in remote regions in order to investigate mechanisms of teleconnections. The observational data and the modeling results show that the sea-ice cover in the Bering Sea and the Sea of Okhotsk remains heavy in spring (March-May) during the years characterized by reduced precipitation in the area of the East Asian summer (June–July) monsoon (EASM) in the southeastern China and, vise versa, the ice cover shrinks simultaneously with an increase in precipitation [1]. The abrupt millennial-scale climatic oscillations, named the Dansgaard-Oeschger (DO) cycles first established in the ice core in Greenland [2], and then in the North Atlantic (for example [3]), were recorded in the numerous sediment cores from the northern Pacific Ocean (NP; for example [4]). In this study, we reconstruct changes in paleoceanographic conditions in the western Bering Sea as a response to the glacioeustatic variations of the global sea level and to the remote climatic signals for the past 180 kyr.

The sediment core SO201-2-85KL (57°30.30′ N, 170°24.77′E, water depth 968 m) was retrieved from the Shirshov Ridge, western Bering Sea, in 2009 in the framework of the Russian–German KALMAR Project (Fig. 1). The age model of the core is provided in [4].

The changes in accumulation rates (AR) and species composition in benthic foraminiferal (BF) assemblages, as well as the variations of pebble grains (1–10 mm) AR, were studied with a time resolution of 300–1000 years throughout the core. The procedure for the quantitative analysis of BF assemblages is described in [5]. The BF accumulation rates were used as an indicator for the average annual biological productivity of surface waters, and percentages of benthic species *Alabaminella weddellensis*, typical of the regions with seasonal ice cover and episodic supply of phytodetritus to the sea floor [6], were used as a seasonal bioproductivity proxy. Based on the pebble AR calculated using linear sedimentation rates [4], the relative changes in the concentrations of melting drifted sea ice in spring above the Shirshov Ridge were estimated.

Changes in percentages of *A. weddellensis* demonstrate the orbital variability characterized by an antiphase relationship with the global sea level oscillations (Fig. 2). Over the intervals of penultimate (190–131 kyr BP) and last (73–12 kyr BP) continental glaciations in the Northern Hemisphere, the Bering Strait was closed [7]. The Pacific Ocean was separated from the Arctic basin by the terrestrial Beringia connected Eurasia and North America. The dominance of *A. weddellensis* (up to 90%) in BF assemblages within the glacial intervals may indicate very low bioproductivity conditions, unfavorable for the majority species. Judging by the mostly increased AR of pebbles within these intervals, reduced sea surface bioproductivity was related to a high density of drifted sea ice concentrations that prevented active phytoplankton bloom in spring in the western Bering Sea.

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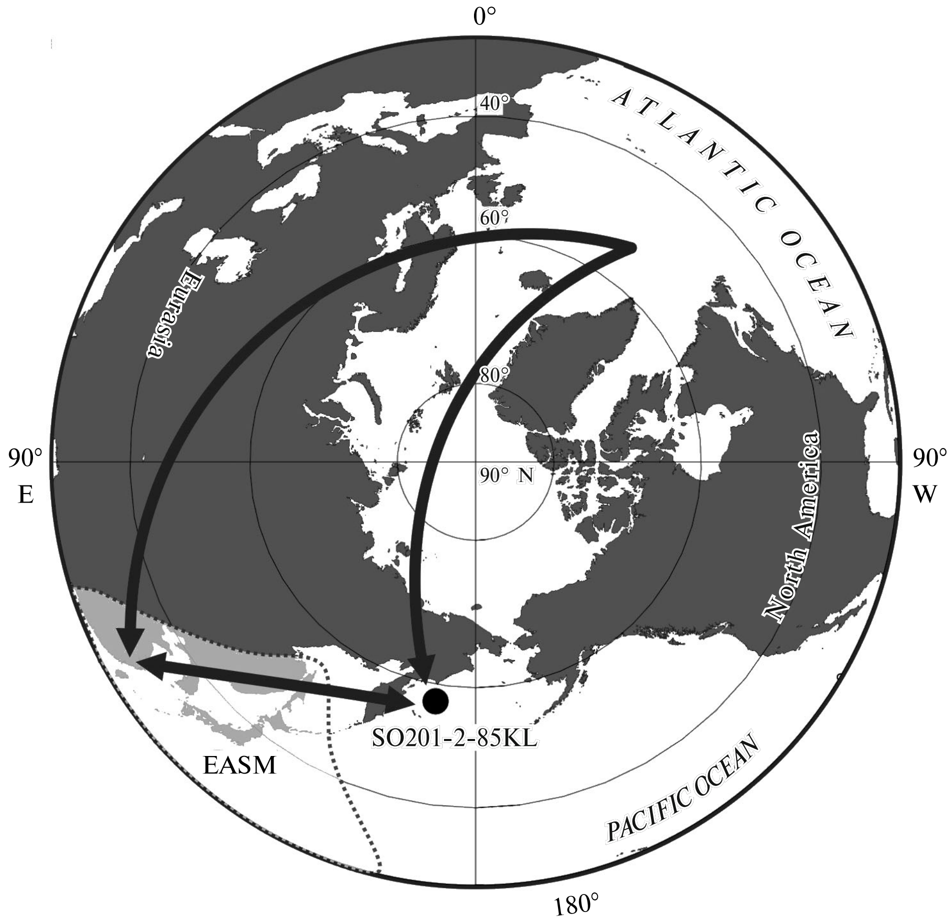

Fig. 1. Location of the core SO201-2-85KL and directions of climatic teleconnections (arrows) considered in this work according to [1, 10] in the Northern Hemisphere. The region of East Asian Summer Monsoon (EASM) [1] is shown in gray.

As the global sea level increased, the share of *A. weddellensis* decreased due to the interspecies competition that likely occurred during an increase in bioproductivity of the photic layer. Since the pebble AR decreased, the ice rafted debris depositional center was probably retreated northwards from the studied region; however, nutrients supplied by melting sea ice reached the latitude of the core location, contributing to an intensive phytoplankton bloom over the Shirshov Ridge.

The interval of marine isotope stages (MIS) 5.5–5.1 (131—73 kyr BP) is characterized by a strong dissolution of carbonate shells and coincides with the interval of establishing the connection between the NP and the Arctic Basin through the Bering Strait (Fig. 2). The intensification of dissolution was likely to be caused by an increase in corrosiveness of intermediate waters that bathed the Shirshov Ridge due to the increased concentration of dissolved carbon dioxide (CO_2). Rise of carbon dioxide content could have been caused by several factors. First, CO_2 could have been released during respiration of numerous benthic organisms that settled at the bottom under high-productivity conditions reconstructed from elevated values of C_{org} at that time [4].

Secondly, the upper boundary of the "old" CO_2-enriched waters of subantarctic origin could have risen to intermediate depths due to decreased rates of sea ice formation as seen from the low pebble AR and, consequently, reduced intermediate water production. Finally, significant river discharge might result in strengthening of halocline prevented an ocean-atmosphere gas exchange.

Traces of corrosion of foraminefa shells are also recorded in the interval of the modern interglacial MIS 1 (11.6–9 kyr BP); however, the content of BF shells in the samples remains sufficient for quantitative analyses. We suppose that the CO_2 content near the bottom was lower within the MIS 1 as compared to MIS 5.5–5.1.

The millennial variations in paleoceanographic conditions are recorded in the pebble AR records (Fig. 2), which are compared with oxygen-isotopic composition of stalagmites from Hulu (32°30′N, 119°10′E) and Sanbao (31°40′N, 110°26′E) caves. Stalagmite records reflect the relative oscillations in the amount

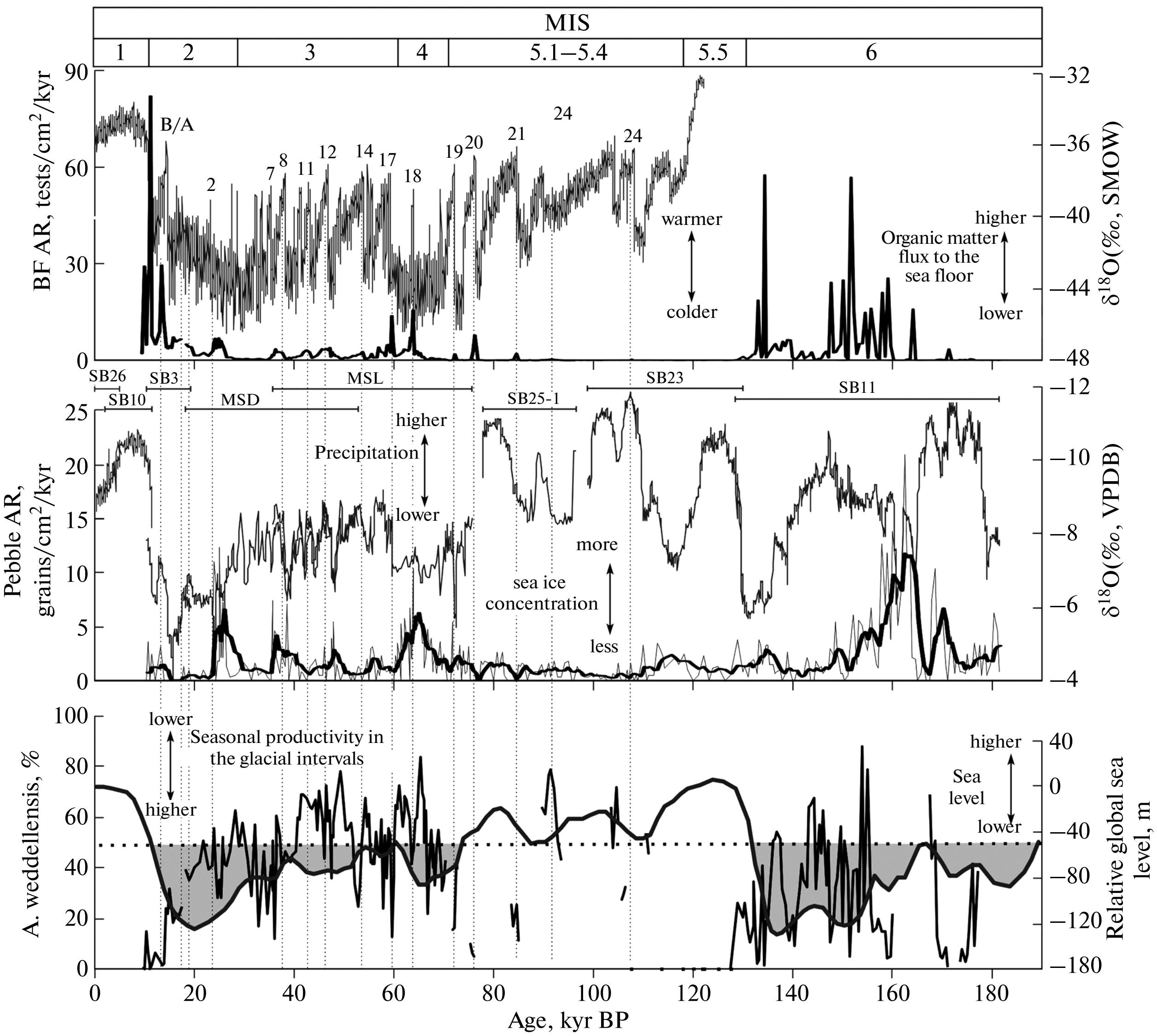

Fig. 2. Comparison of the data from the core SO201-2-85KL and the global sea level curve [7], the oxygen isotope records from Chinese stalagmites from the Hulu and the Sanbao caves [8, 9], and the NGRIP ice core data [11]. The numbers designate the warming (interstadials) of the DO cycles, the dashed line denotes the modern depth of the Bering Strait, and the gray-shaded area represents the intervals when the Bering Strait was closed. The pebble AR plot (fine line) shows a curve of linear filtration through the five points (thick line). The Latin letters with the numbers indicate names of stalagmites from the Hulu and the Sanbao caves [8, 9].

of precipitation in summer in the EASM region [8, 9]. The relatively good correlation between the intervals of the EASM intensification and a decrease in the drifted sea ice melting activity in the western Bering Sea and vice versa are established for the first time by the paleodata. This means that the relationship between these two phenomena does not exist only under modern conditions, but is also well documented in the sediments of the past 180 kyr. The mechanism for high-to-low latitude teleconnection was likely to be similar to the modern one when a reduction of sea-ice cover in the NP led to an increase in the temperature gradient between the high and low latitudes, the subsequent intensified supply of cold air masses to the monsoon region, and their intense vertical rise [1]. This contributed to an increase in precipitation in southeastern China between 28° and 35° N [1]. During the intervals of expanded ice cover, the temperature gradient decreased, the zonal winds weakened, and the vertical rise slowed, which led to a reduction in precipitation in the monsoon area [1].

On the contrary, a signal could have been transferred from low to high latitudes via atmospheric moisture [10] and most likely heat transport within the subtropical atmospheric gyre. Thus, intensification of the EASM could have led to a decrease in the rates of sea ice formation on the Bering Sea shelf.

In this case, the maximal abundance of BF, indicating an increase in the average annual organic matter flux to the seafloor, which is limited by the sea ice in the polar and subpolar regions, corresponds to the short episodes of monsoon intensification in southeastern China and to the most pronounced warming events of the DO cycles (8, 11, 12, 14, 17(?), 19–21, and 24) in Greenland (Fig. 2). The latter supports the hypothesis about the synchronous millennial-scale paleoceanographic events in the NT and the North Atlantic over the last glacial interval. The synchronicity could be explained by simultaneous heat supply from the low to high latitudes in the Northern Hemisphere during the climate warming in the both oceans [12]. Teleconnection, in turn, could occur via atmospheric heat and moisture transport from the NT to the North Atlantic [10, 12] due to the formation of the specific cyclonic trajectories, as was shown in the diagnostics of the modern climate [13, 14].

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