論文内容の要旨

論文題目

Abrupt changes in ventilation at intermediate water depth of the northwestern Bering Sea: a possibility of intermediate to deep water production in the Bering Sea during the last glacial period

(ベーリング海西北部中層水深での急激な循環変動：
最終氷期のベーリング海に おける中・深層水形成の可能性)

氏名　　レラ　シュテファン

Abstract:

Considering the importance of ocean circulation to global and regional climate, it is of formost interest to understand the controlling factors of its variability in the past. The present study concentrates on past ocean circulation at intermediate water depths in the North Pacific, a region that has received far less scientific attention than its Atlantic counterpart. During the present interglacial, a low salinity water mass defined as North Pacific Intermediate Water (NPIW) is extending from its primary source, the Okhotsk Sea, into the North Pacific Ocean. NPIW formation is associated with sinking dense waters originating in the polynya growth region of the northern Okhotsk Sea. Polynya development offshore at its turn is largely driven by dominant northeasterly winds during winter. There is evidence that NPIW was ventilated to deeper depths and was more wide spread in the North Pacific during the last glacial period than today (e.g. Matsumoto et al., 2002). Yet, the behavior and sources of glacial NPIW are poorly

understood. Based on radiolarian abundances it was hypothesized that the Bering Sea may have been a glacial source of NPIW (e.g. Ohkushi et al., 2003). On the other hand, deep sea sediments from the California margin suggested possibility of waning and waxing of NPIW intensity in association with Dansgaard-Oeschger cycles (Behl and Kennett, 1996). To test the possibility of such hypotheses, I investigated a piston core (PC-23A) recovered from the north-eastern continental slope at a water depth of 1002m during the cruise MR06-04 Leg2.

I conducted visual and soft X-ray observations in order to describe the lithological changes of the core. Fourteen ^{14}C dates and last occurrence datum of the radiolarian species *L.n.sakaii* were used to establish an age model. I picked up benthic foraminifera *Uvigerina akitaensis* and *Buliminella tenuata*, which were analyzed for oxygen and carbon isotopes at Woods Hole Oceanographic Institute (U.S.A.) to reconstruct changes of intermediate water properties. High resolution geochemical analysis was also conducted using an XRF micro-scanner supported by conventional XRF analysis in order to examine inter-element relationships among the major elements and their relation with lithology.

According to the age model, the stratigraphic intervals with distinct increases in benthic foraminiferal $\delta^{18}O$ ($\delta^{18}O_{bf}$), which suggest colder and/or more saline intermediate water conditions, correspond to Heinrich events (surges of icebergs from the Laurentide ice sheet into the North Atlantic), characterized by cold air temperatures observed in the Greenland Ice Core. These same intervals correspond in most cases to increases in benthic foraminiferal $\delta^{13}C$ ($\delta^{13}C_{bf}$), indicating a proximal source of intermediate water and/or decreased values of surface productivity. On the other hand, increases in carbonate content were found to correspond to Dansgaard-Oeschger Interstadials.

I furthermore investigated the lateral gradient of $\delta^{13}C_{bf}$ and $\delta^{18}O_{bf}$ between the Bering Sea and the Okhotsk Sea at intermediate depths. I demonstrate that during the particularly severe stadials of Heinrich event 5 (H5) and H4, intermediate water was colder and/or more saline in the Bering Sea than in the Okhotsk Sea. I also demonstrate that a lateral gradient of $\delta^{13}C_{bf}$ existed from the Bering Sea (heavier $\delta^{13}C_{bf}$) to the Okhtosk Sea (lighter $\delta^{13}C_{bf}$) during H5, H4, H1 and the Younger Dryas (YD), while no significant gradient was observed during interstadial periods. Such observation gives evidence that the Bering Sea could have been a source to better ventilated glacial intermediate waters observed in the NW Pacific during H5, H4, H1 and YD. I further conclude that at least during H1 and YD, intermediate water ventilation at the Bering Sea contributed to the enhanced ventilation of intermediate water off Shimokita Peninsula (northern Japan). I argue that ventilation was reduced during B/A compared to today, based on a comparison of surface productivity during B/A and today, and suggest that the decrease in ventilation may have been one reason of sluggish ventilation off Shimokita Peninsula during B/A.

For more direct evidence of NPIW variation, I examined the grain size distribution of the detrital component, which shows unimodal or bimodal distributions. I identify a fine mode lithologically characteristic of bioturbated or laminated silty clay, and a coarse mode characteristic of layers of bioturbated very fine sand. Petrographical observation together with paleoceanographical and sedimentological considerations revealed that the fine mode represents fine detrital material accumulated under calm hemipelagic conditions, while the coarse mode may be explained by detrital material accumulated under the influence of contour currents. Based on this interpretation, the modal position of the coarse mode should represent the velocity of contour current, whereas sortable silt content (including a very fine sand fraction) should represent the frequency of strong bottom currents. To further extend grain size results, I investigated the relation between major element composition of the sediments and grain size parameters of the detrital component, and found that Si/Al is mostly explained by the difference in grain size and can be used as a proxy for sortable silt. I demonstrate that maxima in the median diameter of the coarse mode and Si/Al are generally associated with high $\delta^{18}O_{bf}$ and $\delta^{13}C_{bf,}$ which were correlated to stadial periods of the Greenland ice core record. Because bottom currents may be responsible for shifts in the median diameter of the coarser fraction of the grain size distribution and increases in sortable silt content, I conclude that bottom current intensity increased during Heinrich events, several more stadial periods of the last glacial period and the YD, which is consistent with cooler and/or more saline water and enhanced ventilation as suggested from the benthic isotopic record.

The present study suggests that the Bering Sea may have experienced large climatic and oceanographic changes in association with Dansgaard–Oeschger cycles. Intermediate water would have been produced in the Bering Sea during Heinrich events and YD, while its production may have been subdued during interglacials both in the Okhotsk and Bering seas.

Based on the correlation between $\delta^{18}O_{bf}$ and $\delta^{13}C_{bf}$ at site PC-23A and Greenland ice $\delta^{18}O$, I suggest a possible teleconnection between the North Atlantic and the North Pacific mediated by the atmosphere. During Heinrich events, when the Atlantic Meridional Overturning Circulation weakened or shut down, high latitudes of the Northern Hemisphere experienced severe cooling (e.g. Bond et al., 1992). Cold temperatures were associated with decreasing sea surface temperatures and increasing sea surface salinities in the Bering Sea due to a decrease in net fresh water input supporting destabilization of the water column. On the other hand, the water column may have been better stratified in the Okhotsk Sea during the last glacial period, due to closed winter sea ice coverage, moist air advected from the Pacific and enhanced Amur river input. As an important second factor I suggest that changes in the northern hemispheric wind patterns during Heinrich events associated with increases in northerly winds during severe cold periods over the Bering Sea could have promoted the formation of polynya and generated

dense waters that would have sunken down to intermediate and/or deep depths, thereby providing a source of ventilation to NPIW. Dominant northerly winds over the Bering Sea, which occur today during cold winters, are commonly associated with a strong high pressure cell over northeastern Siberia and an eastward shift in the position of the Aleutian Low. Such a configuration of atmospheric circulation is, however, not favorable for northwesterly winds over the Okhotsk Sea, which is consistent with the presented observation of a preferential NPIW generation in the Bering Sea, rather than Okhotsk Sea, during cold episodes of the last glacial period.