IODP Expedition 372: Creeping Gas Hydrate Slides and Hikurangi LWD

Site U1517 Summary

Background and Objectives

Site U1517 (proposed Site TLC-04B) is located in the extensional, creeping part of the Tuaheni Landslide Complex (TLC) in ~720 m water. The primary drilling objective was to log and core through the landslide mass and the gas hydrate stability zone in order to understand the mechanisms behind the creeping behavior.

Predrilling interpretation was based largely on high-resolution 3-D seismic site survey data. Initial data interpretation confirmed that, in general, the transition from compressional to extensional (creeping) regime coincides with the predicted landward edge of the gas hydrate stability zone. The 3-D seismic cube provided detailed images of the architecture of the TLC, in particular a horizon within the debris mass that is interpreted to mark the décollement for the slowly deforming part of the TLC.

In 2016, before Expdition 372, this location was cored to 80 m with the MeBo system during Sonne Voyage SO-247 (Site GeoB20831 at proposed Site TLC-04B). Deformed clayey silt landslide debris was recovered between 0 and 28 m with good core recovery. Between 28 and 60 m recovery was poor, yielding disturbed very fine sandy coarse. The cores were highly disturbed by the drilling process and mixed with seawater. From 60 to 78.8 m, stiff clayey silt was sampled from within the bedded sedimentary sequence underlying the landslide complex with good core recovery.

Site-specific objectives include the following:

- Obtain lithologic information within the creeping slides, including material across the interpreted décollement as well as the lower part of the landslide debris.
- Collect samples for shore-based laboratory studies. Potential laboratory studies include long-term deformation tests on gas-hydrate-bearing sediments as well as geotechnical investigations of hydrate-bearing and hydrate-free sediments.
- Constrain in situ gas hydrate saturation and composition to better understand the local gas hydrate system and to calibrate seismic data.
- Analyze pore water profiles to improve calibration of gas hydrate saturation and to study possible fluid sources and chemical disequilibria.
- Obtain pore pressure and temperature profiles in order to investigate possible overpressure and search for evidence of non-steady-state fluid and heat flux.

- Identify fracturing and determine whether fracture patterns change across the base of gas hydrate stability (BGHS) or within the slide mass.
- Calibrate seismic data. Beyond stratigraphic tie-ins, calibration of both 3-D and long-offset 2-D seismic data will improve constraints for extending profiles of gas hydrate saturation and pore pressure away from the borehole.

Operations

Following a 12.2 d transit from Fremantle, Australia, the ship arrived at Site U1517 at 0247 h on 16 December. The advanced piston corer (APC)/extended core barrel (XCB) bottom-hole assembly (BHA) was put together in preparation for coring operations at Hole U1517B. The logging-while-drilling (LWD) tool string was assembled and contained the geoVISION, SonicScope, NeoScope, TeleScope, and proVISION tools. The LWD BHA was 190.72 m long in total.

The precision depth recorder (PDR) placed the seafloor at 722.5 mbsl, and the BHA was lowered to a depth of 672 mbsl for flow and pressure testing of the LWD tools to determine the flow rates at which the tools activate. The subsea video camera was deployed to observe the drill bit tag the seafloor at depth of 725.4 mbsl. The camera system was retrieved and Hole U1517A began at 1935 h on 16 December. LWD in Hole U1517A continued through 17 December, reaching the total depth of 205 mbsf at 1115 h. After a mud sweep, the drill pipe and LWD BHA were pulled from the hole. The bit cleared the seafloor at 1245 h and the rig floor at 1840 h on 17 December, ending Hole U1517A.

The vessel was offset 20 m to the southeast for coring operations in Hole U1517B. The APC/XCB BHA was assembled and run to a depth of 704 mbsl. The bit was spaced out and the first core was shot at 720 mbsl. Hole U1517B began at 0130 h on 18 December, with Core U1517B-1H recovering 9.4 m of sediment. Because of uncertainty in the position of the mudline, the decision was made to abandon Hole U1517B and recover the mudline interval.

The bit was raised 4 m and coring in Hole U1517C began at 0210 h on 18 December. Cores U1517C-1H and 2H were deployed to 15.2 m before switching to the half-length advanced piston corer (HLAPC) to recover a silt-rich interval. Cores U1517C-3F to 14F (15.2–71.6 m) were taken before switching back to the full-length APC for Cores U1517C-15H to 18H (71.6–108.3 m), all of which had partial strokes. The HLAPC was redeployed for Cores U1517C-19F to 36F (108.3–188.5 m). Of these, 13 cores recorded partial strokes. After reaching the total depth of 188.5 m, the drill pipe was pulled out of the hole with the bit clearing the seafloor at 1015 h on 19 December and the rig floor at 1220 h, ending Hole U1517C. The ship was secured for the 20 nmi transit to Site U1518 at 1310 h on 19 December.

All of the APC cores were oriented using either the FlexIt (Cores 1H and 2H) or the Icefield (Cores 15H to 18H) tools. The advanced piston corer temperature tool (APCT-3) was run on

Cores U1517C-15H, 17H, 20F, 23F, 26F, 29F, and 34F. A total of 177.44 m of core was recovered from the 188.5 m interval (94%) at Hole U1517C. This included six APC cores (51.9 m interval, 52.66 m recovered, 101%) and 30 HLAPC cores (136.6 m interval, 124.78 m recovered, 91%).

The vessel returned to Site U1517 at 2300 h on 31 December 2017 following a 32 nmi transit from Site U1520. The BHA was made up and the drill string was assembled in preparation for formation temperature and pressure measurements. Hole U1517D began at 0720 h and was drilled down to 80 m. The center bit was retrieved and the motion decoupled hydraulic delivery system (MDHDS) and temperature dual-pressure tool (T2P) were deployed to make an in situ formation pressure measurement. The shear pins failed to deploy on the first attempt and a second attempt was made ~1 h later. This time the tool was inserted into the sediment. The tool could not be recovered using the Electrical Release System (ERS) on the Schlumberger wireline and had to be picked up using a fishing tool on the coring line. Upon retrieval, the T2P probe tip was damaged, having lost the thermistor in the tip; however, it did record a good pressure measurement. The center bit was installed and the hole was drilled down to 120 m. After the center bit was retrieved, a second T2P probe was deployed. After sitting in the formation for ~45 min, the ERS again could not retrieve the tool and the core line was used. The second T2P was also damaged upon recovery; this time the entire probe tip was missing and the electronics had been flooded. The hole was drilled down to 130 m and the sediment temperature pressure tool (SETP) was successfully deployed using the colleted delivery system (CDS). The hole was drilled to a total depth of 168.7 m and a final SETP measurement was made. The drill string was pulled from the hole with the bit clearing the seafloor at 1030 h and the rig floor at 1315 h. The ship was secured for transit and Site U1517 ended at 1536 h when the ship began the transit to Lyttelton, New Zealand.

Principal Results

Core Lithology and Structure

The Hole U1517C sediments are clayey silt with sandy intervals and we have defined five lithostratigraphic units (I–V) based on the visual description of core material and smear slide analysis, as well as RGB color and magnetic susceptibility logs. Smear slide analysis shows that Units I–IV have distinct characteristics with an overall decrease in grain size downcore from Unit I to Unit IV, while Unit V includes a broad distribution of grain size. A variety of drilling-related core disturbance occurred that makes robust interpretation of the sedimentary structure challenging. Sedimentary structures including sharp upper contacts and irregular basal contacts in graded beds suggest that significant postdepositional modification has taken place. Overall, we interpret this stratigraphic succession as including bedded turbidite sequences, mass transport deposits, and an undetermined amount of background sedimentation. The upper ~67 m are within the TLC and appear to be primarily intact block material likely mobilized from the upper slope sedimentary sequences.

Physical Properties

Physical properties were characterized through a set of measurements on whole cores, split cores, and discrete samples. The magnetic susceptibility data generally corresponds to the lithostratigraphic units, with sequences of sand and mud showing more variable magnetic susceptibility than laminated clay and silt or massive silty clay. Moisture and density measurements on discrete samples from cores indicate relatively low porosities (~44%) starting a few meters below the seafloor. A porosity shift occurs at 66 m, with values increasing to 48%. *P*-wave velocity and strength measurements on cores were compromised or prevented by expansion due to gas disturbance below 20 m. Thermal conductivity measurements yield values averaging 1.2 W/(m·K) in the cored section. Fluctuations in thermal conductivity are small and appear inversely related to porosity, as would be expected based on the higher thermal conductivity of solids.

Downhole Measurements

The APCT-3 was deployed seven times in Hole U1517C. Four successful deployments between 81 and 132 m define a linear temperature-depth profile with a gradient of 39.8°C/km. This gradient combined with the average thermal conductivity measured on cores yields an estimate of vertical conductive heat flow of 49 mW/m^2.

Four attempts were made to measure in situ formation pressure and temperature. The T2P was deployed at 80 and 120 m. The first deployment took a good formation pressure measurement. The second deployment may have collected good data, but it has not yet been retrieved because the electronics flooded. The SETP was deployed at 130 m and 168.7 m. Tool deployment and recovery went smoothly; however, the data file was erased from the memory card of the first measurement and the data file was corrupted for the second measurement. Efforts continue to convert the native data into a clean ASCII file.

Logging While Drilling

Five logging-while-drilling (LWD) tools—the NeoScope, SonicScope, TeleScope, proVISION, and geoVISION—were deployed on the BHA while drilling Hole U1517A. These provided both real-time and recorded mode data through the TLC, through and below the décollement, and through the bottom-simulating reflector. Based on the LWD measurements, five main logging units were identified that closely correspond with the lithological units defined for Hole U1517C. Several significant features were interpreted from the logs, such as the compacted base of the debris flow from 54–60 m and natural gas hydrate occurring in 10–30 cm thick turbidite sands from 110–150 m. Both conductive and resistive fractures were also identified throughout the hole; however, a higher fracture density occurred within the landslide.

Geochemistry

We collected 75 whole-round samples for characterization of the pore water at Hole U1517C. Samples were collected on the catwalk at a frequency of four samples per core in the upper 15.2 m and two samples per core from 15.2 to 112.4 m. Below this depth, sample selection was guided by cold anomalies observed in infrared (IR) camera images that suggested the potential for gas hydrate occurrence. Additional samples were taken away from the cold anomalies to establish the in situ background chloride concentrations. Dissolved chloride measurements indicate the presence of discrete gas hydrate occurrences between ~135 to 165 m, with gas saturation (S_h) values ranging up to ~65%. This distribution is consistent with inferences on gas hydrate saturation based on resistivity data obtained by logging while drilling.

Pore fluid composition reflects the combined effects of microbially mediated organic matter degradation coupled to carbonate and silica diagenetic changes. The sulfate–methane transition (SMT) is well defined at 16.6 m by depletion of dissolved sulfate and a marked increase in methane concentration in headspace samples. Alkalinity, calcium, and magnesium show distributions that are typical for reactions occurring at the SMT.

Below the SMT, methane concentrations rapidly increase to as much as 1%, indicating ongoing methanogenesis. All of the methane concentrations below the SMT are commonly above pore water saturation at ambient conditions. Thus, these values are qualitative estimates only as they reflect the amount of gas remaining in the sediment after core recovery and handling. Ethane was not detected in the headspace samples above 146 m but it was repeatedly measured at very low concentrations of 1 to 2 ppmv between 146 and 166 m, a depth range that coincides with the inferred presence of gas hydrate from the chloride data.

Analyses of the solid phase yielded $CaCO_3$ values ranging from 4.63 to 8.99 wt%. Total organic carbon (TOC) concentrations are generally <1%. The total carbon to nitrogen (C/N) ratios ranged from 3.78 to 31.34.

Log-Seismic Integration

LWD logs were tied to seismic profile In-Line 1778 of the Tuaheni 3-D seismic volume through a set of synthetic seismograms. Two sets of synthetics were constructed, one by editing the LWD density and sonic logs to calculate acoustic impedance logs that were convolved with a wavelet derived from the seafloor of the seismic data. The other set used a log-lithological model of the main lithological units and physical properties. Washouts due to silty or sandy lithology led to relatively poor quality of the density and sonic logs. Therefore, the synthetic seismograms did not match well. However, the main lithologic and log units were tied to the main seismic reflection units and their boundaries. The mismatches in depth between the seismic and log data allow us to refine the velocity profile at the drill site in order to reconvert the depth section.

Core-Log Integration

By integrating LWD data taken at Hole U1517A and the core recovered at Hole U1517C, we compared lithologic indicators (natural gamma ray, sonic *P*-wave velocity, porosity, and bulk density) as well as independent estimates of gas hydrate accumulation (pore water geochemistry and resistivity-porosity relationships). Whole-round natural gamma radiation (NGR) measurements are in agreement with those taken through LWD. Additionally, core sample-derived moisture and density (MAD) porosities agreed well with measured natural remanent magnetization LWD porosities, but MAD measurements were consistently lower than the LWD neutron porosity measurements. Furthermore, there appears to be a slight mismatch in the depths at which significant changes in measurement responses occur: in the shallow section above 70 m, excursions from baseline values appear approximately 5 m lower in core data than LWD data. This observation is consistent across both the NGR and porosity measurements, but the trend is difficult to distinguish deeper in the wells. Hydrate saturation was estimated using LWD-based methods and interstitial water geochemistry analysis. These techniques agree in their assessment of the most probable areas of hydrate occurrence but disagree in their predictions of hydrate saturation magnitude. This is likely due to differences in sampling resolution and formation heterogeneity.