IODP Expedition 317: Canterbury Basin Sea Level

Site U1351 Site Summary

6 December 2009

Hole U1351A
Position: 44° 53.0307' S, 171° 50.4037' E
Water Depth: 122.3 m (based on mudline recovered with APC)
Penetration Depth: 28.0 m DSF
Recovered Core: 27.3 m (98%)
Time on Hole: 18 November, 0931 h through 2330 h

Hole U1351B
Position: 44° 53.0422' S, 171° 50.4065' E (20m south from Hole U1351A)
Water depth: 121.7 m (based on mudline recovered with APC)
Penetration Depth: 1030.6 m DSF
Recovered Core: 304.5 m (30%)
Time on Hole: 18 November, 2330 h through 25 November, 1800 h

Hole U1351C
Position: 44° 53.0572' S, 171° 50.4057' E (30m South from Hole U1351B)
Water Depth: 121.7 m (estimated by offset)
Penetration Depth: 967.3 m DSF
Recovered Core: N/A
Time on Hole: 25 November 1800 h through 30 November 0200 h

Background

Site U1351 is located on the outer shelf and is the most basinward shelf site of the Canterbury Basin drilling transect. Site U1351 penetrates seismic sequence boundaries U6 to U19. Upper Miocene-lower Pliocene sequence boundaries (below U9) feature smooth, onlapped paleoshelves and rounded clinoform breaks, or rollovers, with sigmoid internal reflection geometries. In contrast, upper Pliocene-Pleistocene sequence boundaries (above U9) display eroded and incised, downlapped paleoshelves and more pronounced breaks with oblique reflection geometries. U8 to U19 are penetrated on their paleoshelves whereas U6 and U7 are penetrated on their paleoslopes.

Operations

After a one-day transit from Wellington, NZ, covering 257 nm at an average speed of 11.4 knots, the vessel was positioned over Site U1351 (proposed site CB-03B) on 18 November at 0930 h (UTC+13h). Three holes were drilled at this site: two holes with the APC/XCB coring systems, and the third hole was drilled with a 9-7/8" tri-cone bit for logging purposes. Logging was attempted with partial success in Holes U1351B and U1351C.

Hole U1351A was a shallow hole (Cores U1351A-1H through 6H; 0-28 m DSF; 98% recovery) dedicated to whole-round sampling for microbiology, geochemistry, and geotechnical studies. All cores after Core U1351A-2H were partial stroke cores indicating very firm near-surface sediments.

Hole U1351B was offset 20 m south of Hole U1351A. The hole was APC cored to a depth of 94.7 m with a total recovery of 81.1 m (81% recovery). The XCB system was deployed for the next 42 cores (U1351B-14X through U1351B-56X; 30% recovery), and for most of the other cores to total depth. Poor core recovery led to a number of intermittent attempts with the APC system (Cores U1351B-57H through 59H; Cores U1351B-65H, 78H and 85H) but only short cores were recovered in these attempts. Coring was terminated with Core U1351B-116X at a total depth of 1030.6 m DSF, after the XCB core barrel became stuck inside the BHA and was freed only after a few hours of effort. Average recovery rates in Hole U1351B were 84% for the APC system, 23% for the XCB system and 30% for the entire hole.

After the core barrel was freed, the hole was cleaned and displaced with mud in preparation for logging. The triple combo tool string was run from total depth to the bottom of the pipe at ~80 m DSF and revealed a hole that was oversized over most of its length. Next, the FMS-sonic tool was rigged up and deployed. The tool failed to pass 618 m WRF, indicating that the hole collapsed and bridged near that depth. The hole was logged from that point upwards. A 12-barrel cement plug was pumped as per IODP policies for drilling on a continental shelf, with the string at 283 m DSF.

Hole U1351C was offset 30 meters south from Hole U1351B. The hole was drilled to 1100 m DRF with a 9-7/8" tri-cone bit fitted with a mechanical bit release. At 1915 h on 27 November, while sweeping the hole clean with mud in preparation for logging, a sudden wind change forced the vessel outside the maximum positioning offset (8% of water depth, or ~10 m). The vessel lost power to three of the six forward thrusters while trying to respond to the sudden shift. Position and power were re-established within 15 minutes. The maximum excursion from the hole was 38 m. With all drilling parameters still normal, Hole U1351C was displaced with logging mud in preparation for logging. The section of drill string located at the seabed during the excursion was inspected after it was recovered at the surface and no damage to the drill string was visible.

The triple combo logging string was assembled and run into Hole U1351C. With the tool at ~912 m WSF, the winch lost weight, indicating that the logging wire was gripped by the formation above the tool. At that point the tool could not be moved either up or down. The logging tools were recovered after a 36-h effort of tripping pipe over the wire line from 80 m DRF all the way to 708 m DRF. The tools were pulled up into the drill string and the logging line was pulled up onto the rig floor. The hole was cemented with the drill string at ~285 m DRS.

Contamination testing for microbiology was done in all six cores in Hole U1351A and at regular intervals, approximately every 50 m, throughout Hole U1351B. Both per-fluoro-methyl-cyclohexane (PFT) and microspheres were deployed. Temperature measurements were taken with Cores U1351A-4H, 10H and 12H using the APCT3 tool, and below Cores U1351B-16X and 42X using the SET tool, with mostly poor results, probably due to sandy fall-in at the bottom of the hole. Core orientation was measured on the first five cores of Hole U1351B; poor APC coring conditions forced the tool to be removed.

Lithostratigraphy

Stratigraphic changes at Site U1351 on the Canterbury Margin are fairly gradual reflecting progressive differences in sedimentary styles. Two units were differentiated based on transitional sedimentary facies. Unit I (0-262 m CSF) is heterolithic, mainly dark gray to greenish/olive gray in color, comprising mud and sandy mud with lesser shell hash, sand, and muddy sand. In contrast, Unit II (262-1024 m CSF) comprises mainly dark greenish gray to greenish black sandy mud (sandy mudstone) and muddy sand (muddy sandstone), with lesser sand (sandstone) and shell hash (limestone).

Unit I lithologies can be bounded by abrupt to gradational bedding planes including distinct unconformities, locally bioturbated. Fining- and coarsening-upward beds, lamination, convolute bedding, and carbonate concretions are rare. The diverse assemblage of bioclasts/macrofossils are locally concentrated (shell hash), but generally dispersed in the core and become less common with depth. Coarse shelly beds on the boundaries are covered by fining-upward sandy mud and are followed by coarsening upward lithologies. The arrangement of lithologies in Unit I are characteristic of eustatically-influenced shelf successions. Tentatively, eleven candidate erosion surfaces (E1-E11) were identified. The upper nine generally have sharp basal contacts, are commonly bioturbated, and separate coarse lithologies from underlying muds.

Unit II is generally structureless, becoming more lithified with depth owing to carbonate cementation as expressed in short pieces of sandy mudstone in the XCB core catcher. Recovery in Unit II was poor, but contrasts across lithological boundaries appear more gradational downcore from shelly to sandy to calcareous muds. Mineralogy suggests southerly schist rather than more local graywacke provenance, perhaps reinforcing the importance of northeastward-flowing currents during deposition. Alternatively, the schist detritus may be recycled from more local, uplifted and eroded units onshore. The uppermost part of Unit II represents the transition from a shelf to slope environment. Below ~300 m CSF the sediments indicate deposition in an upper slope environment, with some intervals possibly influenced by drift deposition.

Biostratigraphy

The biostratigraphy of Site U1351 is based on the shipboard study of calcareous nannofossils, diatoms, and planktic and benthic foraminifers in core-catcher samples from Holes U1351A and U1351B. Additional calcareous nannofossil samples were taken from within selected cores to address specific age and paleoenvironmental questions. All microfossils groups are present throughout the cored Pleistocene to late Miocene section, except for diatoms, which are only present in a few samples.

The Pleistocene section between Cores U1351-1H and 18X (0-141.6 m CSF) was primarily dated and subdivided with calcareous nannofossils into zones NN21 (Cores U1351B-1H to 5H), NN20 (Cores U1351B-6H to 10H), and NN19 (Cores U1351B-11H through 18X). Benthic foraminifers suggest water depths are variable through the Pleistocene, but generally deepen downcore, from inner middle shelf depths to middle to outer shelf depths. The Pliocene section between Cores U1351B-19X and 94X (151.2-822.3 m CSF) was primarily dated with calcareous nannofossils in the upper part and planktic foraminifers in the lower part. Reworked calcareous nannofossils of Miocene age occur through the lower part of the Pliocene. This was close to the level where the first consistently outer-shelf to uppermost bathyal water depths were recorded, the upper part of the Pliocene being shallower. The Miocene section between Cores U1351B-95X and 116X (831.80-1030.6 m CSF) was primarily dated with planktic foraminifers. The lowermost part of the Miocene section between Cores U1351B-113X-CC and 114X is cut by a major unconformity, provisionally correlated with the U5 sequence boundary in the seismic interpretation. Planktic foraminifers and calcareous nannofossils suggest a hiatus of at least 3.4 m.y. Outer shelf to uppermost bathyal water depths persisted through the cored Miocene section. The age at the bottom of the Hole U1351B was late Miocene (10.60-10.91 Ma).

Paleomagnetism

Natural remanent magnetization (NRM) was measured on all but the most heavily disturbed cores. Intensities generally range from 10^{-2} to 10^{-4} A/m with some higher intensity zones, particularly at core tops, attributed to material that had fallen into the cores. NRM orientations tend to show steep (~80°), positive inclinations and declinations clustered in the northern hemisphere. Alternating field demagnetization was applied at 10 and 20 mT steps and removed approximately 30% of the NRM. Where magnetic core barrels had been used (in XCB coring from 94.7 m DSF), orientations changed very little with demagnetization. In contrast, where non-magnetic core barrels were used with APC coring at shallower depths, orientations of NRM did change with demagnetization. In the upper 65 m CSF of Hole U1351B, inclinations after 20 mT were negative and inclined at ~70°, suggesting a normal characteristic component. Between 65 and 94 m CSF core recovery decreased, and when material was available, inclinations shallowed with demagnetization but remained positive, suggesting that the first polarity change occurs between 65.9 m and 69.7 m CSF. Poor core recovery and a strong drilling overprint at greater depths limited further magnetostratigraphic interpretations.

Physical Properties

Systematic whole-round and/or section-half measurements of magnetic susceptibility, natural gamma radiation, gamma-ray attenuation density and colorimetry revealed patterns of sedimentation characterized by well-defined cyclicity in the upper 280 m CSF. At greater depths, these patterns seem to be missing, but this may be the result of poor core recovery because downhole logging suggests that lower-amplitude cycles may persist to at least 400 m. Discrete sample analyses of shear strength, thermal conductivity and index properties revealed interesting trends. The observed shear strength generally reflects the cyclicity seen in other parameters in the upper 250 m CSF. Additionally, abrupt changes or offsets in both magnetic susceptibility and shear strength suggest the presence of unconformities. A gradual increase in bulk density with depth was matched by a similarly subtle decrease in porosity from an average of about 45% at the surface to about 37% at 1000 m CSF. Thermal conductivity variations seemed to follow these trends.

Geochemistry

High frequency sampling established the midpoint of the sulfate-methane transition (SMT) at a depth of 16 m CSF, based on the dissolved sulfate and methane gradients. The maximum alkalinity at the SMT was 10 mM, with marked cation depletions of 15 mM for Mg^{2+} and 5 mM for Ca^{2+}. The apparent levels of carbon oxidized and low levels of ammonium and phosphate generated suggest that sulfate reduction is fueled primarily by anaerobic oxidation of methane. The initial gas present beneath the SMT contained ethane at relatively high levels (C_1/C_2 = 500-800), but absolute gas contents were low (15,000-20,000 ppm C_1 in headspace or 1-2 mM in pore space). This suggests preferential loss of methane, possibly when the shelf at Site U1351 was emergent due to anaerobic oxidation of methane, or by gas loss from sands during core recovery and sampling. The gas did not show any major deviations from established trends at greater depths down to 1000 m CSF. The pore waters in the uppermost 250 m CSF have moderately elevated salinity, Cl^-, and Na^+ (about 10% greater than seawater). Ca^{2+} increases from 15 to 35 mM, while Mg^{2+} decreases from 30 to 20 mM over the interval between 200-250 m CSF. There are also marked differences in the sediment geochemistry, with higher carbonate, higher nitrogen, and lower sulfur above 200 m CSF. Organic carbon contents range from 0.3 to 1.5%, with more of the higher values in the uppermost 200 m CSF. Pyrolysis characterization suggests the organic matter is dominated by degraded higher plant debris.

Heat Flow

Only one out of five temperature measurements taken at this site was of acceptable quality based on their conductive cooling curve over >300 sec. Using all five temperature measurements yields a poorly fit geothermal gradient of 14.1 $°C \cdot km^{-1}$, much lower than that obtained from Clipper-1 of 40-50 $°C \cdot km^{-1}$ (Reyes, 2007) and almost certainly in error. Thermal conductivity measured in laboratory was corrected to in-situ conditions. The resulting values increase linearly with depth. Use of a Bullard plot yields a heat flow of 20.1 $mW \cdot m^{-2}$. However, as with the estimated geothermal gradient, heat flow values are suspect because of insufficient reliable temperature measurements.

Downhole Logging

Downhole logging took place in Holes U1351B and U1351C. Two tool strings were deployed in Hole U1351B: (1) The “triple combo”, measuring natural gamma ray, bulk density, porosity and electrical resistivity, was run from the seafloor to 1032 m (WSF: wireline depth below seafloor); and (2) the FMS-sonic tool string, measuring electrical resistivity images and sonic velocities, could not reach the total depth of the hole and acquired data from 74 to 488 m WSF. In Hole U1351C, only the triple combo was deployed, recording gamma ray and resistivity during its descent between the seafloor and 801 m (WSF). The tool was trapped by hole collapse, preventing logging of the deeper section of Hole 1351C. The complete toolstring was later recovered after a 36-hour recovery effort.

Three logging units were identified in the logs. Logging Unit 1 (83-260 m WSF) is characterized by relatively high-amplitude variations in gamma ray values, overall increasing with depth. In this unit, gamma-ray minima associated with high resistivity and sonic velocities are consistent with sand layers alternating with clay. Logging Unit 2 (260-510 m WSF) is defined by low-amplitude variability in all logs and trends of decreasing gamma ray and resistivity. Three distinct intervals of increasing upwards gamma ray within this unit suggest fining-up, transgressive sequences. Caliper readings consistently higher than 19.5 inches in Units 1 and 2 show that the formation has little cohesion. The top of Logging Unit 3 (510-1032 m WSF) is defined by a significant downhole increase in gamma ray, density and resistivity, which remain variable with no distinct trends within this unit. The borehole diameter is slightly smaller (12-18 inches), but irregular, suggesting a change to more cohesive sediments.