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Orbital and suborbital environmental changes in the southern Bering Sea during the last 50 kyr

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ABSTRACT

High-resolution geochemical, paleontological and lithological records of two sediment cores in the southern Bering Sea manifest regional environmental changes over the last 50 kyr on orbital and millennial time scales. High ice rafted debris (IRD) content and percentages of radiolarian species *Cycladophora davisiana* (Ehrenberg) during Marine Isotope Stages (MISs) 3 and 2 indicate active intermediate water ventilation driven by intensive winter sea ice formation in the southern Bering Sea. Although the total abundance of siliceous microfossils in glacial sediments is relatively low, glacial productivity is higher than in the Late Holocene.

On the millennial time scale, decreases in the abundance of calcareous and siliceous microfossils and in *C. davisiana* % at studied core may imply enhancement of sea ice influence synchronous with Heinrich events H 5 to 2. Changes in the $\delta^{18}O$ of fossil benthic and planktonic foraminifera during H 5–3 are inferred to be related to variability in ice sheet volume similar to the pattern from Antarctica accompanied by glacioeustatic sea-level fluctuations up to 20–30 m in amplitude. The maximum benthic and planktonic $\delta^{18}O$ values in the studied cores occur during the LGM when sea level was at the lowest stand and sea bottom water temperature was around −0.4 °C. Strong environmental changes during the Heinrich event 1 and B/A warming in the southern Bering Sea provide evidence of deglacial injection of very old water and the subsequent increase in productivity due to surface and intermediate water mixing. From the LGM to the mid-Holocene the $\delta^{18}O_{benth\ foram}$ changes corresponded to changes in the global deep-water $\delta^{18}O$ and a rise in the deep-water temperature to +1.0 °C at 8.5–6.5 kyr BP. The subsequent environmental changes in late Holocene helped establishment of near modern-day hydrological and environmental conditions, featuring strong surface water stratification and weakened deep-water ventilation.

1. Introduction

The Late Quaternary paleoceanography of the Bering Sea has been poorly studied in spite of its huge size, high bioproductivity and important role in the North Pacific intermediate water formation. Today, the Bering Sea also plays an important role in the North Pacific surface water cyclonic circulation where the warm Alaskan Stream is transformed into the cold and freshened Kamchatka Current. But questions remain outstanding: how the millennium scale environmental and climate changes of this marginal sea covered by sea ice in the late Quaternary influenced the contemporary intermediate water formation? How the production of siliceous and calcareous organisms responded to the late Quaternary environmental changes? Recent works indicate that the percentage variability of *Cycladophora davisiana* in the radiolarian assemblages can be used to infer intermediate water formation in the Bering Sea and possibly also in other parts of the North Pacific (Tanaka and Takahashi, 2005; Abelmann and Nimmergut, 2005; Wang et al., 2006).

High-resolution studies of this marginal sea are often complicated by relatively poor preservation of calcareous microfossils in most late Quaternary samples, which may hamper a proper construction of age model. Here we present new geochemical, paleontological and lithological high-resolution data from two cores in the southern Bering Sea covering the last 55 kyr. The age model for one core has been constructed by oxygen isotope records and AMS ^{14}C dating (Gorbarenko et al., 2005), and for the second core from a nearby locality by correlation with the first core using biological and sedimentological proxies, as well as oxygen isotope chronostratigraphy. The results provide insight into the millennial scale environmental and sedimentological changes in the southern Bering Sea as relating to intermediate water formation in the region during the last 55 kyr. Special attention was paid to the history of the sea ice variability, the relative abundance of *Cycladophora davisiana*, and related environmental and hydrological changes since Heinrich events 5–1.

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2. Oceanographic setting

Surface water circulation in the Bering Sea is initiated by the warm water of the Alaskan Stream, which enters into the Bering Sea through Near Strait (2000 m depth) and Buldir Pass (640 m depth) and turns east toward Bowers Ridge (Favorite et al., 1976) (Fig. 1). Therefore, the hydrology of the studied area of the Bering Sea are strongly influenced by the North Pacific water.

The upper water layer in the central part of the present-day Bering Sea is mainly characterized by a dichothermal structure (Ohtani, 1973). The lower boundary of the pycnocline in this area is vague and occurs at depths of 25–50 m. Temperature gradients are low: varying from 7–12 °C at the surface to 4–7 °C at the lower boundary of the pycnocline. In the southern part of the sea, near the Aleutian Islands and continental slope, where relatively warm waters of the Alaskan and Coastal Alaskan Currents are mixed with Bering Sea waters, the dichothermal structure is poorly manifested and the temperature remains constant (4 °C) down to a depth of 200 m.

Influenced by various oceanic waters, the Bering Sea intermediate water is poorly developed between 50 and 150–250 m at 55°N, with a temperature range of 2.8–3.5 °C and salinity of 33.1–33.2‰ (Arseniev, 1967).

3. Materials and methods

Gravity cores GC-11 (53°31′N, 178°51′E, water depth 3600 m) and GC-13 (53°41′N, 178°43′E, water depth 2630 m) were obtained from Bowers Ridge (Fig. 1) during the Russian–USA–Canadian cruise in 1991. Core sediment samples as 1-cm slice at 5 cm intervals were taken for microscopic micropaleontological and lithological examinations using standard procedures.

3.1. Microfossil examination

Planktonic and benthic foraminifera (PF and BF) in grain size fraction >150 μm were counted under binocular microscope and their absolute abundance per 1 g of dry bulk sediment was calculated. Because of scarcity of foraminifera in sediments of the studied cores, these records were used as indicators of calcareous microfossil productivity and carbonate dissolution in the past. For siliceous microfossil analysis, diatoms and radiolarians in fraction >63 μm were counted and their absolute abundance per 1 g of dry bulk sediment was calculated. Relative abundance (%) of species *Cycladophora davisiana* in the radiolarian assemblages of this fraction was also calculated.

The planktonic foraminifer *Neogloboquadrina pachyderma* (sinistral coiling form) from fraction 150 to 250 μm and the benthic foraminifer *Uvigerina auberiana* from fraction 250 to 350 μm were picked for isotope analyses according to standard procedure (Keigwin, 1998). The oxygen isotopes in the planktonic and benthic foraminifera were measured at the Laboratory of Marine Geology in Tongji University. Specimens were cleaned with ethanol (≥99.7%) in an ultrasonic bath. They were dried in an oven at 60 °C and reacted with orthophosphoric acid in an automatic carbonate device (Kiel III) at 70 °C to generate CO_2. The CO_2 was then transferred to a Finnigan MAT252 mass spectrometer to measure the stable isotopes. Precision was regularly checked with a Chinese national carbonate standard (GBW04405: $\delta^{13}C = 0.57‰$ to PDB, $\delta^{18}O = -8.49‰$ to PDB); the standard deviation is 0.07‰ for $\delta^{18}O$ and 0.04‰ for $\delta^{13}C$. Conversion to the international Pee Dee Belemnite (PDB) scale was performed using the NBS19 standard.

From core GC-11, specimens weight 2–4 mg of monospecies *Neogloboquadrina pachyderma* s. and *Uvigerina auberiana*, respectively from fractions 150–250 μm and 250–350 μm, were also picked for dating by accelerator mass spectrometry (AMS) at the Lawrence Livermore National Laboratory (Gorbarenko et al., 2005).

3.2. Terrigenous sediment examination

Terrigenous sediment grains observed in the >150 μm fraction were assumed to have been transported to the study site by ice-rafting, therefore representing ice rafted debris (IRD) as an indicator of the activity and distribution of seasonal sea ice and icebergs (Kent et al., 1971). Terrigenous grains in the >150 μm subsamples of GC-11 and GC-13 were identified, counted and the number of lithic grains per gram of dry bulk sediment was calculated. Because of the close proximity of the site to the volcanically active Aleutian Islands, grains of volcanogenic origin were excluded from these counts. The weight of the coarse grains >150 μm and >63 μm in the total sediment weight may be also useful for indicating the sea ice activity (Gorbarenko and

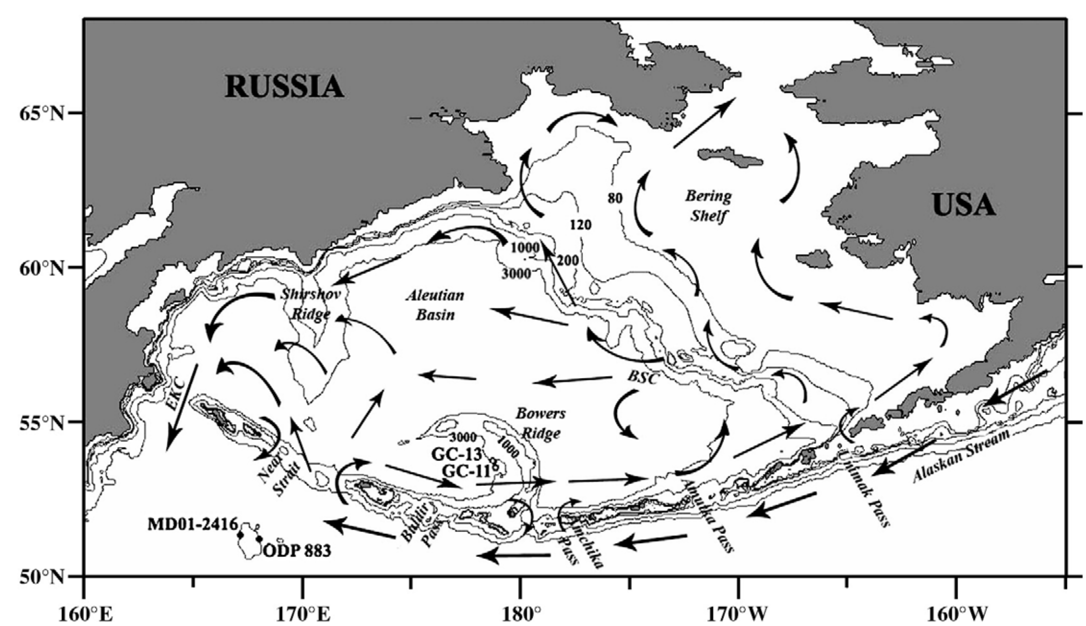

Fig. 1. Location of cores GC-11, GC-13, MD01-2416 and ODP 883 (open and closed circles, respectively), surface water currents (arrows) and bathymetry (m) in the Bering Sea and Northern Pacific. BSC — Bering Slope Current, EKC — East Kamchatka Current. Map drawn using "Online Map Creation" software.