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IODP Expedition 323:
Pliocene-Pleistocene paleoceanography and climate history of the Bering Sea

Site U1339 Summary

30 July 2009

Background and objectives

The primary objective of drilling this site was to study high-resolution paleoceanography in the easternmost part of Bering Sea, a marginal sea that is expected to exhibit large variations during times of global climate change. The Umnak Plateau is located off Bristol Bay and it is well situated to study past changes in surface water conditions, and in sea ice extent and associated biological productivity. Today, parts of the relatively warm Alaskan Stream surface water flows into the Bering Sea through Unmak and Amukta Passes and hence sea-ice is not formed in this region. However, during the Last Glacial Maximum (LGM) when sea-level was ~100 m lower than today, substantial sea-ice coverage has been noted indicated that the influence of relatively warm water from the distal end of the Alaskan Stream was reduced. This may have been due to the fact that water entering the Bering Sea from the Pacific Ocean through the Unimak and Amukta Passes was at least partially restricted when sea level dropped; the warm Pacific water could have more easily passed through the deeper passes located in the central and western Aleutians such as Amchitka Strait. Thus, monitoring past environmental condition at the Umnak Plateau can provide an understanding of the impact of changes in water exchange between the Pacific and Bering Sea waters. Since these eastern passes are fairly shallow (~50 m and 430 m) little intermediate or deep water flows out to the Pacific in this region. As such, records from the Umnak Plateau should provide us with different information than the western sites which are closer to deep passes where surface water flow may not have been strongly inhibited by sea level changes, and where dense water exchange with the Pacific Ocean is more likely to occur. To make this west-east comparison, records from the drill site on the Umnak Plateau (U1339) can be compared to those of the planned drill site at a similar water depth, BOW-14B (planned IODP site U1341, w.d. = 2177 m).

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The drill site at the Umnak Plateau 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, Umnak Plateau drilled sediments 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.

According to the results from DSDP Leg 19, Pleistocene diatomaceous sediments with ash layers were found in the top 120 m at DSDP Sites 184 and 185, both drilled at the Umnak Plateau, followed by Pliocene diatomaceous sediments below. Sedimentation rates are approximately 67 m/m.y. They also indicated that the diatomaceous sediments have neritic components, probably influenced from the Bristol Bay region. A piston core study from the same general region provided the sedimentation rate of 262 m/m.y. Thus, prior to drilling, the predicted ages for the bottom of U1339, at ~200 m, ranged from the mid-Pleistocene to the Pliocene.

Operations

We arrived at Site U1339 (Site UMK-4D in the Scientific Prospectus) early on 16 July 2009 after a 6.5 day, 1782 nm transit from Victoria, Canada and operations officially began.

A total of four holes were drilled at Site U1339 employing APC at a water depth of 1867 m on the Umnak Plateau, with the deepest Hole U1339D reaching a maximum depth of 200 m DSF. One relatively shallow and three relatively deep holes were drilled and cored as follows. Hole U1339A was cored to 34 m DSF. Three holes were cored to the following depths: Holes U1339B (196 m DSF), U1339C (195 m DSF), and U1339D (200 n DSF). The first 4 cores of Hole B (U1339B-1H to 4H) were primarily used for the subseafloor microbial study with both PFTs and whirl packs deployed. The remainders of the cores were used for paleoceanographic studies. Most of the cores had nearly 100% or

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greater due to gas expansion except for two incidents: two short cores (U1339B-13H, 2 m; U1339C-16H, 4.5 m) were recovered when the APC fired into an unknown object, most likely a glacial drop stone.

Hole U1339A

Hole U1339A was spudded at 0430 hours on 17 July 2009. The first core was shot with the bit at 1873 m DRF and recovered the mud line and 4.94 m of core. The hole was terminated after Core U1339A-4H with a suspected Bottom Hole Assembly (BHA)/coring system problem resulting in almost 100,000 lbs of overpull on the last core. The drill string was tripped out of the hole, the coring system components were inspected and several parts were changed. There was no conclusive evidence found for the mechanical problem encountered. The BHA was run and the coring system was tested successfully in the water column.

Hole U1339B

The vessel was offset 20 m and the rest of the string was then tripped to the seafloor and Hole U1339B was spudded at 2315 hours on 17 July 2009. The first 4 cores (U1339B-1H to 4H) were dedicated to microbiology with both PFTs and whirl packs deployed. The remainder of Hole U1339B recovered the sedimentary sequence from the total depth of Hole U1339A down to 196 m DSF with one short core (U1339B-13H) when the APC fired into an unknown object, most likely a glacial drop stone. The non-magnetic core barrel was switched to a steel core barrel when the resistance became exceedingly high at Core U1339B-19H. Hole U1339B was cored to a depth of 196 m DSF, and coring ended at 2010 hours on 18 July 2009 when the bit cleared the seafloor.

Hole U1339C

The vessel was offset 28 m and Hole U1339C was spudded at 2230 hours on 18 July 2009. The first core was over 9.5 m long, but contained the mudline at its top. Core advance was a continuous 9.5 m except from Core 16H, which contacted an apparent drop stone at 4.5 m. The non-magnetic core barrel was used through U1339C-17H, and APC coring proceeded with a steel core barrel through Core U1339C-21H to a depth of

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195.8 m DSF. The drill string cleared the seafloor at 1610 hours on 19 July 2009, officially ending Hole U1339C.

Hole U1339D

The vessel was offset 28 m and U1339D was spudded at 1724 hours on 19 July 2009. Core U1339D-1H was 6.6 m long. All cores taken below the first one was 9.5 m long, with the exception of one that was short due to premature firing of the APC. The non-magnetic core barrel was used through U1339D-17H, and APC coring proceeded with a steel core barrel through Core U1339D-22H to a depth of 200.0 m DSF. Rig-up for wireline logging in Hole U1339D started at 1130 hr on 20 July 2009. The triple combo and FMS-sonic tool were deployed; both obtained good data. The drill string was pulled and secured for transit. Transit to Site U1340 (BOW-12B) began at 0745 hours on 21 July 2009.

In all, APC coring for Site U1339 totaled 69 cores, 642.2 m penetrated, 643.67 m recovered, for 103.1% recovery.

Litholostratigraphy

The sediments recovered at Site U1339 are the result of the mixture of three components: biogenic, volcaniclastic, and siliciclastic. Other accessory lithologies identified include authigenic dolomite and pyrite. In general, the color of the sediment reflects their lithologic characteristics. Sediment composed of mixed lithologies of diatom silt or diatom ashy silt is dark greenish gray while diatom ooze is olive gray to olive. Most of the volcaniclastic ash layers are black. Only one lithologic unit spanning the Pleistocene was defined and it was further subdivided in six subunits. The largest-scale sedimentary features are decimeter- to meter-scaled bedded alternations of sediment color and texture, reflecting alternations in lithology. Well-preserved lamination caused by alternating millimeter-scaled dark and light laminae, was mainly observed in five distinct intervals, each ranging from 10 and 40 cm in thickness. Laminated intervals seem mainly associated with ash layers and occur either below or above them. Distinct volcaniclastic layers from few mm to 10 cm thickness occur throughout the unit. Some black

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volcaniclastic layers are also characterized by graded bedding, indicating re-deposition by gravity flows.

The major component is biogenic and predominantly composed of diatoms with generally good preservation. Diatom frustules hosting pyrite framboids are also observed. Both benthic and planktonic foraminifers are observed, although their abundance level was low. Thin laminae dominated by foraminifer tests are observed with dominance of benthic foraminifera *Bulimina* sp., characteristic of low oxygen content. Calcareous nannofossils, radiolarians and sponge spicules are rare. Terrigenous grain, a common component in the sediments, are silt-sized quartz and feldspar, clay, mica and rock fragments. Gravel- to pebble-sized, rounded to angular clasts are interpreted as dropstones delivered by melting sea-ice or icebergs. Some pebbles are composed of pumice or obsidian, suggesting a volcanic source. Authigenic dolomite was found in five distinctive intervals, mostly in the upper and lower part of the sedimentary record. It occurs either as dolomite rhombohedra scattered in the sediment, or as (semi-) lithified layers of 5-10 cm thickness. Depth variations of the color reflectance (CR) parameters a* and b*, of the gamma-ray attenuation porosity (GRA) and of magnetic susceptibility (MS) were compared to the lithologic variations. Overall, these four parameters show distinct short-term variability and longer-term trends that can be correlated to lithologic variations at both short- and long term scales. The depth variations of the CR parameter b*, which reflects the yellowness of the sediment, show a remarkable negative correlation with the GRA data, with lower b* values corresponding to denser, more siliciclastic-rich sediments. The color reflectance value a* is tentatively correlated to the concentration of diatom ooze. Changes of MS with depth mainly reflect the volcaniclastic content, and a very good correlation exists between the thickest volcanic ash layers and the highest MS excursions.

Micropaleontology

Constant presence and relatively high abundance of siliceous microfossil groups were found throughout the sections at this site compared to those of calcareous counterparts. All of age determinations have been achieved with the siliceous microfossil groups.

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Diatoms provided two important last occurrence datums of *Thalassiosira jouseae* (0.31 Ma) and *Proboscia curvirostris* (0.28 Ma) in the middle section of the four holes that were studied. The most important datum were derived by studying silicoflagellates despite that their abundances were generally “trace” to “few” in many samples with rare instances of “common” category. They are the first occurrence (FO) *Distephanus octangulatus* (0.741 Ma) and the last occurrence (LO) of *Dictyocha subarctios* (0.736 Ma), respectively. These two datums are considered to occur above the Brunhes/Matuyama boundary (0.781 Ma). With the absence of definite paleomagnetic datum of the Brunhes/Matuyama boundary as to where it is located, the silicoflagellate datums serve only the reliable ones at this time. The LO of *Distephanus octonarius* (0.244 Ma), another silicoflagellat datum, provided harmonious age information concordance with those of diatoms and radiolarians. Despite of their relatively low abaundances due to massive occurrences of diatoms in bulk of samples. radiolarians provided five pertinent datums spanning from near the top through the middle part of the drilled sections. They are *Lychnocanomma nipponica sakaii* (50 ka); *Amphimelissa setosa* (80-100 ka); *Spongodiscus* sp. in Ling (1973) (0.28-0.32 Ma); *Axoprunum acquilonium* (0.25-0.43 Ma); and *Stylatractus universus* (0.41-51 Ma).

Due to proximity to the Bering Shelf of this site, in particular during the glacial low stand, coastal water diatoms including *Chaetoceros* spores and freshwater diatoms were observed. Furthermore, the relative abundances of ubiquitous *Neodenticula seminae,* an indicator species of the Alaskan Stream, fluctuated throughout the sections, indicating the change in the Pacific water entry into the Bering Sea. The extent of sea-ice associated diatoms also fluctuated throughout.

Calcareous nannofossils were either barren or sparse throughout the sections. Reworked specimens of calcareous nannofossils were found in the upper section indicating the transport by ice rafted debris or other processes. Planktic foraminifers were present in almost all samples except for a few samples. Both Planktic and benthic oraminifers appear to be abundant enough to proceed with further detailed studies such as oxygen and carbon isotopic analyses. Abundant benthic calcareous foraminifers with general low

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diversity showed close affinities to those recorded in recent sediments within or near the oxygen minimum zone in the Okhotsk Sea. The exceptionally high productivity in surface waters acted to greatly expand the oxygen minimum zone.

Dinoflagellate assemblages were moderate to abundant with relatively low species diversity. They showed heterotrophic protoperidinial dinoflagellates feeding on diatoms. Such assemblages can be related to the extremely high diatom production. In the upper section, a taxon indicative of the North Water Polynia condition has been noted, implying significant sea-ice formation.

Paleomagnetism

Paleomagnetic analyses indicate that all sediments are likely from the Brunhes Chron (0-780,000 y). However, anomalous NRM intensities along with low or negative inclinations in the same intervals may be due to authigenic growth of greigite related to sulfate reduction or methanogenesis. As such, it is possible that the Brunhes/Matuyama boundary was reached at about 180 mbsf, but that the reversal in polar intensity was obscured by the presence of greigite. At this time, it is difficult to say which hypothesis is more likely.

Stratigraphic Correlation

Three holes, dedicated to paleoceanographic studies, were drilled at this site. Cores were drilled at offset depths in order to obtain a continuous sedimentary section. By comparing Fast Track Gamma Attenuation Density (GRA) and Magnetic Susceptibility (MS) variations, the cores from different holes can be placed into a continuous stratigraphic framework. A continuous record mainly using Holes U1339C and U1339D was constructed by splicing together the GRA and MS records; this splice will serve to guide the post-cruise sampling strategy designed to generate continuous paleoceanographic records without gaps. The splice at Site U1339 is continuous from the mudline to approximately 200 CSF-A.

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Geochemistry

Interstitial water samples were taken at Hole U1339A at low resolution from 0–200 m (CSF-A) and at high resolution at Hole U1339B were analyzed for chlorinity, salinity, alkalinity, dissolved inorganic carbon (DIC), pH, sulfate, hydrogen sulfate, ammonium, phosphate, silica, Ca, Mg, Na, K, Fe, Mn, B and Sr. In addition, methane and ethane were analyzed. The analyses show that the sulfate–methane transition zone at present is at 8–10 m CSF-A. Methane is detectable throughout, and at approximately 10 m CSF-A, where sulfate is depleted, methane concentrations increase dramatically. Notably, alkalinity increases from 3 to 30 mM in the top 10 m, reaching a maximum at ~120 m CSF-A. Solid-phase analyses show that calcium carbonate content range from 0 to 13.3 wt% (average = 2.1 wt%) and total organic carbon is 0.47 to 1.83 wt% (average = 0.98 wt%).

Physical Properties

Whole round measurements of Magnetic Susceptibility (MS) and Gamma Ray Attenuation bulk density (GRA) using the FastTrack, and of MS, GRA, P-wave velocity (PWV) using the WRMSL track were made on each core recovered at Site U1339. One thermal conductivity (Tcon) measurement per core was also analyzed. Discrete samples of cores from Holes U1339A and U1339B were taken to analyze for moisture, density, porosity, water content and grain density. MS varied downcore, with the highest peaks likely related to volcanic ash layers, and cyclical variations likely due to varying amounts of siliciclastics versus diatoms. Such variations in lithology likely contributed to the variations in GRA bulk density and discrete bulk density measurements, which indicate cyclical variations from 1.6 to 1.3 g/cm^3. Porosity, water content, and grain density measurements exhibit an oscillating cyclicity similar to the wet bulk density record. They are likely tracking variations in the concentration of biogenic debris, in particular highly-porous, diatom frustules, with respect to lower porosity terrigenous sediment with higher grain density. Discrete bulk density measurements increase gradually with depth at a rate of ~0.1 g/cm^3/100 m most likely because of sediment compaction. Compaction likely explains the decrease in porosity downhole from a near-surface value of ~85% to ~65% at a depth near 200 m CSF-A.

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NGR counts/sec varied rhythmically from high counts/sec of 25 to 40 to low counts of about 10, evidently tracking clay-mineral bearing sediment in contrast to sediments with more biogenics. Because the PWV measurements were seriously degraded by gas expansion, the P-wave logger was turned off for all core sections deeper than ~33 m CSF-A. Tcon values ranged widely, from a low of ~0.5 W/m/K to greater than 1 W/m/K, with lower values presumably reflecting water-rich diatomaceous sections and higher values reflecting abundant terrigenous debris.

Electrical conductivity to determine formation factor was measured every 10 cm in the working half of the first core of Hole U1339A, then every 20 cm in cores two and three. Sediment conductivity ranges from 1.37 to 3.70 µS/cm. The highest values were recorded in ash layers and formation factor generally increased downhole.

Downhole Measurements

Employing the deployed triple combo and the FMS-sonic combination, the data recorded below the bottom of the pipe depth. They indicate good hole conditions and only minor excursions from the nominal size of the drill bit. The comparison of the gamma ray and density logs with the NGR and GRA track measurements on cores recovered and with moisture and density (MAD) measurements show good agreement, which should allow for reliable core–log integration. All logs were referenced to the seafloor depth of 1875 m WRF identified during the last pass of the FMS-sonic tool string. Comparison of the gamma ray logs measured during the main pass of the two runs shows an excellent repeatability between the two runs. The resistivity values measured by the electrode SFLU measurement were lower than those recorded by induction measurements, probably because of current loss at the electrodes. The higher induction resistivities are closer to values typically measured in deep-sea sediments.

The display of the high coherence in sonic waveforms used to derive the compressional velocity suggest that despite the closeness of the formation velocity to the sound velocity in the borehole fluid (~1500 m/h), the dipole sonic imager (DSI) was able to capture

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compressional wave arrivals and measure a reliable V_p profile over the entire open interval logged. Additional postcruise processing will however be necessary to derive V_s logs from the recorded dipole waveforms.

The downhole log measurements of bulk density, porosity and electrical resistivity correlate very well. Variations in sediment composition result in variations of porosity that affect bulk density and resistivity in a similar manner. The measurements also correlate significantly with the gamma ray logs as a result of the overall uniform mineral matrix of the sediments in the interval logged. In particular the parallel decrease with depth in gamma ray, density and resistivity from 86 to 102 m WMSF is typical of a retrograding fining upward sequence.

The downhole variations of gamma ray radioactivity are controlled by the sediment content of naturally occurring radioactive elements (K, U, and Th). The computed gamma ray, or gamma ray without uranium, is a more accurate measure of the clay content than the total gamma ray which can be influenced by such factors as organic matter or detrital minerals. The most significant feature in the gamma ray logs is the increase at ~142 m WMSF, associated with an increase in its three radioactive components and a peak in uranium. It coincides with the transition from lithological Subunits ID to IE (Diatom Ooze and Diatom fine ash to Diatom Ooze). The peak in uranium can be related to the occurrence of dolostones observed in the cores in this interval.

The downhole APCT-3 temperature measurements show a range of 3.65°C at 23.0 m DSF to 12.83°C at 158.0 m DSF, and fit closely a linear geothermal gradient of 68.0°C/km. The temperature at the seafloor was 2.1°C, based on the average of the measurements at the mudline during all the APCT-3 deployments. The obtained heat flow, from the product of the geothermal gradient by the average thermal conductivity (0.80 W/m°C), gives a value of 54.4 mW/m^2, within the range of previous measurement in the area.