IODP Expedition 323:

Pliocene-Pleistocene paleoceanography and climate history of the Bering Sea

Site U1342 Summary

19 August 2009

Hole U1342A
Latitude: 54° 49.6987’ N
Longitude: 176° 55.0027’ E
Water depth (mbsl): 818.3
Total penetration (m DSF): 49.3
Total core recovered (m): 57.39
Core recovery (%): 108

Hole U1342B
Latitude: 54° 49.7004’ N
Longitude: 176° 55.0232’ E (~20 m East of Hole U1342A)
Water depth (mbsl): 818.9
Total penetration (m DSF): 43.3
Total core recovered (m): 44.83
Core recovery (%): 104

Hole U1342C
Latitude: 54° 49.7017’ N
Longitude: 176° 55.0232’ E (20 m east of Hole U1342B)
Water depth (mbsl): 818.8
Total penetration (m DSF): 45.4
Total core recovered (m): 47.06
Core recovery (%): 104

Hole U1342D
Latitude: 54° 49.6987’ N
Longitude: 176° 55.0027’ E (20 m east of Hole U1342C)
Water depth (mbsl): 818.2
Total penetration (m DSF): 127.7
Total core recovered (m): 86.37
Core recovery (%): 68

Background and Objectives

The primary objective of drilling at Site U1342 (originally BOW-15A) was to study high-resolution Plio-Pleistocene paleoceanography at a relatively shallow water depth on the Bowers Ridge in the Bering Sea where relatively low sedimentation rates have been

observed in an earlier site survey piston core study. The Bowers Ridge is well situated to study the past extent of water masses exchange with the Pacific Ocean through the adjacent Aleutian passes such as Amukta, Amchikta and Buldir Passes. As with the other Bowers Ridge sites, the record of changes in the flow of warm Alaskan Stream water mass into the Bering Sea and its impact on the distribution of the past sea-ice coverage is of particular interest.

According to the pre-expedition site survey piston core study, during the last glacial maximum Site U1342 (BOW-8A) experienced more open water conditions compared to Site U1340 (BOW-12A) near the ridge crest. While the productivity in the Bering Sea in general is very high with respect to the other parts of the global oceans, the expected productivity at this site, along with the other Bowers Ridge sites, is lower than at Site U1339 on the Umnak Plateau which has substantially greater influence from the adjacent Bering Sea Shelf. Site U1342, with its relatively shallow water depth at 818 m (DSF) will serve as the shallow end member in comparison to the other Bowers Ridge sites (U1340, 1295 m; U1341, 2140 m), and therefore will provide an important constraint on the intensity and depth of the water column oxygen minimum zone (OMS). Based on the site survey piston core study, sedimentation rates of approximately 32 m/My, and Pliocene age sediments at the bottom of the sedimentary section, are expected.

The drill site at the Bowers Ridge can also be used to study the impact of subseafloor microbes on biogeochemical fluxes. Organic-fueled subseafloor respiration and its impact on biogeochemistry in such a highly productive region have never been quantified previously. To do this, the Bowers Ridge drilled sediments will be 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. Compared to the other Expedition 323 drill sites where detailed microbiological studies have and will occur, U1342 is expected to have relatively lower (but still high) surface ocean productivity. As such, because of its more open ocean location farthest away from the high productivity zone of the shelf, Site U1342 serves as the low productivity end member of the expedition's microbiological study.

Operations

Four holes were drilled at this site. The first was cored using the APC system to refusal. When refusal was met early, the XCB system was deployed to confirm formation material. The XCB recovered 0.5 m of basalt, effectively ending Hole U1342A. The second hole, Hole U1342B, was dedicated to microbiology. Hole U1342C was cored with the APC system to 45.4 m DSF. The last hole, Hole U1342D was APC cored to 44.0 m DSF. At that point, a center bit was dropped and the hole was drilled ahead for 18.6 m to determine if the basalt was continuous or not. At a drilling break, the XCB system was deployed and was used to take 13 cores of hard rock to the total hole depth of 127.4 m DRF. A complete set of site specific tide tables were provided by the science party for Site U1342. The tide tables were used to make adjustments relative to initial mudline core and for each successive core on each hole. APC coring totals include 182 m penetrated with 194.11 m recovered (a recovery of 107 %). XCB coring totals for Site U1342 include 66.1 m of penetration with 41.54 m recovered (63 % recovery). The total cored interval was 248.1 m, with 235.65 m of core recovered for a 95% total recovery. The time spent on Site U1342 was 33.25 hours or 1.4 days.

Hole U1342A

Hole U1342A was spudded at 1320 hr on 3 August recovering 1.8 m of sediment in the first APC barrel and establishing an official sea floor depth of 829.7 m DRF. APC coring continued through Core U1342A-8H to 49.3 m DRF. Coring with the APC system was suspended after two successive short, incomplete strokes of the core barrel and apparent refusal. Three meters of hole were then drilled with the APC/XCB bit and the XCB system was deployed and a short core (1 m) was drilled to identify the material at APC refusal. Basalt was recovered and Hole U1342A was terminated. Overall recovery for Hole U1342A using the APC coring system was 116 % with 56.93 m recovered. Recovery for the XCB core was 0.46 m or 46% recovery.

Hole U1342B

The vessel was offset 20 m east of Hole U1342A. Hole U1342B was spudded at 2315 hr on 3 August. The barrel recovered 5.33 m of core and an official sea floor depth was established at 830.4 m DRF. APC coring continued through Core U1342B-5H to a depth of 43.3 m DRF.

Hole U1342C

The vessel was moved 20 m east of Hole U1342B. The first APC barrel recovered 7.2 m of core and an official sea floor depth was established at 830.3 m DRF. Hole U1342C was spudded at 0235 hr on 4 August. APC coring continued through Core U1342C-6H to refusal. Overall recovery for Hole U1342C using the APC coring system was 104% with 47.06 m recovered.

Hole U1342D

The vessel was moved 20 m east of Hole U1342C. The first APC barrel recovered 6.0 m of core and an official sea floor depth was established at 829.7 m DRF. Hole U1342D was spudded at 0830 hr on 4 August. APC coring continued through Core U1342D-5H to 873.7 m DRF. On reaching refusal, the center bit was dropped and the hole was drilled 18.6 m to see if there were sediments under the layer of hard rock (basalt). After a drilling break was observed the XCB coring system was deployed and used successfully to core an additional 65.10 m into the formation. Overall recovery for Hole U1342A using the APC coring system was 102.9% with 45.29 m recovered. Recovery for the XCB core was 41.08 m or 63.1% recovery.

Lithostratigraphy

The sediments recovered at Site U1342 are a mix of biogenic, volcaniclastic and siliciclastic sediments. In general, the color of the sediment reflects its lithologic characteristics: sediment composed of siliciclastic sediment or mixed lithologies tends to be very dark greenish gray to dark gray, while biogenic sediment is olive gray to olive. Volcaniclastic ash layers are dark gray to black or shades of light gray to white. The sedimentary sequence can be divided into three lithologic units: Unit I consisting of silt

and laminated ooze; Unit II, of sponge spicule-bearing, diatom bearing sand; and Unit III of volcanic rock and volcaniclastic sedimentary rock.

The occurrence of well-preserved laminations in Unit I indicates the absence of bioturbating fauna, and thus suggests low oxygen conditions in the bottom waters and the sediment pore water. Burrows or mottles at the gradational tops of laminated sediment intervals indicate an increase in oxygenation of bottom waters after the deposition of the laminated sediments. In contrast, the sharp bottom boundaries suggest either a sudden increase in sedimentation rate at the onset of laminated intervals or a hiatus between the laminated sediments and underlying siliciclastic sediments. The winnowing of sediment by bottom currents may have caused the apparent low average sedimentation rate (3 cm/ky), and the sedimentary record might inherit strongly variable sedimentation rates or even phases of non-deposition or erosion. The total number of well-correlated laminated intervals is roughly equal to the total number of interglacial cycles that occurred during the last 1.1 Ma. The occurrence of laminated ooze reflects the interglacial times, which is consistent with the preliminary paleomagnetic age model.

Moderately to well-rounded and mixed volcaniclastic and metamorphic mineral or rock fragments in the sand encountered in Unit II indicates that the source is terrestrial. While the base of Unit I is dated to only 1.2 Ma, several Miocene diatom species were observed in Unit II. This suggests the following possible processes: extremely low sedimentation, a hiatus, or reworking by sediment gravity flows. The sandy material may be derived from the underlying volcanic basement.

The volcanic rock (basalt) of Unit III was most likely deposited as lava as indicated by the flow-alignment of the plagioclase laths and the vesicular texture. The volcaniclastic rocks beneath have a mafic volcanic source and contain both lava fragments and tephra fragments (scoria).

Biostratigraphy

Eighteen biostratigraphic datum events indicating a Late to Middle Quaternary sequence were identified based on radiolarians, diatoms, silicoflagellates and calcareous nannofossils. The sedimentation rate at the site is relatively low, 3 cm/ky, as implied by the age estimated for the bottom of Unit I based on biotstratigraphic markers, 1.2 Ma. The calcareous microfossils reflect a high latitude environment indicating variations of sea surface temperatures. The benthic foraminifera are generally reflecting environments within or near the oxygen minimum zone in high latitude regions. The preserved siliceous microfossils are mainly composed of high latitude pelagic species indicating changes to surface water productivity. Dinoflagellates consistently occur throughout the record with poor preservation in the lower part. The dinoflagellate assemblages show changes between low to high primary productivity together with general low sea surface temperatures and low seasonal sea ice coverage.

Both dinocyst assemblages and sea-ice diatoms suggest low seasonal sea-ice coverage. In general, dinocysts suggest high primary productivity, low sea surface temperature (SST) and seasonal sea-ice coverage. However, the co-dominance of the autotrophic *Operculodinium centrocarpum* and the heterotrophic *Brigantedinium* spp. at 20.96 m CSF-A in Hole U1342A could be associated with relatively low primary productivity and/or an incursion of oceanic/oligotrophic waters. There are planktic foraminifera present throughout the section from ~36 m CSF-A showing polar-subpolar conditions. Benthic foraminifers generally exhibit high abundances, and variation in species dominance is probably related to changes in oxygen levels and/or organic fluxes.

The uppermost one or two cores depending on holes are assigned to the calcareous nannoplankton Zone NN21 (Ma to the present), characterized by *Emiliania huxleyi*. Sample U1342A-3H-CC contains *P. lacunosa*, and is therefore assigned to the calcareous nannofossil Zone NN19 (>0.44 Ma). The planktic foraminifera are only present in the upper four cores in all the holes except for Hole U1342D where they also occur in Core U1342D-5H. The fauna is dominated by *Neogloboquadrina pachyderma* (sinistral) in all samples. Over 20 species of benthic foraminifers were recovered from this site.

Occasionally dominant species are *Cassidulina* sp. and *Uvigerina peregrina*. Persistently occurring species include *Brizalina pygmaea*, *Brizalina spathula*, *Bulimina* aff. *exilis*, *Globobulimina pacifica* and *Valvulineria* spp. This assemblage shows similarities to those at the top ~100 m CSF-A of Sites U1339, U1340 and U1341, and also those within or near the oxygen minimum zone in the Sea of Okhotsk. This assemblage does not appear to reflect shallow water (shelfal) deposition.

The LO of *Proboscia curvirostris* (0.3 Ma) is observed at the base of Cores U1342A-3H and U1342C-3H, which is consistent with Sites U1340 and U1341 also located on the Bowers Ridge. Due to poor diatom preservation below Core 5H at each hole the biostratigraphic zonation was constrained by one species: *P. curvirostris*, which places the *N. seminae* Zone 12 at 0-11.41 m CSF-A at Hole U1342A and 0-17.04 m CSF-A at Hole U1342C. Based on the observed silicoflagellate species, the age of the upper four cores at Holes U1342A and U1342D is probably Pleistocene. Cores U1342A-5H and below may possibly be older than 2.5 Ma with the occurrence of *Ebriopsis antiqua antiqua,* assuming it is not reworked.

Six radiolarian datums derived in the subarctic Pacific were identified at this site. These datums showed relatively low sedimentation rates (~5cm/ky) in the upper 20 m at each hole compared to the other Bowers Ridge Sites (U1340 and U1341). Although radiolarian datums are scarce in the lower intervals , the LO of *E. matuyamai* (0.9-1.5 Ma) was found at the base of Core U1342B-4H. This datum provides a constraint for the age estimation for the lower intervals and an average sedimentation rate at Hole U1342B of 2-4 cm/ky.

Poor preservation of organic-walled dinoflagellate cysts in the lower part of the sequence and particularly in the sandy layer suggests significant oxygen concentrations in the bottom water. The dinoflagellate assemblage composition is modern, suggesting Pleistocene age for all analyzed samples.

Paleomagnetism

The average inclination values are nearly 70° over the entire normal polarity intervals, which are close to the site axial dipole inclination (about 72°), indicating that we can effectively remove overprint magnetizaiton caused by drill pipes and/or core barrel from the NRM records. We defined a polarity zonation from the inclination record, and correlated the zonation to the polarity time scale based on micropaleontology datums. The Brunhes/Matuyama boundary and the base of the Jaramillo subchron are clearly identified through Holes U1342A, U1342C and U1342D. The top of the Jaramillo subchron and both of the top and base of the Cobb Mountain subchron are identified at Holes U1342C and U1342D, but not Hole U1342A. We also tentatively note the existence of three excursions, which are visible in all three holes: the Kamikatsura, Santa Rosa, and Punaruu excursions.

It is possible to see a correlatable pattern of relative paleointensity at the present site and Site U1341, as indicated by the relative numbering scheme within the Brunhes Chron (the last 780,000 years). However the relative paleointensity estimates are both still significantly influenced by lithological variability and should not be considered high-resolution estimates of true geomagnetic field intensity variations. We estimate that the fine-grained hemi-pelagic marine sediments were deposited over the last 1 Ma with essentially a constant sediment accumulation rate. Discrete intervals where both magnetic parameters undergo more than order-of-magnitude decreases indicate intervals of significant magnetic mineral dissolution. They appear to be closely related to the laminated sediment intervals and both are probably related to enhanced rates of reduction diagenesis during those selected time intervals. Our chronostratigraphic estimates suggest that these dissolved intervals (and the associated laminations) occur in the interglacial sediments. Note that there are a few narrow intervals of significantly stronger remanence, which we are due to authigenic greigite. It is interpreted that they always occur within the glacial stage sediments with lower porosity.

Stratigraphic Correlation

The composite depth scale and splice at Site U1342 is complete and continuous from 0.0 to 46.71 m CCSF-A. Sediment cores below the splice are included in the composite depth framework by appending them with a constant affine value of 2.783 m. Color reflectance data were examined, and the b* parameter is considered useful for correlation but L* and a* did not appear to correlate between holes. Within the splice, the composite CCSF-A depth scale is defined as the CCSF-D depth scale. Note that CCSF-D rigorously applies only to the spliced interval. Intervals outside the splice, although available with CCSF-A composite depth assignments, should not be expected to correlate precisely with fine-scale details within the splice or with other holes, because of normal variation in the relative spacing of features in different holes. Such apparent depth differences may reflect coring artifacts, or fine-scale variations in sediment accumulation and preservation at and below the sea floor. The cumulative offset between CSF-A and CCSF-D depth scales is approximately linear. The affine Growth Factor at Site U1342 is 1.06 between 0 and 44.0 m CSF-A. Calculation of mass accumulation rates based on the CCSF-A or CCSF-D scales should account for this affine growth factor, by dividing apparent depth intervals by the appropriate Growth Factor. After dividing by the growth factor this scaled depth scale should be referred to as CCSF-B.

Sedimentation Rates

The apparent sedimentation rate in the upper most section between the mudline and 3.6 m CCSF-A (marked by the LO of *Amphimelissa setosa*) was 5 cm/ky with relatively high water contents and hence it may not be significantly different from those of below it. The sedimentation rates stayed at fairly constant values of 2 to 3 cm/ky between 3.6 m CCSF-A and the magnetics Kamikatsura Excursion ca. 29 m CCSF-A, followed by an increasing trend up to 9 cm/ky down to the bottom of magnetics Cobb Mountain at ca. 43 m CCSF-A. The presence of the Miocene diatoms in lithological Unit II warrants further refinement of the age model.

Geochemistry

Interstitial water sulfate, dissolved inorganic carbon (DIC), PO_4^{3-} and NH_4^+ profiles indicate that sediments at Site U1342 are characterized by low rates of anaerobic carbon mineralization predominantely driven by organoclastic sulfate reduction. Additionally, small increases in Mn concentration might indicate microbial Mn reduction as a further mineralization pathway. It is more likely, however, that dissolved Mn is released during reaction of hydrogen sulfide with Fe/Mn-(oxyhydr)oxides. Comparison with Site U1341 also located on Bowers Ridge, reveals one order of magnitude lower NH_4^+ concentrations and approximately 50% less phosphate concentrations at the present site. This highlights the extremely low mineralization rates at Site U1342 despite its shallower depth and similar total organic carbon (TOC) concentrations at both sites. The low extent of anaerobic carbon mineralization at the present site can be attributed to the extremely low sedimentation rates. Very low sedimentation rates probably prolong the time that organic matter is degraded via oxic respiration and nitrate reduction in the oxic/suboxic sediment zone. This leaves rather refractory organic material which is only inefficiently degraded during anaerobic carbon mineralization.

Solid-phase data however suggests that the present-day geochemistry might only give a limited picture of past conditions. High TOC concentrations that correlate strongly with high TS concentrations in several laminated intervals discovered throughout the sediment column indicate events of high organic carbon input that probably resulted in high sulfate reduction rates during these periods and hence elevated hydrogen sulfide production which is reflected in high pyrite (TS) concentrations. However, the contents of $CaCO_3$ are not always high in the laminated layers.

Another interesting feature of Site U1342 is the inverse relationship of the (almost linear) calcium and magnesium profiles which give indication for the influence of signals linked to the alteration of the underlying basalt on the interstitial water calcium and magnesium concentrations. Most likely both profiles are the result of diffusion between the seawater and the relatively shallow basaltic basement. Low-temperature interactions of seawater with the basaltic basement e.g. the dissolution of basaltic glass, calcic plagioclase, and

olivine result in the liberation of calcium while the precipitation of smectite leads to the consumption of magnesium.

Microbiology

Samples for abundance of prokaryotes were collected adjacent to interstitial water whole-rounds in sections cored using APC. High resolution sampling took place in the microbiological dedicated cores from Hole U1342B as well as additional samples taken once per core to APC refusal at Hole U1342A. These additional samples were taken to evaluate cell abundance and community structure in the deepest portion of Site U1342. PFT analyses performed on these cores show no contamination from the drill fluid. Samples from all cores were fixed. These analyses will assist with understanding the global distribution and abundance of subseafloor life in a highly productive oceanic regime. A special focus will be directed toward the function of Archaea in the sulfate reduction zone, the sulfate methane transmission zone and the methanogenesis zone.

Physical Properties

The downhole decreasing trend of magnetic susceptibility (MS) ranges from a near-surface value of ~100 units to about half this value at ~ 35 m CSF-A, which is the base of Lithostratigraphic Unit I. Below this depth MS readings in Unit II increase in steps to as high as 400 units at 40 m CSF-A. The higher values in Unit II likely track the downward increasing abundance of sandy material derived from the underlying volcanic basement, which was wave-based leveled sometime in the early late Miocene. In Hole U1342D, at a depth of ~73-74 m CSF-A (29-30 m below the sediment-basement contact), MS values are much higher, with an average of ~1500 units, and decrease deeper in the section to about 750 units at a depth of ~116-117 m CSF-A (~72-73 into basement).

A prominent downhole profile of increasing average wet bulk density is noted. The higher gradient of the lower trend is within the sandy sediment of Unit II, which is presumably granular material derived during the wave-beveling, final stage of destruction of a stratavolcano that formerly rose above Ulm plateau. P-wave velocity increases downhole from near-surface readings of just over 1.45 km/s to a ~1.55 km/s in Unit II

near the contact with basement rock at ~45 m CSF-A. In the sandy sediment of the Unit II at Hole U1342D, P-wave velocity increased to ~1.65 km/s and somewhat higher.

Natural Gamma Radiation (NGR) readings increase irregularly downhole from a near-surface average of ~18 to ~24 counts/s at the base of Unit I. The gradient of increasing counts/s continues within the sandy beds of Unit II to reach ~33 counts/s just above basement contact at ~44 m CSF-A. Presumably, the elevated NGR readings record a downhole increase in clay minerals, and at least within Unit II, clay minerals derived from the underlying bedrock of arc lava and volcaniclastic deposits. Rock clasts recovered in core sections exhibit evidence of oxidation. Presumably clay minerals accounting for the higher readings in the basal sediment of Unit II reflect subaerial weathering of the stratavolcano that formerly towered above Ulm plateau prior to its early late Miocene destruction.

In general moisture and density (MAD) values of discrete samples track those of Gamma ray attenuation (GRA) but with a much greater spacing of measurements. The contrast between Unit I and the denser Unit II sediment is nonetheless well shown by the MAD data. The near-surface porosity is ~80% but decreases to ~55 % in the sandy sediment of Unit II and just above basement at 44 m CSF-A. The downward trend of overall decreasing porosity and water content presumably reflect compaction of the section with notable excursions to higher values in the basal 10-12 m of Unit I that may identify a higher relative content of siliceous microfossils. The relatively elevated grain density in Unit I in comparison to the upper beds of Site U1341 on the deeper flank of Bowers Ridge can be attributed to the availability of nearby bedrock sources for Site U1342 deposits.

Downhole Measurements

The measured temperatures employing the APCT-3 tool in Hole U1342C were 4.46 °C at 26.2 m DSF and 5.32 °C at 35.0 m DSF. From these two measurements, the geothermal gradient should be 97.7 °C/km. The estimated heat flow is 96.9 m W/m^2, significantly higher than existing measurements in the area. Alternately, considering the variations in

thermal conductivity with depth, a more accurate measure of the heat flow in a conductive regime can be given by a “Bullard” plot, which gives a heat flow value of 80.9 m W/m^2, closer to the other measurements in the Bowers Ridge area.