Bering Sea Expedition Summary: Pliocene-Pleistocene Evolution and Glacial-Interglacial Changes in the Bering Sea

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Introduction and Drilling Objectives

Over the last 5 million years (m.y.), global climate has evolved from being warm with only small Northern Hemisphere glaciers and ice sheets (~5-3 Ma) to being cold with major Northern Hemisphere glaciations occurring every 100 to 40 thousand years (k.y.). The reasons for this major transition are unknown. Although there are data to show that the Pacific experienced oceanographic reorganizations that were just as dramatic as those in the Atlantic, the scarcity of data in critical regions of the Pacific (the largest ocean with arguably the largest potential to influence global climate) has prevented an evaluation of the role of North Pacific processes in global climate evolution.

Over the last hundreds of thousands of years, glacial-interglacial and millennial-scale climate oscillations have occurred. Although the exact mechanisms are unknown, several studies from the North Pacific subtropical and mid-latitude regions indicate that the generation and/or transmission of climate oscillations around the globe might involve intermediate water ventilation of the North Pacific. Drilling in the Bering Sea (Fig. 1) to recover comprehensive records of environmental conditions during periods of time with different climate boundary conditions can help answer questions about the global extent of climate oscillations and mechanisms that produce them.

Figure 1. Planned IODP Bering Sea Expedition drill sites. NIPW- North Pacific Intermediate Water.
This expedition will obtain sedimentary sequences to study the Pliocene-Pleistocene evolution of millennial- to Milankovitch-scale climatic oscillations in the Bering Sea, the marginal sea connecting the Pacific and Arctic Oceans. Paleoclimatic indicators will be used to generate complete and detailed records of changes in the biological, chemical, and physical oceanographic conditions in the Bering Sea, as well as of the adjacent continental climate. In addition to being sensitive to regional and potentially global climate change, the Bering Sea is one of the source regions of the North Pacific Intermediate Water (NPIW). Because the production of the NPIW is thought to be linked to global climate change and to Pacific Ocean circulation and nutrient distributions, investigating the evolution of conditions in regions of NPIW formation is critical for understanding the paleoceanography of the Pacific Ocean.

Drilling in the Bering Sea will also document the effect of changes in the Bering Strait gateway region. The Bering Strait is the main gateway through which communication (flux of heat, salt, and nutrients) between the Atlantic and Pacific, via the Arctic Ocean, occurs today. Investigating the evolution of the Bering Strait is critical for understanding transitions in global ocean heat and nutrient budgets.

Detailed high resolution paleoenvironmental reconstructions from the Bering Sea have not been achieved in the past, although there was some reconnaissance work during DSDP Leg 19 (Scholl and Creager, 1973) and piston core work focused on generating paleoceanographic records from the latest Pleistocene (e.g., Takahashi et al., 2005). The planned drilling, including triple APC holes at all sites, will provide the first continuous sedimentary records that can be used to reconstruct the history of this important marginal sea and its role in global changes over the past 5 m.y.

Specifically, the sedimentary records from the Bering Sea will provide an understanding of the following:

1. The evolution of Pliocene-Pleistocene surface water conditions, paleoproductivity, and sea-ice coverage, including millennial- to Milankovitch-scale oscillations.
2. The history of past production of the Pacific Intermediate and/or deep water masses within the marginal sea, and its link to surface water processes.
3. The interactions between marginal sea conditions and continental climate.
4. The linkages between processes in the marginal sea (e.g., variations in deep water formation, or water mass exchange through gateways) and changes in the pelagic Pacific.

All of these scientific objectives will focus both on the long-term ocean and climate trends, as well as the evolution of higher frequency glacial-interglacial to millennial-scale oscillations through the Pliocene-Pleistocene. These results should lead to a better understanding of how the Bering Strait gateway region may have been involved in North Pacific and global climate.
Background

The Bering Sea contains sediments with high accumulation rates appropriate for the reconstruction of surface and deep water conditions, and for the validation of climate/ocean hypotheses that call on this region as a variable source of open Pacific intermediate and deep water. In addition, climate change records from the Bering Basin tend to be extremely sensitive to high-frequency changes due to the semi-isolated nature of the marginal sea. Sea level drop, for example, may produce a profound effect on water mass circulation, sea-ice formation, salinity, and biological productivity in the basin (e.g., Takahashi, 1999). The more robust pelagic signals of the open Pacific do not adequately provide the high-frequency climatic history of the northwest Pacific Rim.

Changes in ventilation of subsurface water in the North Pacific may also influence climate downstream and be tied to North Atlantic climate changes on millennial timescales. Interestingly, millennial cycles in sea-ice expansion in the Okhotsk Sea correspond to those at the California margin, Japan Sea (Ono et al., 2005; Sakamoto et al., 2005; Behl and Kennett, 1996; Tada et al., 1999), and North Atlantic, although the mechanisms for strong teleconnections between different sides of the North Pacific and the Atlantic are not known. It has been proposed that changes in the Okhotsk or Bering Seas source(s) of NPIW could reach the California margin and influence the depth or strength of the Oxygen Minimum Zone (OMZ: Cannariato and Kennett, 1999; Zheng et al., 2000), thereby connecting climate/ocean changes across the Pacific Ocean.

Current theories that explain paleoceanographic data from the Pacific by implicating changes in NPIW formation (e.g., like that used by Behl and Kennett [1996] to explain observations in the Santa Barbara Basin), would greatly benefit from documentation of surface and deep water conditions from the North Pacific marginal seas. Only drilling will allow for the reconstruction of climate cycles and for the evaluation of whether the patterns observed in the last glacial cycle are characteristic of all glacial-interglacial cycles. Only recovery of continuous Pliocene-Pleistocene sediments will allow us to evaluate if the mean state of the climate system (warm vs. cold) determines the higher frequency sensitivity, behavior, and climatic impact of these marginal seas. Finally, comparing millennial climate oscillations in the Bering Sea in the Pleistocene when there were large Northern Hemisphere ice sheets to those in the Pliocene warm period when there were only small Northern Hemisphere ice sheets will provide insight into whether the generation of these oscillations is related to NPIW ventilation and/or to ice sheet size and dynamics.

In the last glacial cycle, there was enhanced dense water formation, probably from the Okhotsk and the Bering Seas (e.g., Zahn et al., 1991; Gorbarenko, 1996). In fact, the degree of ventilation of deep and intermediate Pacific waters appears to have been fluctuating during the cold and warm periods, implying changes in the configuration of Pacific Ocean circulation (Keigwin, 1995; Matsumoto et al., 2002). However, there are some contradictory results depending on the nutrient proxy used ($^{13}$C vs. Cd/Ca in benthic foraminifers). Furthermore, the limited spatial coverage of sites in the open Pacific prevents detailed identification of the exact source of intermediate and deep water as well as the exact circulation path of subsurface water masses. Observations have been made in glacial records from the Bering Sea and just outside of it on the Detroit Seamount in the North Pacific, suggesting a source of ventilated intermediate water coming from the Bering Sea and/or Detroit Seamount region (Gorbarenko, 1996). Thus, it is clear that the influence of
changes in conditions in the Bering Sea on subsurface water formation may play a critical role in determining glacial-interglacial climate variability in the open Pacific Ocean.

Despite evidence that Pacific circulation was different in the last glacial cycle, little is known about what caused circulation to change or what role the Pacific played in determining extreme climate conditions. From extensive studies of the North Atlantic, it is clear that ice sheet dynamics and changes in thermohaline circulation can readily influence climate, yet there is no widely accepted paradigm that explains how the North Pacific participates in and possibly dominates global climate change. Construction of long records of glacial-interglacial changes, especially under a range of boundary conditions over the Pliocene-Pleistocene, will contribute critical information needed to formulate a new North Pacific climate change paradigm.

In the warm Pliocene (~4.5 to 3.0 Ma) there is compelling evidence that North Pacific mid-depth water (~2500 m) had much lower nutrient concentrations than today, indicating that it was more strongly ventilated (Kwiek and Ravelo, 1999; Ravelo and Andreasen, 2000). Although increased sub-surface ventilation in the cold Last Glacial Maximum (LGM) and the warm Pliocene could be interpreted in a number of different ways, and are likely not explained by the same processes, only data that directly reflect conditions in the Bering Sea (and the Okhotsk Sea) can help to constrain interpretations.

The end of the early Pliocene warm period is characterized by the development of modern density stratification in the surface and deep North Pacific. Ice-rafter debris pebbles recovered at DSDP and ODP sites indicate that the increased water mass stratification coincided with more extensive glaciation (Haug et al., 1999; Kwiek and Ravelo, 1999; Ravelo and Andreasen, 2000; Rea and Schrader, 1985). Furthermore, more ice-rafter debris (IRD) are found along the Aleutian Islands (DSDP Site 192) than further north in the Bering Sea (Sites 186 and 191) due to more extensive ice cover in the north compared to more seasonal ice cover at the Aleutian site (McKelvey et al., 1995; Krissek, 1995). The fact that this North Pacific climate reorganization occurred synchronously with the onset of significant Northern Hemisphere glaciation, as recorded in the Atlantic Ocean, highlights the importance of studying North Pacific climate evolution as part of a comprehensive investigation of the regional expression of global climate trends.

The emergence of the Bering land bridge (Beringia) prior to the Neogene is not well understood. However, Pliocene climate change, perhaps the onset of Northern Hemisphere glaciation specifically, could have been affected by changes in the marine gateway connection through the Bering Strait region. The connection may have developed in the late Miocene or the early Pliocene, based on the occurrences of Atlantic type mollusks in Hokkaido, Kamchatka, and Alaska Peninsula in the late Miocene and early Pliocene. The oldest ages for these occurrences range from 6.3-5.1 Ma to 2.2 Ma (e.g., Uozumi et al., 1986), but a recent study documented that the age of first occurrence was 5.5-5.4 Ma (Gladenkov, 2006). One of the objectives is to recover better records of the oceanographic evolution related to the Miocene-Pliocene gateway history.

Pacific to Arctic flow through the Bering Strait (~0.8 Sv; Coachman and Agaard, 1981) significantly influences the Pacific-Atlantic partitioning of physical and nutrient properties in the modern ocean, and was possibly quite sensitive to past changes in sea level change due to its shallow sill of about 50 m (see Takahashi, 2005, for an illustration of the cross
section). During glacial intervals, Atlantic Ocean biogenic sedimentation and preservation became more “Pacific-like”, and vice-versa, and there were major changes in nutrient distributions. Drilling near the Bering Strait will help to resolve whether major changes in Pacific-Atlantic partitioning of oceanographic properties were related to changes in flow through the Bering Sea. Recent findings of *Neodenticula seminae*, a dominant extant subarctic Pacific diatom, in Atlantic waters may be in response to global warming, with the Arctic Ocean providing a passage for this species from the Pacific to the Atlantic (M. Poulin, pers. comm., 2003). This species has been extinct in the Atlantic since 0.8 Ma (Baldauf, 1987), and thus the recent re-emergence in the Atlantic appears to be a significant indication that climate change in the Arctic influenced the distribution of this species.

IODP Expedition 302 (Arctic Coring Expedition: ACEX) to the Lomonosov Ridge in the central Arctic Ocean took place in 2004 and the scientific community anticipated the acquisition of new information regarding the age and effects of the Bering Strait gateway to the Arctic. However, despite the success of the ACEX in terms of the acquisition of sediments spanning from the Holocene down to the Cretaceous (Backman et al., 2006; Moran et al., 2006), it has been difficult to advance the understanding of the significance of the Bering Strait gateway on global or regional climate change without being able to compare new Arctic records to those on the Pacific side of the Bering Strait. Thus, the present plan for drilling in Bering Sea is essential to be able to decipher the history of the Bering Strait gateway and its potential impact on global and regional climatic and oceanic processes. The role of the exchange of heat and chemical constituents through the Bering Strait on Arctic and North Pacific environments, and the influence of changes in this exchange on Northern Hemisphere glaciation and higher frequency climate oscillations, can only be assessed by comparing results from the Bering Sea drilling together with the results from ACEX.

**Preliminary Drilling Plan**

The Bering Sea expedition is tentatively scheduled for July-August 2008. The schedule is subject to change and the most current version is available at [http://iodp.tamu.edu/scienceops/](http://iodp.tamu.edu/scienceops/). The drilling plan prioritizes eight sites in the Bering Sea (Table 1; Fig. 1). However, the exact operations plan and number of sites will depend on the total number of operations days scheduled and whether we can obtain permission to occupy three sites in Russian territorial waters. The plan includes drilling to relatively deep depths of ~700 mbsf (triple APC holes to refusal, single XCB hole to ~500 mbsf, and RCB to ~700 mbsf) at four sites: two on the Bowers Ridge (BOW-12B and BOW-14B) and two near the Bering Strait gateway (GAT-3C and GAT-4C). XCB drilling will allow penetration through a significant portion of the Pliocene and possibly into the upper Miocene. Drilling to shallower depth of ~200 mbsf (triple APC to refusal) is planned at four additional sites: SHR-3B, BOW-15A, KST-1B, and UMK-4D.
Table 1. Proposed Bering Sea Expedition drill sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>Water Depth (m)</th>
<th>Planned Penetration (m)</th>
<th>Expected Sediment Type</th>
<th>Estimated Bottom Age</th>
<th>Site-specific Objectives</th>
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</thead>
<tbody>
<tr>
<td><strong>Bowers Ridge</strong></td>
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<tr>
<td>BOW-12B</td>
<td>53°24.0N</td>
<td>179°31.3W</td>
<td>1313</td>
<td>Hemipelagic silty clay with siliceous &amp; calcareous microfossils</td>
<td>Upper Miocene</td>
<td>Entry location for Pacific water, shallow end of depth transect</td>
</tr>
<tr>
<td>BOW-14B</td>
<td>54°02.0N</td>
<td>179°00.5E</td>
<td>2166</td>
<td>Hemipelagic silty clay with siliceous microfossils</td>
<td>Upper Miocene</td>
<td>Entry location for Pacific water, deep site on the Ridge</td>
</tr>
<tr>
<td>BOW-15A</td>
<td>54°49.7N</td>
<td>176°55.0E</td>
<td>837</td>
<td>Hemipelagic silty clay with siliceous &amp; calcareous microfossils</td>
<td>Middle Pliocene</td>
<td>Shallow end of depth transect</td>
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<tr>
<td><strong>Gateway</strong></td>
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<tr>
<td>GAT-3C</td>
<td>59°03.0N</td>
<td>179°12.2W</td>
<td>3209</td>
<td>Silty clay with siliceous microfossils</td>
<td>Upper Miocene</td>
<td>Gateway to the Arctic, deep end of depth transect</td>
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<tr>
<td>GAT-4C</td>
<td>57°33.4N</td>
<td>175°49.0W</td>
<td>1975</td>
<td>Hemipelagic silty clay with siliceous &amp; calcareous microfossils</td>
<td>Upper Miocene</td>
<td>Gateway to the Arctic</td>
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<tr>
<td><strong>Kamchatka Strait</strong></td>
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<tr>
<td>KST-1B</td>
<td>55°55.6N</td>
<td>164°54.9E</td>
<td>3435</td>
<td>Hemipelagic silty clay with siliceous microfossils</td>
<td>Pliocene</td>
<td>Gateway to the Pacific, western end, deep end of depth transect</td>
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<td><strong>Shirsho Ridge</strong></td>
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<tr>
<td>SHR-1B (Alternate)</td>
<td>57°19.0N</td>
<td>170°06.4E</td>
<td>963</td>
<td>Hemipelagic silty clay with siliceous microfossils</td>
<td>Pliocene</td>
<td>Sea-ice &amp; water mass distribution in NE region</td>
</tr>
<tr>
<td>SHR-3B</td>
<td>57°37.2E</td>
<td>170°26.1N</td>
<td>2232</td>
<td>Hemipelagic silty clay with siliceous microfossils</td>
<td>Pliocene</td>
<td>Sea-ice &amp; water mass distribution in NE region</td>
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<tr>
<td><strong>Umnak Plateau</strong></td>
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<tr>
<td>UMK-4D</td>
<td>54°40.2N</td>
<td>169°58.9W</td>
<td>1900</td>
<td>Hemipelagic silty clay with siliceous microfossils</td>
<td>Pliocene</td>
<td>Sea-ice &amp; water mass distribution, distal to Pacific water</td>
</tr>
<tr>
<td>UMK-3B (Alternate)</td>
<td>54°25.1N</td>
<td>170°14.6W</td>
<td>1898</td>
<td>Hemipelagic silty clay with siliceous microfossils</td>
<td>Pliocene</td>
<td>Sea-ice &amp; water mass distribution, distal to Pacific water</td>
</tr>
</tbody>
</table>

The plan includes triple APC-coring at each site so that we can build a composite section and a complete stratigraphic record. Deeper XCB-drilling at four of the sites will obtain a significant portion of the Pliocene and possibly the late Miocene.

The drilling strategy is intended to capture important processes in the Bering Sea, as well as to achieve good geographical coverage to be able to reconstruct deep and surface ocean conditions, including sea-ice distribution and gradients. Proposed drill sites range between 837 and 3435 m water depth, allowing for the reconstruction of vertical gradients in deep and intermediate water conditions. Based on the results of DSDP Site 188 (2649 m) on the Bowers Ridge and piston cores recovered during the site survey Cruise KH99-3, good carbonate and foraminiferal assemblages preservation is expected in addition to excellent preservation of siliceous microfossils (Okazaki et al., 2005; Katsuki and Takahashi, 2005; Tanaka and Takahashi, 2005; Gorbarenko et al., 2005; Cook et al., 2005; Takahashi et al., 2005).

References


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