

## **IODP Expedition 323:**

### **Pliocene-Pleistocene paleoceanography and climate history of the Bering Sea**

#### **Site U1345 Summary**

1 September 2009

#### **Background and objectives**

The primary objective of drilling at Site U1345 was to study high-resolution Holocene-Late Pleistocene paleoceanography at a proximal gateway location to the Arctic Ocean at a water depth of ~1008 m. The drill site is located on an interfluvial ridge near the large and broad head of Navarin Submarine Channel off the Bering Sea Shelf. It is anticipated to receive ample supply of terrigenous sediments from the shelf during the glacials. This is also in the area of high biological productivity called “Green Belt”. The Green Belt is formed by the Bering Slope Current (BSC), which has an origin in the incoming Alaskan Stream water in the western Aleutians into the Bering Sea. As going further northwest, the higher primary productivity and % organic carbon is observed at the sea-floor. Thus, the expectation of the impingement by the dissolved oxygen minimum zone (OMZ) in the past is relatively high at this site. Because the expected sedimentation rates are high with intermittently laminated sediment of mm to sub-mm in thickness (see below) it should be possible at this site to pursue reconstructing detailed climate changes of sub-millennial time scales. Therefore, it is possible to compare the data from this site with those from other pertinent high-resolution records from such places as the Santa Barbara Basin, the Cariaco Basin, and GISP2. It is also important to compare the vertical extent of water mass conditions in a basin wide scale extent including the Bowers Ridge and gateway as well as Umnak sites.

Furthermore, this site is located close to the maximum extent of the present day seasonal sea-ice cover. Thus, it is expected that this site had been extensively covered by the seasonal or perennial sea-ice during the glacial low sea-level stands. Due to the proximity to the location of sea-ice formation, where cold and dense brine is expelled when sea-ice is formed, this site, as well as Site U1344, provide crucial information regarding the formation of the North Pacific Intermediate Water (NPIW).

This relatively shallow drill site in the gateway region to the Arctic Ocean can also be used to study the impact of subseafloor microbes on biogeochemical fluxes in the highest surface ocean productivity areas of the drill sites in the Bering Sea. Organic-fueled subseafloor respiration and its impact on biogeochemistry in such a highly productive region have never been quantified previously. To do this, the drilled sediments in the gateway region were used to determine subseafloor cell abundance and to investigate the link between the mass and characteristics of subseafloor microbes and the extent of export productivity from the surface ocean.

The sedimentation rates at the site location vary significantly from 14 cm/k.y. during the Holocene and 91 cm/k.y. during the last glacial maximum to as much as 242 cm/k.y. during the deglaciation. Prior to drilling, the recoveries of the Holocene to Late Pleistocene sections were expected at this site.

### **Operations**

Five holes were cored at this site. With the exception of Hole U1345B that was cored down to 36.7 m DSF for microbiological sampling, four holes were cored to ~150 m DSF. Coring in general was routine except for biogenic methane encountered in the cores which complicated the curation of all cores at this site. Two complete splices were obtained at Site U1345 to approximately 150 m CSF. APC coring totals for Site U1345 include 68 cores, 632.1 m penetrated, 648.35 m recovered, for 102.6 % recovery. The time spent on Site U1345 was 2.2 days.

### Hole U1345A

Hole U1345A was spudded at 0045 hr on 23 August. The first APC core barrel recovered 4.39 m of sediment establishing a seafloor depth of 1019.1 m DRF. APC coring continued through Core U1345A-16H to a depth of 146.9 m DSF using non-magnetic coring assemblies. Temperature measurements were taken on Cores U1345A-5H, -8H and -12H with the APCT3 temperature tool. APC core recovery for Hole U1345A was 101.1% with 148.49 m recovered.

### Hole U1345B

The ship was offset 20 m northwest of Hole U1345A. Both per-fluoro-methyl-cyclohexane (PFTs) and microspheres were deployed for contamination testing. A total of 4 APC cores were recovered to be used as samples for microbiology to a depth of 36.7 m. Average core recovery for the APC on Hole U1345B was 104.2 % with 38.24 m of sediment recovered.

### Hole U1345C

The ship was offset 20 m northwest of Hole U1345B. APC coring continued through Core U1345C-16H to a depth of 148.5 m DRF using non-magnetic coring assemblies. APC core recovery for Hole U1345C was 102.9 % with 152.85 m recovered.

### Hole U1345D

The ship was offset 20 m northwest of Hole U1345C. APC coring continued through Core U1345D-16H to a depth of 150.0 m DRF using non-magnetic coring assemblies. APC core recovery for Hole U1345D was 103.1 % with 154.62 m recovered.

### Hole U1345E

The ship was offset 20 m northwest of Hole U1345D. APC coring continued through Core U1345E-16H to a depth of 150.0 m DRF using non-magnetic coring assemblies. APC core recovery for Hole U1345E was 102.8 % with 154.15 m recovered.

## **Lithostratigraphy**

Only one lithostratigraphic unit was recognized at Site U1345. Unit I includes the same time period as Unit I at the other sites: the Middle Pleistocene to the Holocene. Site U1345 is distinct among the near-shelf sites due to the abundance and generally coarser texture of the siliciclastic component in the sediments as well as the higher frequency of laminated intervals. Intervals characterized by >25% sand and by thin sandy layers occur at all depths at all the holes drilled at this site. The laminations and thin-bedded sediments are numerous and well correlated between holes.

Site U1345 is located in the central portion of the modern oxygen minimum zone (OMZ). The sediments that were deposited at this site can provide important information concerning Pleistocene to Holocene variability of bottom water oxygen concentrations. The preservation of laminated and thinly bedded sediments (beds <10 cm thickness) could be interpreted as the result of a reduction of the activity of benthic macrofauna due to low oxygen concentrations in the bottom waters and surface sediments. Laminations do not have a clear signature in the physical properties or reflectance data as observed at Site U1342.

The laminated intervals can be divided into two categories based on the abundance of biogenic grains: (1) couplets or triplets of diatom oozes, mixed siliciclastic/biogenic sediments, and siliciclastic sediments, or (2) couplets of siliciclastic sediments of alternating textures that may include minor (<40%) amounts of diatoms. Laminated sediments of the first category are similar to laminated intervals at other sites, which are typically biogenic rich, olive green, dark olive gray, and very dark greenish gray. This category of lamination seems to occur mainly during interglacials. This relationship supports previous observations of higher flux of diatoms during interglacial compared to glacial periods. The second category of laminated sediments is mainly siliciclastic and unique to Site U1345. This type of lamination occurs in sediments that are tentatively identified as deposited during glacial conditions. Since these sediments are not biogenic-rich, changes in intermediate water ventilation may have been the controlling parameter for bottom water oxygen concentrations during these periods.

We observed intermittent, finely disseminated authigenic carbonates deeper than ~30 m CSF-A in all holes at this site. The sulfate–methane transition zone (SMTZ) is at ~6.5 m CSF-A, the shallowest observed during the Expedition 323. Calcium and magnesium concentrations in the pore water decrease towards the SMTZ, suggesting active authigenic carbonate precipitation at and below this depth today.

There are few ash layers observed at Site U1345. The ashes that do appear are light colored, suggesting that their source is explosive rhyolitic volcanism. This site is distant from the nearest likely source of volcaniclastic grains, the Aleutian Arc, so the transport mechanism must have been one capable of widespread dissemination.

The lithologies at Site U1345 are sandier than at any other Expedition 323 site. Lithologies with >25% sand and thin sandy layers occur throughout all holes. The presence of this coarse material is probably related to the position of Site U1345 at the crest of an interfluvial at the mouth of Navarin Canyon. The siliciclastic grain sizes at Site U1345 contrast even stronger with Site U1339, located on a submarine plateau isolated from the continental shelf. At the latter site, there were virtually no sand-sized grains recorded. This may be due either to less transport of terrigenous material to the site or to a high biogenic flux to Site U1339 sediments.

### **Biostratigraphy**

High frequency variations can be seen in the abundance and composition of all microfossil groups. The decrease in sea-ice diatoms and the increase in dinoflagellates, planktonic foraminifers and calcareous nannofossils, % open ocean diatoms *Neodenticula* and *Actinotichus*, and in the high productivity dinoflagellate *Islandinium minutum*, associated with increases in the low oxygen benthic foraminifer *Bulimina* aff. *exilis* indicates the approximate depth intervals of distinct interglacials (at ~5, 40, 130 and 145 m CCSF). These intervals also coincide with low GRA bulk density, and are consistent with the age model.

Overall, the distribution of calcareous nannofossils at Site U1345 seems to follow glacial/interglacial cyclicity with higher numbers during interglacials. Changes in their abundance generally reflect changes in environmental factors such as temperature and nutrients. Calcareous nannofossils do not become dominant components of the biota in areas of sea-ice coverage. Elevated content of subpolar planktonic foraminifer species with *G. bulloides* appear at ~5, 40, 90, 130 and 145 m CCSF largely coinciding with the inferred interglacials. This shows increased sea surface temperatures during these

intervals. *G. bulloides* is controlled by temperature rather than food availability in the Bering Sea. These periods of elevated sea surface temperatures are probably reflecting interglacial conditions.

As at the previous Bering Sea sites, the benthic foraminifer assemblage faunal composition shows large changes in species dominance. These changes are interpreted as shifts in local oxygen concentrations associated with surface productivity and/or deep water ventilation on Milankovich time scales. *Bulimina* aff. *exilis* is generally regarded as a low oxygen/deep infaunal species and occurs in samples associated with high productivity and low sea-ice. This suggests that higher productivity during some interglacials may have caused an expansion and intensification of the oxygen minimum zone.

The LO of *Proboscia curvirostris* and the LO of *Thalassiosira jouseae* were observed from 71.1 to 73.3 m CSF depending on the holes, giving the age of 0.3 Ma. In general, diversity is lower for this Site than at the other Gateway sites. The diatom assemblage for this Zone (NPD 11) is dominated by *Thalassiosira antarctica* spores, *Fragilariopsis* spp., *Paralia sol*, *P. sulcata*, *Thalassiothrix longissima*, *Thalassionema nitzschioides*, *T. latimarginta* S. L., and to a lesser extent *Neodenticula seminae*, *Bacteriosira fragilis* and *Actinocyclus curvatulus*. The core interval above the LO of *P. curvirostris* to the Recent is assigned to *Neodenticula seminae* Zone (NPD12). This Zone is dominated by *T. antarctica* spores, *T. latimarginta* S. L., *P. sulcata*, *T. hyalina*, *B. fragilis* and minor presence of *N. seminae* and *A. curvatulus*. In general, this site reveals a higher proportion of coastal neritic diatoms together with freshwater species compared to the other Gateway Sites U1343 and U1344. Low proportions of sea-ice diatoms and high proportions of open water diatoms correspond well with the interglacial horizons. The last occurrence of silicoflagellate *Distephanus octonarius* (0.2-0.3 Ma) was observed in Core U1345A-9H (71.01-80.64 m CSF-A).

Radiolarian zones at Site U1345 could not be established due to the absence of *Stylatractus universus*. Four radiolarian datums derived in the subarctic Pacific were

identified at this site. The LO of *Lychnocanomma nipponica sakaii* (50 ka) and *Spongodiscus* sp. (280-320 ka) were determined. The LOs of *Amphimelissa setosa* (70-90 ka) and *Axoprunum aquilonium* (250-410 ka) were supported only by seldom occurrences, indicating uncertain top positions of the stratigraphic age. Estimated sedimentation rates between LOs of *L. nipponica sakaii* and *Spongodiscus* sp. are ~25cm/kyr at each hole. Among all radiolarian species, *C. davisiana* shows high fluctuations in abundance, possibly relating to ventilation changes with glacial–interglacial cycles. The *Sphaeropyle langii/robusta* group, which were commonly found at Sites U1343 and U1344, show very low abundances. Since abundances of *Sphaeropyle langii/robusta* group at the shallower Sites U1339, U1340, and U1342 were also very low, their dwelling depth might be in deep water below 1000 m.

The dinoflagellates species *Brigantedinium* spp. is one of the most ubiquitous taxa among protoperidiniids, and its distribution in modern sediments is closely related to primary productivity in temperate regions and also to polar and subpolar regions of the North Atlantic and Arctic oceans with seasonal sea-ice coverage. *Islandinium minutum* is one of the principal, if not the dominant components of assemblages in the modern Arctic Ocean. The overall abundance of dinocysts and particularly the above mentioned species suggest high productivity and upwelling during prominent interglacials. Extremely high abundance of dinocysts, especially in the mudline from Hole U1345B and Samples U1345A-5H-CC (44.4 m CCSF) and U1345A-13A-CC (130.6 m CCSF) suggests interglacial periods. This coincides with relatively low pollen and spore concentrations.

### **Paleomagnetism**

No polarity reversal boundary was observed in the cores at Site U1345, therefore the whole sequence is assigned to the Brunhes normal polarity zone. The relative paleointensity pattern is consistent with that seen at all other sites. Based on the correlations, marine isotope stages (MIS) 1-12 were assigned. The significant changes in NRM indicate notable effects of early sediment diagenesis, as this has also been seen at the previous sites. Significant magnetic mineral dissolution starts within 5 m CSF-A due to processes related to anaerobic oxidation of methane (AOM) and sulfate reduction. This

is also evident at Sites U1344, U1343, and U1339. The active zone of dissolution appears to be limited to the top 10 m, so that magnetization does not change significantly at deeper depths.

### **Geochemistry**

Site U1345 shows the shallowest SMTZ of all sites investigated, at ~6.25 m CSF-A. Likewise this site is characterized by the steepest flux of methane into this zone and the highest interstitial water hydrogen sulfide concentrations. Similar to the other shelf Sites U1343 and U1344, the almost linear sulfate and methane profiles suggest that AOM coupled to sulfate reduction accounts for most of the sulfate consumption in the sediment. Preliminary modeling of the DIC profile suggest that net DIC production in the SMTZ accounts for 70% of the DIC production in the top sediment layers. The organic matter degradation products phosphate and ammonium show accumulation in the pore water, the distinct minimum in phosphate concentration between 22.25 m and 27.25 m CSF-A however, also indicates the consumption of this species is most likely due to the formation of phosphate-bearing minerals such as apatite.

The occurrence of high concentrations of interstitial water hydrogen sulfide in the SMTZ can be attributed to very high sulfate reduction rates at this depth and probably also to a lack of sufficient pool of reactive Fe-mineral phases, e.g. Fe-(oxhydr)oxides that can react with hydrogen sulfide on short time scales. Distinct peaks in dissolved Fe and Mn concentration immediately below the SMTZ are the result of microbial dissimilatory Fe reduction. Calcium and magnesium profiles show depletion at the depth of the present SMTZ, suggesting the formation of authigenic Mg-rich carbonate (e.g., dolomite) driven by the production of DIC during AOM and an increase in pH leading to oversaturation of the pore water with respect to carbonate. Interestingly, the dissolved calcium profile shows a further decrease with depth and a minimum concentration at around 40 m CSF-A. This depth corresponds to a dolostone layer found at 40.27 m CSF-A. Sites U1343, U1344 and U1345 furthermore show high concentrations of dissolved Ba in the pore water and indicate a sink of this ion just above the SMTZ. The distribution of Ba at these sites can be attributed to diagenetic remobilization of Ba deposited as biogenic barite into

the sulfate-depleted pore water. The upper end of the SMTZ where the sulfate and dissolved Ba profiles overlap marks the present front of authigenic barite formation.

### **Microbiology**

Samples for abundance of prokaryotes were collected adjacent to interstitial water whole-cores. High resolution sampling took place in the microbiological dedicated cores as well as additional samples taken once per core to APC refusal. It is of interest to examine the relationship between microbial productivity and diversity in the upper 25 m of sediment dedicated for microbial ecology. A special focus will be directed toward the function of Archaea in the sulfate reduction zone, the SMTZ and the methanogenesis zone. The sulfate–methane transition is a “hot spot” for microbial activity and abundance within deep-sea sediments and we will expect an increase in the abundance and activity of microbial life, while the remainder of the core should see a significant decrease with depth in microbial life both active and benign. To obtain an estimate of active seafloor life samples were also taken in low resolution for CARD-FISH at all aforementioned zones and at depth.

As indicators of productivity we will rely on estimates generated by shipboard participants (cell counts, geochemical profiles) and shorebased participants (amino acid and amino sugar composition). We will examine overall bacterial and archaeal diversity by a combination of conventional 16S rRNA clone libraries, as well as quantitative polymerase-chain-reaction (qPCR) and/or a new quantitative community fingerprinting method involving automated ribosomal intergenic spacer analysis (ARISA; Ramette 2009).

### **Physical Properties**

Wet bulk densities at Hole U1345A appear to be higher by 0.1 to 0.2 g/cm<sup>3</sup> compared to those measured at Hole U1344A in the upper 150 m of the sedimentary section; the higher densities of sediment at Hole U1345A probably reflect their higher sand content. Similar to stratigraphic sections drilled at Beringian margin sites, Sites U1343 and U1344, GRA density values at Hole U1345A also document rhythmic fluctuations. MS

measurements seem to have realistically recorded the downhole contour of changing values that are functions of many factors. An explanation for the higher counts for the Hole U1345A section is its coarser and higher content of siliciclastic mineral debris. In downhole profile, the contour of NGR readings is broadly similar to that of GRA bulk density. The downhole distribution of thermal conductivity readings displays an overall trend of increasing conductivity. Down-section profiles of MAD-measured porosity and water content record a progressive decrease in average values. The downhole distribution of water content and porosity is rhythmic. Little change is seen in average grain density with depth. The higher average grain density ( $2.75 \text{ g/cm}^3$ ) of Unit I at Hole U1345A is interpreted to be a consequence of its greater abundance of coarse siliciclastic grains.

### **Stratigraphic Correlation**

The composite depth scale and splice at Site U1345 is complete and continuous from 0.0–167.6 m CCSF-A. The splice ranges from the top of Core U1345A-1H to U1345D16H-7, 146.6 cm. There are no appended intervals. Most of the splice points are clear and convincing based on the multiple copies of the section recovered in five holes. The splice tie point between U1345A-10H4, 50.0 cm and U1345C-10H1, 100.18 cm (93.024 m CCSF-A) is uncertain because Core U1345A-10H contains disturbed flow-in starting approximately in the middle of Section 4 and extends through the bottom of Section 7. The disturbed section is not included in the splice. The splice tie point between U1345D-10H-7, 58.4 cm and U1345A-11H-3, 115.4 cm (103.284 m CCSF-A) and between U1345D-13H-6, 138.4 cm, and U1345A-14H-3, 94.7cm (133.637 m CCSF-A) are tentative because of low signal amplitudes in MS. The cumulative offset between CSF-A and CCSF-D depth scales is roughly linear. The affine growth factor at Site U1345 is 1.11.

### **Downhole Measurements**

The only downhole measurements made at Site U1345 were three deployments of the APCT-3 tool in Hole U1345A. The measured temperatures ranged from  $4.92 \text{ }^\circ\text{C}$  at 42.4 m DSF to  $8.15 \text{ }^\circ\text{C}$  at 108.9 m DSF, indicating a local geothermal gradient of  $48.5 \text{ }^\circ\text{C/km}$ . A simple estimate of the heat flow can be obtained from the product of the geothermal

gradient by the average thermal conductivity, which gives a value of 51.6 mW/m<sup>2</sup>, in agreement with existing measurement in the area.

### **Sedimentation Rates**

Based on the four holes that were studied, the following two mean radiolarian biostratigraphic datums were employed for the determination of sedimentation rates: the last occurrences (LO) of *Lychnocanomma nipponica sakaii*; and the LO of *Spongodiscus* sp.. Only one sedimentation rate of 28 cm/k.y. appears to be applicable to this site. This sedimentation rate is lower than that of adjacent and deeper water Site U1344 of ~39 cm/k.y.