IODP Expedition 317: Canterbury Basin Sea Level

Site U1353 Site Summary

1 January 2010

Hole U1353A
Position: 44° 46.1079’ S Latitude, 171° 40.4368’ E Longitude
Water Depth: 84.2 m (based on mudline recovered with APC)
Penetration Depth: 56.0 m DSF
Recovered Core: 56.38 m (101%)
Time on Hole: 21 December, 2320 h through 22 December, 1115 h

Hole U1353B
Position: 44° 46.1203’ S Lat, 171° 40.4407’ E Long (20 m south from Hole U1352A
Water Depth: 84.7 m (based on mudline recovered with APC)
Penetration Depth: 614.3 m DSF
Recovered Core: 211.48 m (34%)
Time on Hole: 22 December, 1115 h through 26 December, 2050 h

Hole U1353C
Position: 44° 46.0982’ S Lat, 171° 40.4380’ E Long (20 m North from Hole U1353A)
Water Depth: 84.7 m (adopted from Hole U1353A)
Penetration Depth: 529 m DSF
Recovered Core: N/A (dedicated logging hole)
Time on Hole: 26 December, 2050 h through 28 December, 2100 h

Background

Site U1353 is located on the mid-shelf within the Canterbury Bight and is the most landward shelf site of the Canterbury Basin drilling transect. As a result, Site U1353 was considered the most challenging site, both because the water depth at the site (85 m) is the shallowest among all Expedition 317 sites and also because the lithologies at this inboard setting were likely to be particularly coarse grained.

Site U1353 penetrates a middle Miocene to Holocene section containing seismic sequence boundaries U5 to U19. All sequence boundaries are penetrated landward of their rollovers, or paleo-shelf edges, with the goal of recovering proximal facies, yielding evidence of shallow-water deposition, and providing optimal paleo-water depths from benthic foraminiferal biofacies. Cores from Site U1353 contrast upper Miocene to lower Pliocene sequence boundaries (below U10), which feature smooth, onlapped paleoshelves and rounded rollovers with mid-Pliocene to Pleistocene sequence boundaries (U10 and above), which display eroded and incised, downlapped paleoshelves and more pronounced rollovers.

Operations

After an 18-nm transit from Site U1352, the vessel was positioned over Site U1353 (proposed site CB-01A) at 2320 h (UTC+13h) on 21 December. Three holes were cored or drilled at this site. The first hole was cored with the APC system to 56 m DSF to provide sufficient samples for microbiology, chemistry, and geotechnical studies. The second hole was cored with the APC/XCB coring systems to the target depth of 614 m DSF. The third hole was drilled to 529 m DSF as a dedicated logging hole with a center bit installed in the APC/XCB BHA.

Hole U1353A has the shallowest water depth of any hole drilled by the *JOIDES Resolution* for science. Rig floor operations commenced at 2320 h on 21 December when the vessel shifted to auto DP control. APC Cores U1353A-1H through 8H (0- 56.0 m DSF) recovered 56.38 m of core (101%). Non-magnetic coring assemblies were used and orientation measurements were taken on the first six cores. The APCT3 temperature tool was deployed once (Core U1353A-5H) without success. The type of formation encountered proved too difficult for our temperature measurement tools. Contamination testing was done on all cores with microspheres.

The vessel was offset 20 m south of Hole U1353A and coring in Hole U1353B began with 13 APC cores to a depth of 80.2 m DSF with a total recovery of 80.74 m (101%). Because of the rough piston coring conditions noted in Hole U1353A, orientation and temperature measurement tools were not deployed in this hole. In an effort to maximize recovery and make progress in the hole, the XCB coring system was deployed intermittently from Core U1353B-14X through 60H (80.2-257.7 m DSF). In this interval, nine XCB deployments cored 69.7 m and recovered 2.53 m of core (4%), and 38 APC deployments cored 107.8 m and recovered 107.6 (100%). The superior recovery with the APC came with partial strokes (average 3.7 m) and thus slow advance, shattered core liners, damaged components, and recovery of large amounts (>50%) of reworked or fallen in material. Below 257.7 m DSF, Cores U1353B-61X through 98X were taken to a total depth of 614.3 m DSF, recovering 20.55 m (6%). The hole was cemented per IODP policies, ending Hole U1353B. A total of 211.48 m of core were recovered over an interval of 614.3 m (average recovery of 34%).

The ship was offset 20 m north from Hole U1353A and drilling of a dedicated logging hole, Hole U1351C proceeded to 529 m DSF. The hole was swept clean with a 50-barrel high viscosity mud sweep, and displaced with 300 barrels of high viscosity 10.5 ppg mud. The triple combo logging tool string was rigged up without nuclear sources (neutron porosity, gamma ray density) to minimize the operational risk. The tool string descended to 621 m WRF and the hole was logged up from there. Next, the FMS-sonic tool string was assembled and run in the hole to 343 m WRF where an obstruction was encountered. The hole was logged up from 343 m WRF. A second attempt was made to run down with the FMS-sonic tool string but was only able to reach ~300 m WRF. Hole conditions while logging the tool upwards continued to deteriorate until complete collapse of the hole just below 202 m WRF. After working to free both the drill string and the logging string, the logging string partially re-entered the drill string. The drill string and the logging line were pulled up onto the rig floor from ~200 m DRF using T-bars. The hole could not be cemented with the logging tools stuck in the drill string and the hole completely collapsed as the BHA was pulled clear of the hole. The logging tools were rigged down and operations at Site U1353 ended at 2100 h on 28 December.

Lithostratigraphy

Site U1353 provides an excellent and unique sedimentary record of deposition through the Holocene-late Quaternary period of global sea-level fluctuation. Hole U1353B also penetrated some of the older Early Pleistocene-Miocene seismic reflectors in the offshore Canterbury Basin, which at this site are at relatively shallow sub-bottom depths of <500 m. Poor core recovery, however, hindered lithostratigraphic interpretation in deeper portions of the hole.

Cores recovered from Holes U1353A and U1353B show a downhole transition from a heterolithic upper section with abrupt contacts (Unit I), to a more featureless mud-dominated section with depth (Unit II). These changes suggest a progressive and gradual change in sedimentary style as the margin evolved.

Unit I (Hole U1353B, 0-151 m CSF) is characterized by its overall muddy character, the dominant lithology being a dark greenish gray homogeneous mud with a few percent very fine sand. Shells are either rare and scattered, or locally concentrated in layers up to 15 cm thick. Bioturbation is common with ichnofabric indices of 3-4.

Subordinate lithologies include shelly mud to shell hash, micaceous well sorted very fine sand, clay, and sandy marl.

The dominant lithology of Unit II (Hole U1353B, 151-614 m CSF) consists of dark greenish gray, micaceous, very fine sandy mud and mud, typically with shells. Both types of sediment are slightly to heavily bioturbated (bioturbation indices of 2-4). Sand and cemented intervals were recovered sporadically throughout the unit as minor lithologies.

Close similarities are noted between Sites U1353 and U1351, 20 km to the southeast. Comparable Unit I and II subdivisions and constituent lithotypes are recognized at both sites and potential lithologic expression of seismic unconformities can also be matched between the sites. Site U1353 is interpreted to represent a slightly more shoreline-proximal equivalent of Site U1351. Deposition was dominated by shelf processes, characterized during Unit I time (late Quaternary) by frequent sea-level variations and preceded by inner- to mid-shelf depositional settings through Unit II time (early Pleistocene-Miocene).

Biostratigraphy

Calcareous nannofossil, planktic and benthic foraminifer and diatom assemblages from Site U1353 core catcher samples were used to create a shipboard biostratigraphic framework. Benthic foraminifers were also used to estimate paleo-water depths. Diatoms were sparse to absent for this site.

Site U1353 contains a Holocene to Miocene succession. Thirteen biostratigraphic events were recognized, most of them in the Pleistocene interval. Pleistocene abundances were high and exhibited good preservation that allowed for robust age control, particularly of nannofossil assemblages. A hiatus was recognized within the middle-early Pleistocene between Samples U1353B-12H-CC and 14X-CC (80.12-80.77 m) where ~0.8 m.y. is missing.

The Pliocene/Pleistocene boundary was biostratigraphically picked between Samples U1353B-21H-CC and 23H-CC (121.16-135.71 m) and is unconformable, missing most, if not all, of the late Pliocene. Biostratigraphic analysis of Site U1353 Pliocene and Miocene sediments was particularly problematic for all microfossil groups because of either low abundances and/or absence of biostratigraphic markers. Below Sample U1353B-60H-CC (257.69 m), nannofossil abundances dropped sharply and remained low for the rest of the downhole succession. Samples below this level were nearly barren of planktic foraminifers. Shelfal benthic foraminifers were present in abundance, but lacked reliable markers.

Nevertheless, several important datums allowed for biostratigraphic constraint and critical correlation with Sites U1351 and U1352. The early-middle Pliocene boundary was distinguished by a nannofossil datum (3.7 Ma) between Samples U1353B-27H-CC and 28H-1, 124 cm (149.68-150.64 m). In combination with a planktic foraminifer datum (<4.3 Ma) it constrained the interval from 150.64 to 256.04 m between 3.7-4.3 Ma (early Pliocene). The Miocene/Pliocene boundary could not be picked biostratigraphically.

Although Site U1353 yielded no biostratigraphic evidence for late Miocene sediments, the adjacent Site U1351 contained an expanded late Miocene section. Extrapolation of correlative seismic reflectors from Site U1351 to Site U1353 supports the presence of a late Miocene interval. A nannofossil marker in Samples U1353B-89X-

CC and U1353B-90X-CC (518.66 and 528.87 m, respectively) was dated >12.03 Ma indicating a substantial hiatus above this interval, though the amount of time missing is unknown. Samples below Sample U1353B-90X-CC were barren of calcareous nannofossils and planktic foraminifers except for the bottom-most core catcher, U1353B-98X-CC (604.60 m), which contained sparse nannofossils with an assemblage age of middle to early Miocene.

Paleo-water depths derived from benthic foraminifers ranged from subtidal to outer shelf environments throughout the Miocene-Pleistocene section, but no deeper than outer shelf. Pleistocene paleo-water depths fluctuated largely from subtidal down to mid-shelf environments, though a notable deepening to outer shelfal depths (correlated to the interval just above the middle-early Pleistocene hiatus) was noted in Cores U1353B-10H-CC and 11H-CC (67.5-73.19 m). Pliocene water depths were generally subtidal to inner shelf but ranged down to outer shelf in the early Pliocene. Middle-early Miocene paleo-water depths could not be interpreted because of low numbers of benthic foraminifers.

Paleomagnetism

Natural remanent magnetization was measured on all but the most disturbed cores from Site U1353. NRM intensities were of the order of 10^{-3}-10^{-2} A/m and decreased to 10^{-4}-10^{-3} A/m by AF demagnetization at peak fields of 20 mT. A steep, northerly, downward drilling overprint was removed from APC cores that were recovered using non-magnetic barrels (Hole U1353B, 0-67.6 m CSF) by AF peak demagnetization at 20 mT. After demagnetization, remanence direction is upward oriented with mean inclination around -60°, consistent with a Brunhes age for this component. The overprint persisted (with declinations clustered at north) where standard steel core barrels were used at greater depths. Consequently, no reversals could be detected at Site U1353.

Rock magnetic experiments reveal lithology-dependent changes in magnetic behavior between gray muds and green, silty/sandy intervals in Hole U1353B. Gray muds show relatively higher coercivities (~80 mT) and lose ~80% of their remanence between 250ºC and 360ºC heating steps. Green, coarser grained sediments have coercivities ~40-50 mT and lose only 40-50% of their remanence between the same heating steps. Rock magnetic parameters are consistent with the presence of magnetic iron sulfides throughout the sediments and indicate the presence of an additional remanence carrier, particularly in the greenish intervals, which is likely magnetite.

Physical Properties

In the upper 260 m CSF, systematic whole-round and/or section-half measurements of magnetic susceptibility, natural gamma radiation, gamma-ray attenuation density, P-wave velocities and colorimetry and moisture and density (MAD) revealed patterns of sedimentation characterized by cyclic variations as well as evidence suggestive of unconformities. Two abrupt excursions in magnetic susceptibility, natural gamma, and color occur between 13 and 17 m, and between 27 and 36 m and are associated with thick, sandy units. These peaks may correlate with the two most recent glacial/interglacial cycles, MIS 1-5 and 6-7, and provide tentative age estimates for the Holocene and latest Pleistocene.

Overall, magnetic susceptibility decreases, and P-wave velocities and bulk density increase downhole. Several abrupt shifts were observed in these trends. These shifts correspond to intervals where biostratigraphic evidence indicates hiatus and those intervals could be related to erosion or missing section.

A number of prominent peaks in magnetic susceptibility in the upper 80 m may be linked to caved-in shell hash material observed at the top of each core, as observed previously at Site U1351. These findings indicate that the noisy magnetic susceptibility signal below ~100 m may also be mainly caused by the drilling process, including material falling down onto the top of cores (cave-in) or sucked in material in the bottom of core liners (flow-in). Caution is required before additional on-shore analyses confirm or re-interpret tentative shipboard observations.

Good P-wave velocity results were obtained in the muddy portions of the sediment to a depth of over 585 m. Gas in the previous two sites, U1351 and U1352, destroyed the P-wave signal below the top ~20 m of soft sediments.

Vane shear and fall cone penetration strength correlate well in very soft and soft sediments, but the values of the vane shear tests are about three times lower than the fall cone values in firm to very stiff sediments. These findings, consistent with those at sites U1351 and U1352, suggest that the applicability of the vane shear in firm to very stiff sediments is limited in that the vane shear test underestimates the strength of such sediments.

Geochemistry

Gaseous hydrocarbon monitoring at Site U1353 did not show significant levels of hydrocarbons above the background laboratory air concentration of ~2 ppmv. Sulfate levels never become strongly depleted and no sulfate–methane transition is apparent, suggesting that either (1) methanogenesis did not occur in the sediments, (2) previously generated methane was lost when the shelf was emergent, or (3) methane was oxidized when sulfate was replenished by diffusion after a subsequent sea level rise.

The interstitial water chemistry in the top 150 m is dominated by a salinity minimum, reaching values of 2.4 or 70% of seawater at ~50 m. Below this depth, salinity increases again to seawater values and reaches a value slightly higher than seawater in the deepest sample at 595 m. The presence of this less-saline lens can be explained by either modern intrusion of meteoric water from land, or by the historic remains of freshwater emplaced when the shelf was emergent and now being slowly replaced by the downward diffusion of seawater. The profiles of chloride, sodium, sulfate, and to some extent potassium closely track the salinity trend and also show minima at 50 m. Normalization of alkalinity, sulfate, calcium and magnesium profiles to seawater chloride concentrations allows the evaluation of changes due to reaction rather than dilution with fresh water. Chloride-normalized alkalinity shows an increase from 3.2 mM near the seafloor to 9 mM at a depth of 54 m, which co-occurs with a depletion of 8 mM in chloride-normalized sulfate. This implies that some sulfate reduction has occurred and that alkalinity is affected by additional processes such as carbonate precipitation and dissolution. The normalized calcium concentrations increase with depth to 16 mM and possibly reflect dissolution of calcareous microfossils. The chloride-normalized magnesium profile shows a steady decline downhole and levels out at 45 mM. Increasing boron concentrations indicate release of a desorbable boron fraction and degradation of organic matter. Similarly, the increasing lithium amounts can be explained by desorption reactions. Barium concentrations seem to be coupled to the sulfate profile and increase slightly when sulfate concentrations decline, possibly related to dissolution of barite.

Average carbonate content is low (0.5-2 wt%) and decreases with depth. The decrease of total organic carbon over the upper 100 m can be correlated with the intervals of alkalinity increase and sulfate decrease and might represent active biological oxidation. Pyrolysis characterization of organic matter suggests a major contribution of terrestrial plants, whereas C/N ratios from elemental analysis are consistent with a significant marine influence.

Heat Flow

Temperature measurements were not obtained due to difficult drilling conditions and therefore heat flow could not be determined. Thermal conductivity measurements, covering the depth interval 5.2-413.5 m CSF, provided a range of 1.122-1.840 $W/m^{-1} \cdot K^{-1}$ and show two downhole increasing trends: an increasing trend in the interval 0-32 m CSF with a local maximum at ~30 m, and a subsequent drop followed by another increasing trend to 413 m CSF. The origin of the local maximum at ~30 m CSF is unclear, since porosity and bulk density are constant in the interval 20-50 m CSF. In general, thermal conductivity varied positively with the bulk density and negatively with porosity. Below 414 m CSF thermal conductivity measurements were unreliable.

Downhole Logging

Downhole logging of dedicated logging Hole U1353C took place on 28 December 2009. Two toolstrings were deployed: (1) a modified “triple combo” (without radioactive sources due to unstable hole conditions at this site), measuring natural gamma ray and resistivity from seafloor to a total depth of 528 m WSF (wireline depth below seafloor); and (2) the FMS-sonic toolstring, measuring electrical resistivity images and sonic velocities, which acquired data from 105 to 249 m WSF. Below 249 m WSF, the FMS-sonic toolstring encountered a blockage that prevented it from reaching the total depth of the hole.

Two units were identified in the logs. Logging Unit 1 (105-260 m WSF) is characterized by an increasing trend form the top of the unit to 180 m WSF. Below that interval, the gamma ray trend decreases downhole to ~250 WSF. These trends are interrupted by abrupt high-amplitude lows in gamma ray and peaks in resistivity and velocity that are interpreted as sandy intervals, many of which coincide with sand or gravel at corresponding depths in Hole U1353B. These features also show good correspondence with significant seismic reflections. Logging Unit 2 (260-528 m WSF) is characterized by overall decreasing trends with depth in gamma ray and resistivity, with low variability. The top of the unit is roughly the same depth as the onset of low core recovery in Hole U1353B and the point at which the FMS-sonic toolstring was unable to descend deeper into the hole, suggesting a change in the properties of the formation across the unit boundary.