

## **IODP Expedition 323:**

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

#### **Site U1344 Summary**

31 August 200

#### **Background and objectives**

The primary objective of drilling at Site U1344 (Site GAT-3C) was to study high-resolution Pliocene-Pleistocene paleoceanography at a proximal gateway location to the Arctic Ocean at the deepest water depth of Expedition 323. The site is located at ~3200 m along the small summit of a canyon interfluvium ~10-15 km southeast of Pervenets Canyon, a large submarine canyon that deeply and widely incises the Beringian continental slope. Pervenets Canyon, along with companion Zhemchug Canyon adjacent to Site U1343, was discovered in the early 1960s by the Soviet fishing industry and named after one of the canyon's discovering trawlers. At times of glacially lowered sea level, the head of Pervenets Canyon is commonly presumed to have been one of the outfall locations for the Anadyr River, which presently drains the Russian far northeast and enters the Bering Sea at the Gulf of Anadyr. It is anticipated to receive supply of terrigenous sediments from the shelf during both the interglacials and the glacials.

This is also the area of high biological productivity called the "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. The water that entered into the Bering Sea moves eastward along the Aleutian Islands and consequently encounters the shallow blocking Bering Shelf. The bottom depth of the BSC is ~300 m, therefore the BSC cannot flow eastward against the shelf any longer at the shelf break and it upwells and its flow turns to the northwest along the shelf break. Moreover, tidal mixing causes further vertical mixing of the water masses along the BSC, enhancing biological productivity within the "Green Belt", a zone adjacent to the northwest trending shelf break where high primary productivity in the surface waters and high %organic carbon accumulation at the seafloor are taking place. However, we anticipate finding less organic carbon supply to the seafloor than at the other gateway sites or Site

U1339 due to deeper water depth than at the other sites. Thus, the expectation of the impingement by the dissolved oxygen minimum zone (OMZ) in the past is relatively small at this site. Nevertheless, it is important to compare the vertical extent of water mass conditions in a basin wide scale extent including this site. Hence, the records from the shallower drill sites on the Bowers Ridge as well as the other gateway sites can be fully employed for the comparison.

Site U1344 also is located close to the maximum extent of the present day seasonal sea-ice cover. Thus, it is expected that this site had been covered by the seasonal or perennial sea-ice during the glacial low sea-level stands. Since it is adjacent to the Bering Shelf, high amount of terrigenous sediment supply is expected especially during the glacial low stands.

This relatively deep drill site in the gateway region to the Arctic Ocean can also be used to study the impact of seafloor microbes on biogeochemical fluxes in the highest surface ocean productivity areas of the drill sites in the Bering Sea. Organic-fueled seafloor 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 seafloor cell abundance and to investigate the link between the mass and characteristics of seafloor microbes and the extent of export productivity from the surface ocean.

Sedimentation rates at this site have been estimated at 170-180 m/m.y. based on an earlier site survey piston core studies. Neither of the piston cores taken in these studies recovered the Holocene section, possibly indicating erosion during the recent past. Prior to drilling, recovery of the Pleistocene to the Pliocene section was expected at this site.

### **Operations**

Five holes were cored at Site U1344. The first used the APC/XCB systems to 745.0 m DSF. Hole U1344A was then successfully logged with the triple combo and FMS-Sonic logging tools. The second hole, a planned dedicated microbiology hole, was cut short due

to contamination when the core liner split during the mudline coring. Therefore, the third hole was assigned to microbiology. Hole U1344D was cored with the APC system to 286.5 m DSF. The last hole, U1344E, was cored with the APC system to 202.8 m DSF. A complete set of site specific tide tables provided by the science party were used to make adjustments relative to initial mudline core and for each successive core on each hole. Coring in general was routine except for biogenic methane encountered in the cores which complicated the curation of all cores at this site. APC coring totals for Site U1344 include 87 cores, 781.8 m penetrated, 791.1 m recovered, for 101.2% recovery. XCB coring totals for Site U1344 include 52 cores and 489.9 m penetrated, 384.1 recovered for 78.4% recovery. Total cored interval for Site U1344 was 1271.7 m, with 1175.19 m of core recovered for a 92.4% total recovery. The time spent on Site U1344 was 8.5 days.

#### Hole U1344A

The first APC barrel recovered 9.1 m of core and an official seafloor depth was established at 3183.4 m DRF. Hole U1344A was spudded at 0932 hr on 14 August. APC coring continued through Core U1344A-26H to 245.6 m DRF using non-magnetic coring assemblies. The XCB system was deployed and coring continued through Core U1344A-79X to a depth of 745.0 m DSF. The coring tools were secured and the hole was swept clean and then displaced with 200 barrels of prepared high viscosity logging mud. There was no fill identified at total depth. The end-of-pipe (EOP) was placed at ~100.0 m DSF. Two logging strings were deployed. The triple combo string reached total hole depth of 745 m DSF and good quality logs were obtained. The second logging string consisted of the FMS-sonic tool, which reached total depth of 745 m DSF on the first pass but reached only 725 m DSF on the second pass as hole conditions began to deteriorate. Good data were obtained on both passes. APC core recovery for Hole U1344A was 103.5% with 264 m recovered. XCB core recovery for Hole U1344A was 78.4% with 384.1 m recovered. Total core recovery for Hole U1344A was 87% with 648.1 m recovered.

#### Hole U1344B

The vessel was offset 20 m north of Hole U1344A. Hole U1344B was spudded with APC at 1335 hr on 19 August. One APC core was recovered. Unfortunately, Core U1344B-

1H came to the surface with a split/damaged core liner and was unfit for use for microbiological studies.

#### Hole U1344C

The first APC barrel recovered 7.12 m of core and an official seafloor depth was established at 3184.4 m DRF. Hole U1344C was spudded at 1505 hr on 19 August. Both contamination testing methods, per-fluoro-methyl-cyclohexane (PFTs) and microspheres were deployed. A total of 4 APC cores were recovered for microbiology to a depth of 35.6 m. Average core recovery for the APC on Hole U1344B was 94.13% with 33.5 m recovered.

#### Hole U1344D

The ship was offset 20 m north from Hole U1344C. The APC was deployed and Hole U1344C was spudded at 1940 hr on 19 August. The first mudline core recovered 2.73 m of sediment and the calculated seafloor was 3185.8 m DRF. APC coring continued through Core U1344C-25H to 224.5 m DRF using non-magnetic coring assemblies. The non-magnetic coring equipment was changed to the standard APC coring system and coring continued. Coring with the APC system was suspended after Core U1344D-32H at a depth of 286.5 m DSF. Cores U1344D-30H and 32H required drill over. Overall recovery for Hole U1344D using the APC coring system was 99.9% with 286.1 m recovered.

#### Hole U1344E

The ship was offset 20 m north from Hole U1344D. The first APC barrel recovered 5.3 m of core and an official seafloor depth was established at 3185.7 m DRF. Hole U1344E was spudded at 0750 hr on 21 August. APC coring continued through Core U1344E-23H using non-magnetic coring assemblies. Coring was uneventful and continuous except for a 3 m section at 3276.5 m DSF, which was drilled to maintain stratigraphic overlap. APC core recovery for Hole U1344E was 101.4% with 202.7 m recovered.

## **Lithostratigraphy**

There was one lithologic unit defined at this site spanning the early Pleistocene to the Holocene. Unit I at Site U1344 encompasses a time period comparable to Unit I defined at the Bowers Ridge Sites U1340 and U1341, and is in general very similar to Unit I at the other Bering Sea margin Sites U1339 and U1343. However, Site U1344 is distinct in that it has an even higher proportion of siliciclastic components and a higher occurrence of sand-sized grains than Site U1343. This is probably related to the location of this site on the continental slope and its relative proximity to sources of terrigenous sediments from the continental margin. Sandy lithologies are concentrated in three relatively distinct intervals at Site U1344. They can be correlated not only between the holes at Site U1344, but also to Site U1343 where three distinctly sandy intervals occur. While the lithologies dominated by diatoms are associated with changes in color reflectance and analogous to those at other sites, the lithology changes here are more subtle due to the overall higher abundances of siliciclastic detritus. Higher abundance of diatoms may reflect high diatom flux during interglacials, as previously observed in the Bering Sea.

Only one diatom-rich laminated interval was observed. All other laminations are defined by faint color changes with gradational boundaries with the surrounding lithologies. It appears that well-oxygenated bottom water conditions probably prevailed throughout most of the Pleistocene, preventing preservation of laminations. Almost all dropstones are well-rounded, indicating a period of reworking prior to incorporation in the ice. The rounding therefore favors a coastal provenance and sea ice rafting rather than icebergs. Unlike most other sites but similar to Site U1343, volcaniclastic material is a minor component of the sediment at Site U1344 because it is more distant from the Aleutian arc. Authigenic carbonate occurs throughout the sediment and is not constrained to deeper parts of the sequence as it was at Site U1343. The shallowest appearance in Hole U1344A is at 63 m CSF-A. The presence of gas in the sediments caused several types of coring disturbance, mostly cracks up to several centimeters wide. In some cases, this affected the stratigraphic integrity of the sediment sequence, similar to Sites U1339 and U1343.

## Biostratigraphy

The water depth at Site U1344 is ~ 3200 m has a potential to reconstruct past deep-water changes because of it is presently located below the oxygen minimum zone. Benthic foraminiferal faunas indicate high frequency changes in the bottom water oxygen content over the entire section, probably related primarily to surface water productivity, but possibly to bottom water ventilation changes and methane seeps as well. There is a general increase in abundance from ~300 m CSF to the top of the section as well as bottom water oxygen variability. The low oxygen indicator *Bulimina* aff. *exilis* can be seen to be more abundant at both Sites U1343 and U1344 after approximately 0.8 Ma, along with benthic foraminifer abundance maxima. Both high abundance and low oxygen benthic faunas were found to be common during the last deglacial at the Bowers Ridge, and the increase in such characteristics from 0.8 Ma may mark the onset of more intense deglacials, greater nutrient availability, and higher surface water productivity. Similarly to Site U1343, the increases of planktic foraminifers also coincide with the highest numbers of sea-ice diatoms and polar dinoflagellate cysts after 1 Ma. The change from low to high abundances of planktic foraminifers coincides with the increases of the abundances of dinoflagellate cysts, calcareous nannofossils, benthic foraminifers and the number of low-oxygen benthic foraminifers, analogous to previously published data for the CaCO<sub>3</sub> preservation peaks during the last deglaciation in the Bering Sea.

This site is characterized by very low abundance of calcareous nannofossils. Only samples from the upper most cores to the base of Core U1344D-4H can be assigned to the calcareous nannofossil Zone NN21, with an estimated age of less than 0.29 Ma. The planktic foraminifer faunal assemblage found during the Late Pleistocene is dominated by *Neogloboquadrina pachyderma* (sinistral) throughout. Below 260 m CCSF-A *N. pachyderma* (sinistral) is reduced or absent from the assemblage and the fauna is replaced by a subpolar assemblage dominated by *G. bulloides*. The occurrence of this species is mainly ruled by sea surface temperature, indicating that the Late Pliocene–Early Pleistocene were warmer than the Late Pleistocene at this site.

The drilled interval above the LO of diatom *P. curvirostris* (ranging from 107.2 to 122.3 m CSF depending on the holes) is assigned to the *Neodenticula seminae* Zone (NPD12). Due to the absence of *Actinocyclus oculatus* at Holes U1344D and U1344E the bottom of each hole is assigned to the Zone NPD 11. The FO datum of *P. curvirostris* was defined at Sample U1344A-56X-CC and assigned the age of  $1.85 \pm 0.1$  Ma in the *A. oculatus* Zone. The LO of *Pyxidicula horridus* (1.9-2.0 Ma) was estimated at the base of Core U1344A-63X. The LO of silicoflagellate *Dictyocha subarctios* was assigned to Cores U1344A-30H (270.25-280.31 m CSF-A) and U1344D-26H (224.41-234.09 m CSF-A). The LO of ebridian *Ammodochium rectangulare* appears to be located in Core U1344A-78X (733.13-739.75 m CSF-A). The radiolarian ages at Site U1344 spans from the *Botryostrobus aquilonaris* Zone (Late Quaternary) to the *Eucyrtidium matuyamai* Zone (Middle Quaternary) in the subarctic Pacific. Five radiolarian datums derived from the subarctic Pacific were identified at this site. Estimated sedimentation rates in the upper 150 m at Holes U1344A, U1344D, and U1344E are greater than 30 cm/k.y., which is slightly higher than at the neighboring Site U1343 (~20 cm/k.y.). The LO of *E. matuyamai* (0.9-1.5 Ma) was identified in samples from Hole U1344A. The occurrence of dinoflagellate *Filisphaera filifera* at the base of Core U1244A-50X (473.4 m CSF-A) suggest an age of 1.41-1.7 Ma, according to its last occurrence datum in the North Pacific and North Atlantic. This species dominates the assemblages in a few samples above this depth, quite similar to Site U1343. The occasional occurrence of the autotrophic species *Operculudinium centrocarpum* may be related to oceanic conditions with relatively low productivity.

### **Paleomagnetism**

The Brunhes/Matuyama boundary is clearly identified at ~280 m CSF-A depth. The Jaramillo, Cobb Mountain and Olduvai subchrons might be correlatable with the extracted normal polarity zones placed at about 380, 420 and 680 m CSF-A, respectively. The paleointensity variation has quite large amplitude and obviously shows a coherent change with the magnetic susceptibility, suggesting that the NRM intensity has been largely influenced by environmental changes. The relative paleointensity pattern seen at this site is consistent with those observed at Sites U1340, U1341, U1342, and U1343.

Based on the correlations, marine isotope stages (MIS) 1-19 have been assigned to ~280 m CSF-A. The dramatic changes in NRM indicate notable effects of early sediment diagenesis. Significant magnetic mineral dissolution starts within 10 m CSF-A due to anaerobic methane oxidation (AOM)–sulfate reduction processes, which is also evident at Sites U1343 and U1339.

### **Geochemistry**

The rate of carbon turnover in the sediment at Site U1344 is similar to or slightly higher than rates at Site U1343, as evidenced by similar  $\text{SO}_4^{2-}$ , DIC,  $\text{PO}_4^{3-}$  and  $\text{NH}_4^+$  concentration profiles. Similar to Site U1343, profiles of  $\text{CH}_4$  and  $\text{SO}_4^{2-}$  at Site U1344 suggest that sulfate reduction is largely driven by  $\text{CH}_4$  diffusing into the sulfate zone. The  $\text{CH}_4$  flux into the  $\text{SO}_4^{2-}$  zone, as calculated from the concentration gradient between 8-13 m CSF-A, is approximately 70%-80% of the  $\text{SO}_4^{2-}$  flux into the sulfate–methane transition zone (SMTZ). The importance of AOM for overall carbon turnover is also indicated by the curvature in the DIC profile. The steepest concentration gradient in the upper 10 m CSF-A is observed directly above the SMTZ, suggesting that the highest DIC flux occurs from this zone. Preliminary modeling of the DIC profile suggest that net DIC production in the SMTZ accounts for 80% of the DIC production in the upper 30 m CSF-A of the sediment. Hydrogen sulfide is also at a maximum in the SMTZ most likely because sulfate reduction rates are the highest and the content of oxidized iron is the lowest in this zone. Magnetic susceptibility data obtained during fast scan of the cores confirm a low content of oxidized iron in the SMTZ.

It is well known that AOM favors the deposition of carbonates in the SMTZ. At Site U1344 a relatively high flux of  $\text{Ca}^{2+}$  into the SMTZ is observed that indicates the formation of calcium carbonate. There were also indications for  $\text{Mg}^{2+}$  flux into the SMTZ, which may suggest dolomite formation. The curvature of the  $\text{NH}_4^+$  profile suggests production from organic matter degradation throughout the sediment column. Microbial mediated degradation is either conducted via a respiratory or via a fermentative pathway. According to the classical reduction scheme in sediments, only fermentation and hydrogenotrophic methanogenesis occurs below the SMTZ; however, at this site the

Fe profile suggests that Fe reduction occurs below the SMTZ. Organic matter degradation also leads to the accumulation of DIC and  $\text{PO}_4^{3-}$  in the interstitial water. The accumulation of these species; however, is much lower than predicted from the  $\text{NH}_4^+$  profile assuming steady state and a constant ratio between C, N and P of remineralized organic matter. This suggests both production and consumption of DIC and  $\text{PO}_4^{3-}$  in the sediment. Consumption of these species is most likely due to formation of apatite and calcium carbonates (e.g., dolomite). The interstitial water profiles suggest that rates of net consumption of  $\text{PO}_4^{3-}$  and DIC are the highest between 300-350 m CSF-A.  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  concentration profiles likewise indicate net consumption of these species between 300-350 m CSF-A.

### **Microbiology**

Samples for abundance of prokaryotes were collected adjacent to interstitial water whole- rounds in sections drilled using APC system. High resolution sampling took place in the microbiological dedicated cores as well as additional samples taken once per core to APC refusal in Hole U1344A. Additional samples were taken from Cores U1344A-78X to - 80X recovered using the XCB system to evaluate cell abundance and community structure in the deepest portion of Hole U1344E. PFT analyses performed on these cores show no contamination from the drill fluid. Samples from all cores were fixed.

It is of interest to examine the relationship between microbial productivity and diversity in the upper 25 m of the sediment column. Special attention will be directed toward the function of Archaea in the sulfate reduction zone, the SMTZ and the methanogenesis zone. The sulfatemethane transition is a “hot spot” for microbial activity and abundance within deep-sea sediments and we will expect and 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.

### **Physical Properties**

The downhole profile of density for Hole U1344A is remarkably similar to that of Hole U1343E. The overall downward increase in bulk density is interpreted to record

compactive dewatering in a generally lithologically uniform sequence of fine-grained sediment. Magnetic susceptibility (MS), as measured by the wholeround multisensory logger (WRMSL) exhibits little change in average value and character with depth. Based on what has been learned at previous sites, it is presumed that the rhythmic oscillations are a function of lithologic composition and patterns of in-situ sediment alteration.

Except for the upper three cores at Hole U1344A, P-wave velocity readings for the sedimentary section penetrated at this hole were only collected by the FMS-sonic downhole logging tool. Sonic P-wave velocity data reveal a profile similar to that recorded at Hole U1343E in that the average velocity increases down section in step-like sectors. Except for the upper ~80-100 m CSF-A, across which NGR readings increase from a near-surface measurement of ~25 count/s to about 34 counts/s, NGR values at deeper depths oscillate around this average to the base of the Hole U1344A at 745 m. Presumably variations in counts/s reflect downhole changes in content of clay and siliciclastic minerals.

Thermal conductivity measurements can be grouped into an upper and lower sequence. The upper vertical sequence displays an estimated average reading of ~0.905 W/mK and extends downward from the near surface to a depth of ~260 m CSF-A, below which APC refusal caused a change to XCB coring and Vp-wave velocity shifts abruptly to higher readings. At Hole U1344A, porosity decreases most rapidly in the upper part of the drilled section, falling to an average value of ~60% at 80-100 m CSF-A. Below this depth, other than oscillating readings, little detail tracking shifts in average value or changes in trend are exhibited. The overall downward decrease in porosity tracked by MAD and logging data is presumably a manifestation of compaction dewatering.

The upper group of dry grain density extends from the surface to a depth of ~160 m CSF-A is ~2.70 g/cm<sup>3</sup>. The middle sequence, from ~160 to 620 m CSF-A, exhibits an average density of 2.65 g/cm<sup>3</sup>, and the underlying basal group a lower density of ~2.62 g/cm<sup>3</sup>. It appears that an overall upward increase in deposition of denser siliciclastic mineral debris is recorded.

## **Stratigraphic Correlation**

The complete and continuous composite depth scale and splice at Site U1344 is constructed from 0.0–332.02 m CCSF-A. The continuous splice ranges from the top of Core U1344A-1H to Core U1344A-31X Section 5 at 50 cm. The appended cores range from Core U1344A32X, to U1344A79X (790.37 m CCSF-A) with a constant affine value of 43.78 m. All splice points in the interval of 0-50 m CCSF-A are clear and convincing based on multiple data types. The splice tie point between U1344A-5H-7, 4.44 cm and U1344D-6H-3, 79.88 cm (51.99 m CCSF-A) is uncertain, and could be moved about 2.4 m shallower in Core U1344D-6H with equal uncertainty. This is a point to be checked with postcruise data. The splice tie points between U1344E-6H-6, 112.47 cm and U1344A-6H-4, 122.06 cm (60.40 CCSF-A) and between U1344E-14H-1, 10.92 cm and U1344D-14H-2, 136.02 cm (140.43 CCSF-A) and U1334A-16H-7, 1.04 cm and U1334D-17H-4, 1.34 cm (175.52 CCSF-A) are uncertain because of low signal amplitude in MS.

## **Downhole Measurements**

Two tool strings were deployed in Hole U1344A: the triple combo and the FMS-sonic combination. Overall, the caliper of the density sonde shows an irregular borehole, with a particularly large interval between 170 and 260 m WSF, but with very good conditions in the lower section. Deeper in the borehole, small enlargements regularly spaced every ~9.5 m indicate where the bit was sitting whenever a core was recovered. However, all the calipers show that the tools were making at least partial contact with the formation over most of the interval logged, suggesting that the overall quality of the data is good. Irregular hole size has an effect on the measurements that require good contact with the formation, namely density and porosity. The anomalously low density values between 230 and 250 m WSF, within the 100-m interval with the largest hole size, are probably erroneous, as well as most neutron porosity measurements in this entire interval. The quality of the logs can also be assessed by comparison with the NGR and GRA track data and with the moisture and density (MAD) measurements made on cores recovered from Hole U1344A. Except for two short intervals with lower density logging data (230-250 m WMSF and 420-430 m WSF), all density data sets are in good agreement, confirming

the overall good data quality despite the enlarged hole. Comparison of the gamma ray logs measured during the main pass of the two runs shows an excellent repeatability between the two runs.

Logging Unit 1 (100 - 330 m WMSF) is characterized mainly by a steady increase with depth in  $V_p$  and  $V_s$ , while the other log data remain mostly uniform despite some variability such as in the gamma ray. The bottom of this unit is defined by a noticeable drop in  $V_p$ ,  $V_s$ , gamma ray, density and resistivity, immediately above by a sharp peak in these measurements, particularly in  $V_s$  and resistivity, indicating a fine stiff layer. This sequence corresponds to a core with poor recovery. Logging Unit 2 (330-460 m WMSF) is almost uniquely defined by the  $V_p$  and  $V_s$  log, both increasing steadily through the unit. Gamma ray and density also increase with depth in this unit, in a more subdued manner. The top of Logging Unit 3 (460-620 m WMSF) is defined by an inflection in the velocity profiles which, combined with a decreasing trend in density, generates the strong reflector at 4.83 s twtt. The variability with depth in gamma ray and in most logs, displays a cyclicity more clearly defined than in the upper units. Finally, the top of Logging Unit 43 (620 - 745 m WMSF ) is defined by a sharp increase in  $V_p$ ,  $V_s$ , gamma ray and density, as well as a significant change in the trends of all the logs. As in the deepest unit of Site U1343, the gamma ray, potassium, thorium, density, resistivity,  $V_p$  and  $V_s$  logs all display a variability with depth of wider amplitude and lower frequency than in the upper units, suggesting a significant change in the deposition history and rates.

The APCT-3 tool was successfully deployed three times in Hole U1344A. The measured temperatures ranged from 4.51 °C at 47.1 m DSF to 9.57 °C at 142.1 m DSF, and fit closely a linear geothermal gradient of 53.3 °C/km. The temperature at the seafloor was 1.65 °C, based on the average of the measurements at the mudline during all the APCT-3 deployments. A simple estimate of the heat flow can be obtained from the product of the geothermal gradient by the average thermal conductivity (0.911 W/m°C), which gives a value of 48.5 mW/m<sup>2</sup>, within the range of previous measurement in the area

### **Sedimentation Rates**

Sedimentation rates observed at Site U1344 are mostly similar to values within a narrow range of 29-50 cm/k.y. throughout Holes U1344A, U1344D, and U1344E. One exception is the interval between the top and the bottom of the Cobb Mountain Subchron (459.0-469.6 m CCSF-A), which resulted in 89 cm/k.y. Based on the sedimentation rates the bottom age of Hole U1344A was determined to be ~1.9 Ma.