IODP Expedition 317: Canterbury Basin Sea Level

Site U1352 Site Summary

25 December 2009

Hole U1352A
Position: 44° 56.2440’ S, 172° 1.3615’ E
Water Depth: 343.8 m (based on mudline recovered with APC)
Penetration Depth: 42.2 m DSF
Recovered Core: 43.9 m (104%)
Time on Hole: 30 November, 1145 h through 1530 h

Hole U1352B
Position: 44° 56.2558’ S, 172° 1.3630’ E (20 m south from Hole U1352A)
Water depth: 343.6 m (based on mudline recovered with APC)
Penetration Depth: 830.9 m DSF
Recovered Core: 613.9 m (74%)
Time on Hole: 30 November, 1530 h through 5 December, 1615 h

Hole U1352C
Position: 44° 56.2662’ S, 172° 1.3630’ E (30 m South from Hole U1352B)
Water Depth: 343.5 m (adopted from Hole U1352B with adjusted ship draft)
Penetration Depth: 1927.5 m DSF
Advanced without Coring: 631.1
Cored Interval: 1296.4
Recovered Core: 655.0 (51%)
Time on Hole: 5 December, 2015 h through 20 December 2200 h

Hole U1352D
Position: 44° 56.2326’ S, 172° 1.3611’ E (20 m N from Hole U1352A)
Water Depth: 344.2 m (based on mudline recovered with APC)
Penetration Depth: 127.0 m DSF
Recovered Core: 130.8
Time on Hole: 20 December 2200 h through 21 December 2100 h

Background

Site U1352 (proposed Site CB-04B) is located on the upper slope within the Canterbury Bight and is the most basinward site of the Canterbury Basin drilling transect. Site 1352 penetrates sequence boundaries U6-U19 where sediments are finer grained and pelagic microfossils more abundant than at shelf sites in order to provide good age control for sequences drilled on the shelf.

An additional target, requiring deep penetration, was recovery of the mid-Oligocene Marshall Paraconformity. The paraconformity is presumed to record intensified current erosion, or non-deposition at all water depths, that accompanied the development of a partial Antarctic Circumpolar Current system following the opening of the seaway south of Tasmania. There are indications from Leg 181 drilling that the paraconformity developed in deep (bathyal) water ~1-2 m.y. earlier than in shallow water. Dating the paraconformity in the offshore Canterbury Basin at Site U1352 tests this hypothesis by sampling it where paleowater depths were intermediate.

Because of time constraints, drilling into one of the large, elongate sediment drifts of the Canterbury Basin became a secondary, contingency objective. However, it is likely that insights into sediment drift deposition and paleoceanography will be obtained from Site U1352 cores. Current reworking of sediments is evident at Site U1352 even though distinctive drift seismic geometries are absent.

Operations

After a three-hour and 8 nm move from Site U1351 in dynamic position mode, the vessel was positioned at Site U1352 (proposed site CB-04B) at 0500 h (UTC+13 h) on 30 November. Four holes were drilled at this site.

Hole U1352A was a short APC hole with the objective to provide whole-round samples for microbiology, chemistry, and geotechnical studies. APC Cores U1352A-1H through 5H were taken to a depth of 42.2 m DSF with a recovery of 43.9 m (104%). Non-magnetic coring assemblies were used and core orientation was measured on all cores. A temperature measurement was taken with Core U1352A-4H. Contamination testing was done on all cores with per-fluoro-methyl-cyclohexane (PFTs) and microspheres.

The vessel was offset 20 m south of Hole U1352A for operations at Hole U1352B with the APC/XCB coring system. Piston coring extended to a depth of 297.0 m DSF with a total recovery of 299.3 m (101%). Core orientation was measured on the first 17 cores before the FLEXIT tool was pulled because of the more severe piston coring conditions. The XCB coring system was deployed with Cores U1352B-37X through 94X (297.0-830.9 m DSF). Initial recovery for the XCB system was very good but steadily decreased with depth. A total of 533.9 m were cored and 315.0 m recovered (59%). Towards the bottom of the hole, the XCB cutting shoe was overheating and the formation was causing excessive torque. A 50-barrel high viscosity mud sweep was pumped to clean the hole. Contamination testing for microbiology was done every ~50 m throughout Hole U1352B, including per-fluoro-methyl-cyclohexane (PFTs) and microspheres. Temperature measurements with the APCT3 tool were taken with Cores U1352B-6H, -10H, -15H and -20H, all with good results. The total cored interval in Hole U1352B was 830.9 m, and recovery was 614.3 m (74%).

The drill string was tripped back to 80 m DSF and the triple combo logging tool string was rigged up and run into the hole. The first logging run failed to pass 487 m WSF as the hole had evidently collapsed during logging preparations. Two passes were successfully recorded. The caliper readings indicated excessive borehole size that would not permit an adequate clamp for the VSI tool needed to obtain reliable data and the Vertical Seismic Profiling (VSP) plan was canceled. The FMS/sonic tool string was subsequently deployed and also encountered a borehole obstruction, now somewhat higher in the hole. FMS/sonic logs were recorded from a depth of 442 m WSF. After logging was rigged down a 12-barrel cement plug was pumped at 154.4 m DSF.

Operations at Hole U1352C began at 1615 h on 5 December, as the ship was offset 20 m south from Hole U1352B. A new bottom hole assembly was made up for the RCB system, fitted with a mechanical bit release to facilitate logging after coring was complete. The hole was advanced with a center bit installed. At ~300 m DSF the center bit was recovered, inspected and re-installed. The interval 574.7-603.6 m DSF was spot-cored with the RCB and recovered 12.79 m of core (44%). The center bit was reinstalled and drilling continued to 660.0 m DSF before coring resumed to the bottom of the hole. High viscosity, 20 barrel mud sweeps were deployed every ~40-50 m of coring to clean the cuttings from the hole. On 8 December, a wiper trip was made to from 1007-200 m DSF and back. Subsequent coring yielded sections of good and poor recovery. The de-plugger was run and coring intervals were reduced to 5 m several times in attempts to improve core recovery. On 15 December another wiper trip was made from 1662 to ~1000 m DSF and back, and coring resumed ~7 h later.

On 17 December, it became evident that the scientific target for the hole, the Marshall Paraconformity (MP), was deeper than anticipated. Permission was requested and received to exceed the original EPSP limit of 1913 m DSF by up to 250 m, to 2163 m DSF. The MP was cored the following day between 1851-1861 m DSF. Coring continued to 1927.5 m DSF in order to provide sufficient depth to log across the MP.

Contamination testing for microbiology was carried out repeatedly throughout Hole U1352C at ~50 m intervals, starting at 796 m DSF, including both per-fluoro-methyl-cyclohexane (PFTs) and microspheres.

The penetration depth of 1928 m for Hole U1352C established a new single bit, single expedition record for the *JOIDES Resolution*, and the deepest sediment hole ever drilled by the IODP and its predecessor programs. The cored interval in Hole U1352C was 1296.4 m and 655.0 m of core were recovered (51%).

The hole was swept clean with a 50 barrel sweep of high viscosity mud, and the RCB coring bit was released in preparation for logging. 400 barrels of high viscosity logging mud were displaced into Hole U1352C. The trip out of the hole experienced excessive drag and required the top drive to be re-installed. The trip out of the hole continued with rotation until the end of the string reached 545 m DRF. The upper guide horn was removed and the VIT camera was deployed to observe and document the cone of cuttings at the seafloor while logging. The drill string was set to a logging depth of 458 m DRF and the logging string was rigged up to run a modified version of the triple combo. The first logging run indicated that the hole had collapsed and the tool string was unable to pass 562 m WRF. The tool string was pulled back to surface and rigged down. The drill string was tripped back and operations in Hole U1352C ended at 2200 h on 20 December.

At the time operations in Hole U1352C were concluded, the winds and swells were too high for operations at the next site in shallow (<200 m) water. In anticipation of a delay of ~24 h due to weather, it was decided to core Hole U1352D while waiting on weather. Hole U1352D operations commenced at 2200 h on 20 December and Cores U1352D-1H through 14H to a depth of 127.0 m DSF recovered 130.8 m of core (103%). Non-magnetic coring assemblies were used and core orientation was measured on all cores.

Overall recovery for Site U1352 was 102% with the APC, 59% with the XCB, and 51% with the RCB. The total cored interval for Site U1352 was 2296.5 m with 1444.1 m of recovered core samples (63%).

Lithostratigraphy

Three holes were drilled at Site U1352 that reached a total depth of 1927 m CSF, spanning the Holocene to late Eocene. The site contains a gradual lithologic transition between the Holocene to Miocene, and a major unconformity between the early Miocene and early Oligocene at 1853 m CSF. The succession is divided into three lithologic units.

Unit I (0 m to 711 m depth CSF) spans the Holocene to middle Pliocene and contains predominantly mud-rich sediment consisting of calcareous sandy mud, interbedded sandy mud and clay, interbedded sand and mud, massive sand, mottled sandy mud, homogenous mud, shelly mud, and marl. Unit I was subdivided into three subunits. Unit IA (0 m to 98 m) is dominated by interbedded mud, sand and clay lithologies, with frequent greenish gray sharp based muddy sand or sandy mud beds. Unit IB (98 m to 447 m) contains more homogeneous mud, and less frequent sharp-based greenish gray muddy sand or sandy mud beds. Unit IC (447 m to 711 m) represents a transition between mud-dominated lithologies of Unit I to calcareous lithologies of Unit II. This gradual transition reflects a progressive change in water depth to deeper slope depositional environments.

Unit II (711 m to 1853 m) spans the middle Pliocene through early Miocene and contains hemipelagic to pelagic sediment consisting of calcareous sandy mud, sandy marls, chalk, sandy marlstone, and sandy limestone with minor amounts of calcareous mudstone and sandstone. The unit is subdivided into three subunits. Unit IIA (711 m to 1189 m) comprises homogeneous marl (in Hole U1352B) to bioturbated marlstone (in

Hole U1352C). Occasional mudstone, muddy sandstone and chalk lithologies also occur. Unit IIB (1189 m to 1694 m) contains abundant dark colored mudstone beds in the upper part, and more frequent occurrences of current bedding, especially towards the base of the unit. The frequency of mudstone bed occurrence decreases below 1392 m, in concert with other changes in mineralogy and an unconformity detected by biostratigraphy. Packages of recumbent and isoclinal folds, tilted beds, contorted strata and fluid escape features are present both above and below this unconformity. Unit IIC (1694 m to 1853 m) contains a gradual progression from marlstone to limestone, with frequent glauconitic laminae and beds.

A ~12 m.y. unconformity occurs at the base of Unit II, with an abrupt change into lithologic Unit III (1853-1924 m; total depth) comprising hemipelagic to pelagic foraminifera-bearing nannofossil limestone of early Oligocene to late Eocene age. Except for minor abundances of quartz and clay, Unit III lacks siliciclastic components. This unit is correlative to the onshore Amuri Limestone.

Site U1352 represents a late Eocene to early Oligocene and nearly complete Neogene continental slope sedimentary record dominated by pelagic to hemipelagic sedimentation with minor traction and gravity flow sediments. The sediments were deposited along a passive continental margin characterized by large volumes of sediment from a tectonically and climatically evolving hinterland. The site represents a unique downhole record from unlithified sediments to lithified carbonates at depth. The gradual downwards transition in lithofacies from more siliciclastic-rich Quaternary muddy facies into pelagic limestones and glauconitic marlstones and marls appears to reflect the downhole transition, seen on seismic profiles, from an upper slope location on a clinoformal margin with a sharp shelf-slope break in the Quaternary toward a toe-of-slope location on a more ramp-like margin in the Miocene. The lower carbonate content in the upper part of this interval may be linked to higher terrigenous supply, possibly related to the uplift of the Southern Alps and/or Neogene climate change.

Biostratigraphy

Site U1352 recovered a Holocene-late Eocene succession. Fifty-five bioevent datums were recognized and used to provide a detailed biostratigraphic framework. Calcareous nannofossils were the primary dating tool in Pleistocene sediments, while planktic foraminifers provided robust age control in the Pliocene–middle Miocene section. Both fossil groups were integral for biostratigraphic assessment of the early Miocene–late Eocene succession. Diatoms were sparse, but provided two useful Pleistocene datums. Analysis of benthic foraminifer assemblages yielded a detailed estimation of paleo-water depths throughout the succession.

An approximately 500-m thick Pleistocene section was recovered and 16 biomarkers were distinguished. The Pliocene/Pleistocene boundary was constrained between 492-525 m CSF and is potentially unconformable. Sediments below the boundary were dated between 2.45-3.04 Ma suggesting that most, if not all, of the late Pliocene is missing. Pleistocene nannofossil abundances fluctuated dramatically across predicted seismic sequence boundaries (most notably from 0.8 Ma to Recent) and were consistent with similar findings from planktic foraminifers.

The Pliocene interval was also thick and spanned Cores U1352B-57X thru 73R (1150-1285 m CSF). As at Site U1351, all standard nannofossil zonation markers (except *Reticulofenestra pseudoumbilicus*) were absent. The Miocene/Pliocene boundary was identified between 1266-1284 m and is conformable, though potentially condensed towards the base.

Twenty-six foraminifer and nannofossil datum markers were observed within the cored Miocene succession (1275-1851 m CSF). The Miocene interval contained three biostratigraphically-defined hiatuses: a late to middle Miocene hiatus between Cores U1352C-90R and 91R (1395-1410 m CSF), a middle Miocene hiatus between Cores U1352C-101R and 102R (1487-1497 m), and the Marshall Paraconformity between Cores U1352C-139R and 140R (1848-1853 m). This latter hiatus separated early Miocene sediments (~18-19 Ma) from underlying early Oligocene sediments (30.1-32.0 Ma), with approximately 12 m.y. absent.

The Oligocene and Eocene intervals were relatively thin (Cores U1352C-139R to 147R and 147R to 148R, respectively). Microfossil preservation was generally poor in Oligocene sediments, but improved in the Eocene. This boundary was recognized between Cores U1352C-146R and 147R (1903-1917 m CSF) and was unconformable, missing approximately 2.3 m.y. The bottom-hole age was constrained between 35.2-36.0 Ma in Core U1352C-148R (1924 m CSF).

Pleistocene and Pliocene sediments were dominated by middle to outer shelf benthic foraminiferal taxa although the rare, but persistent, presence of bathyal marker species suggest that the shelf taxa were reworked. Paleodepths generally increased downhole to lower bathyal depths in the lower part of the cored succession. Reworked shelfal taxa decrease markedly in early Pliocene and older sediments. This was consistent with a general increase in the abundance of planktic foraminifers downward through the progradational foreset sequence into the bottom sets and basin floor facies and coincided with the change from suboceanic to fully oceanic conditions.

Paleomagnetism

Natural remanent magnetization was measured on all but the most disturbed cores from all four holes at Site U1352. Intensity ranged from 10^{-2} to 10^{-3} A/m in the upper half of the drilled interval and decreased to 10^{-4} in the lower half of the record (consistent with an increase in carbonate). One AF demagnetization step, at peak fields of 20 mT was routinely applied. Where non-magnetic core barrels were used with APC coring (the upper 27 cores in Hole U1352B, to 246 m CSF), inclinations after 20 mT demagnetization are well grouped at -60.1º. The upper 18 cores (to 166 m CSF) were azimuthally oriented and show a mean declination of 27.7º after correction. These values are close to the orientation of the present day magnetic field (inclination -70º, declination 25º). The relatively shallower inclination of this component suggests that it may be a primary magnetization. The change to magnetic barrels occurred within the interval where the B/M boundary was anticipated (from biostratigraphic age determinations) and the boundary was not unambiguously identified at this site. A pervasive drilling overprint hampered any further magnetostratigraphic interpretation.

Rock magnetic experiments and demagnetization of discrete specimens indicate that a low-coercivity mineral is the main magnetization carrier. Thermal demagnetization of the NRM showed unblocking temperatures in the range of 320-340 ºC and an increase of susceptibility at around 400ºC, suggesting the presence of iron sulphides.

Physical Properties

Core physical properties change with depth broadly as anticipated, with decreasing overall trends in magnetic susceptibility (MS) and natural gamma radiation (NGR), and an increasing trend in bulk density obtained from gamma ray attenuation (GRA) and moisture and density (MAD) methods.

The upper 300 m exhibits regular cyclicity in MS and NGR, similar to the NGR record from ODP Site 1119 (Leg 181). For example, three peaks between 50 and 70 m in Hole U1352B correlate with peaks in Holes 1119B and 1119C (between 36 and 46 m), which have been recognized as signals of marine isotope stage 5. MS, NGR, GRA density and color reflectance b* show an unexplained but conspicuous negative peak between 555 and 630 m, followed by a positive peak at 665 m. Below the Marshall Paraconformity (~1853 m), the magnetic susceptibility switches to negative values, consistent with diamagnetic limestone.

Excellent P-wave velocity measurements were obtained using the caliper method on discrete samples (PWC) from cemented sediments in RCB cores from Hole U1352C. PWC values show a slight increase below 1255 m (averaging from ~2500 to ~3500 m/s) and a strong increase between 1500 m and 1670 m (averaging from ~3500 to 4000 m/s). Below ~1795 m the P-wave velocity increases again to 5200 m/s and a further slight increase in P-wave velocity is observed below the Marshall Paraconformity. The unexpected high velocities below 1255 m may require a revision of the traveltime-depth conversion of seismic records.

Reflectance spectrometry measurements on split cores reveal clear trends in both reflectivity and color. Variations in color were observed to correlate with similar variations in magnetic susceptibility.

Results from MAD analyses reveal downhole trends in sediment compaction and lithification. Lithostratigraphic Unit IA shows little downhole variability, but porosity begins to decrease, and bulk density to increase, in Unit IB. Cementation begins at this level and increases down-core towards Lithologic Unit IIB, which is almost fully cemented. Grain density varies little with depth.

Shear strength measured with the Automated Vane Shear (AVS) and the Fall Cone Penetrometer (FCP) indicates that sediments range from very soft (0-20 kN/m^2) to very stiff (150-300 kN/m^2). AVS and FCP shear strengths correlate well in very soft and soft sediments, but the AVS test appears to underestimate shear strength in firm to very stiff sediments. The pronounced cyclicity in shear strength seen at Site U1351 was not observed.

Geochemistry

The sulfate–methane transition (SMT) occurs between 15.2 and 16.6 m. The apparent level of carbon oxidized relative to sulfate reduced suggests that sulfate reduction is driven by both methane oxidation and organic matter oxidation. The initial gas below the SMT contains ethane (2 ppmv) with C_1/C_2 of 16000. Gas composition changes regularly with increasing depth, reaching C_1/C_2 of 60 near the bottom of Hole U1352C at 1920 m. C_3-C_5 hydrocarbon abundance also increases with depth. At an apparent unconformity near 1395 m, gas content was very low (40 ppmv methane) and C_1/C_2 dropped as low as 7, mainly due to the near absence of methane. Below the unconformity the gas resumed the normal trend. An initial predominance of branched C_4 and C_5 alkanes in the gas reduces with depth. Below the unconformity, the normal/(normal+iso) C_4 and C_5 ratios show a large and consistent decrease and then an increase, which so far remains unexplained.

Analyses of sediment samples distinguished the clay-rich lithostratigraphic Unit I from the carbonate-dominated Unit II. Organic carbon content was generally low (<0.6 wt%), with only a few samples having >1% TOC. The character of the organic matter changes from relatively labile volatile material in the shallower sediments to more stable protokerogen downhole, with evidence for increasing thermal maturity at total depth. The organic matter appears to be mainly terrestrial plant in origin.

Interstitial water analyses extend to 1400 m. There are initial reductions in calcium and magnesium in the SMT related to microbial processes (sulfate reduction, methanogenesis). Below 400 m, calcium, magnesium and strontium concentrations in the interstitial water increase and alkalinity decreases, consistent with dissolution of carbonates and the poor preservation of microfossils. Potassium and sodium concentrations decrease markedly below 300 m, possibly related to glauconite formation, whereas fluctuations in silica concentration point to dissolution of siliceous fossils. Increasing boron concentrations below 200 m may reflect a diagenetic opal A/CT transition and microbial degradation of organic matter. A lithium increase below 500 m can be explained by dehydration reactions which remove lithium from clay interlayer exchange sites.

Eleven whole-round samples were taken between 1630 m and the bottom of Hole U1352C at 1927 m for microbiological and organic geochemical characterization of *in* *situ* microbial communities. Onshore investigation of these samples could potentially extend the maximum known depth of habitable sediments.

Heat Flow

Four good quality temperature measurements in the depth interval from 94-313 m CSF yielded a geothermal gradient of 46.2 °C/km. Thermal conductivity measurements from 8 to 1920 m CSF reveal a trend of increasing thermal conductivity with depth except in the topmost 90 m where a decreasing trend is observed. Two individual trends are recognized: one for unlithified sediment from 90-800 m CSF and another for hard rock from 600-1920 m CSF. Thermal conductivity shows positive and negative relationships with bulk density and porosity, respectively. Heat flow is calculated as 57.8 mW/m^2 within the depth interval where the geothermal gradient was established. Assuming steady state heat flow, the temperature profile yields a bottom-hole temperature of ~60 °C.

Downhole Logging

Downhole logging at Site U1352 took place in Holes U1352B and U1352C. Two toolstrings were deployed in Hole U1352B: (1) the “triple combo”, measuring natural gamma ray, bulk density, porosity, and electrical resistivity, was run from seafloor to 487 m WSF, below which an obstruction prevented the toolstring from reaching the total depth of the hole, and (2) the FMS-sonic toolstring, measuring electrical resistivity images and sonic velocities, which encountered the same blockage and acquired data from 82 to 442 m WSF. In Hole U1352C, hole conditions were unstable and a modified triple combo (without radioactive sources) was the only toolstring deployed, recording gamma ray and resistivity between the seafloor and 207 m WSF. Below 207 m WSF, the toolstring encountered a blockage, which prevented it from reaching total depth.

Two logging units were identified. Logging Unit 1 (82-250 m WSF) is characterized by relatively low-amplitude variations in gamma ray, resistivity, and acoustic velocities. A distinct increasing-upward, then decreasing-upward trend in gamma ray is consistent with gamma ray logs at Site 1119 and may be associated with variations in clay content. Resistivity decreases with depth, while velocity increases with depth in this unit. Caliper measurements consistently higher than 19.5 inches indicate an enlarged borehole in this interval. Logging Unit 2 (250-487 m WSF) is defined by a change to higher-amplitude variations in gamma ray, resistivity, and acoustic velocities. Gamma ray and velocity show increasing trends with depth, while resistivity varies around a relatively constant value. Sharp peaks in P-wave velocity associated with variations in density or lithology may correlate with significant seismic reflections in this unit. The borehole diameter is smaller but highly irregular (6-19.5 inches) and may reflect the appearance of more cohesive marls within the formation.