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IODP EXPEDITION 311: CASCADIA MARGIN GAS HYDRATES SITE U1326 SUMMARY

Site U1326 (Prospectus Site CAS-03C) is located on an uplifted ridge of accreted sediments at the southwest end of the multi-site transect established during Expedition 311. Recently acquired bathymetry data reveals a collapse structure near the originally proposed primary site CAS-03B. We decided to switch the former alternate location CAS-03C to the primary site to avoid coring directly into the slump feature, which may have complicated the recent geologic history of this site.

The head wall of the slump feature near the CAS-03B site is ~250 m high and the slump has eroded a ~2.5 km long section into the ridge. Further examination of the bathymetry data from this area also reveals the occurrence of continuous linear features crossing the ridge in an E-W direction. These linear features are clearly associated with faults as seen on the seismics. The outcrop of these faults at the seafloor generate a surface displacement of up to 25 m, and can be seismically traced from the surface down through the sedimentary section to depths below the BSR. The occurrence of these deep-through going faults are generally limited to the area of the slump scar. The seismic character of the ridge also changes from the SW to the NE across the ridge, with the SW-facing part of the ridge characterized by strong, semi-continuous reflectivity, while the seismic reflectivity disappears underneath the NE-facing flank of the Ridge. The differences in the seismic character across the ridge cannot be easily explained, and it is one of the research focuses of the site. The BSR is present underneath most of the ridge, but it is almost absent underneath the slump feature in association with the most heavily faulted sediments.

The objectives of coring and logging this site are tied to completing the transect of scientific research holes across the Northern Cascadia Margin near Vancouver Island. Site U1326 is the closest location to the deformation front and it probably represents the tectonically youngest occurrence of gas hydrate on the Northern Cascadia Margin, as such our primary research objectives include (a) studying the distribution of gas hydrates, (b) defining the nature of the BSR, (c) developing baseline geochemical and microbiological profiles, and (d) obtaining data needed to ground-truth remotely acquired imaging techniques such as seismic or controlled-source EM.

The operational plan to achieve these objectives is based on a general three hole concept, which includes (1) a LWD/MWD logging hole, (2) a continuous core hole to characterize geochemical and microbiological baselines and proxies for the occurrence gas hydrate, and (3) an additional "tool" hole for specialized pressure coring and selected spot-coring using conventional systems. The special tools hole is also intended to be logged with the conventional IODP wireline logging tool strings.

After transiting from Site U1325, the LWD/MWD BHA was tripped to the seafloor. Hole U1326A was spudded at 14:45 hr on the 22 September at an estimated seafloor tag depth of 1828.1 mbsl (1839.0 mbrf). To avoid blowing out the top of the hole, we adopted a controlled spud program that featured reduced drilling fluid circulation rates of only 100 gpm and a bit rotation rate of 10-15 rpm. As the hole was advanced, both the circulation rate and bit rotation rate were increased to maintain a 50 m/hr rate of penetration. The LWD/MWD safety protocol was followed without incident and required no corrective action. The hole was drilled to a total depth of 300 mbsf, the drill string was pulled clear of the seafloor at 06:00 hr on 23 September. Hole U1326B was spudded 15 m NE of Hole U1326A

at 12:05 hr on 23 October, but the first core failed to establish the depth of the mud line and it was decided to start a new hole. Without offsetting from the location of Hole U1326B, Hole U1326C was spudded at 12:45 hr on 23 October. The first core established a seafloor depth of 1828.0 mbsl (1839.6 mbrf). On the fourth APC core (~30 mbsf), we unexpectedly hit APC refusal and switched to XCB coring. Hole U1326C was advanced by XCB coring to a depth of 82.7 mbsf, which was followed by three consecutive pressure core deployments within a high electrical resistivity zone identified on LWD/MWD downhole logs. In this case, the FPC and HRC pressure core runs were added to the traditional continuous core hole to increase the total number of pressure core runs at this site. The FPC was the first pressure core system deployed at this site, it recovered a partial core (15 cm) at less than full pressure. The second system to be deployed was the PCS, which recovered a partial core under pressure. The third pressure core system deployed was the HRC, which was "packed off" with a sand and the cutting shoe and the lower part of the autoclave was unscrewed and left behind in the hole, resulting in the termination of Hole U1326C at a total depth of 86.7 mbsf. After tripping the BHA back to the seafloor, the ship was moved ~30 m to the southwest (15 m from Hole U1326A). Hole U1326D was spudded at 11:30 hr on October 24 and drilled to a depth of 78.8 mbsf in preparation for continued coring to a target depth of 300 mbsf. Because of problems associated with the heave state and schedule limitations, all pressure coring operations were suspended for the reminder of the hole. XCB coring deepened the hole to 271.4 mbsf, with the forecast of deteriorating weather conditions on the morning of 26 October, it was decided to stop coring and complete the hole by drilling to 300 mbsf. Despite the marginal conditions, we did attempt three deployments with the DVTP tool (at 252.2 mbsf, 271.4 mbsf, and 300 mbsf), which yielded degraded data. After completing coring and drilling operations, we then decided to conduct a single downhole log run with a non-standard IODP tool string, which included the Scintillation Gamma Ray (SGT) Tool, Phasor Dual Induction (DIT) tool, and the Dipole Sonic Imager (DSI). At 23:15 hr on 26 October the logging tool was lowered to a logging depth of 298.4 mbsf; two successful logging passes were made with tool string back on deck at 03:45 hr. The drill string was pulled clear of the seafloor at 05:30 hr on 27 October, ending operations in Hole U1326D.

The 271.40-m-thick Quaternary sedimentary section cored at Site U1326 was divided into three lithostratigraphic units. Lithostratigraphic Unit I (0-1.50 mbsf in Hole U1326B; 0-24.13 mbsf in Hole U1326C) is characterized by fine grained (clay to silty clay) detrital sediments with thin silty/sandy interlayered turbidite sequences. Foraminifers, shell fragments, sponge spicules remains, mottling and bioturbation, together with the high marine versus non-marine ratio of diatom indicate hemipelagic sedimentation, mixed with turbiditic inputs (coarse-grained facies). Authigenic carbonate cement are also present in lithostratigraphic Unit I. Lithostratigraphic Unit II (24.13-82.70 mbsf in Hole U1326C; 88.40-146.30 mbsf in Hole U1326D) is also dominated by fine grained (clay to silty clay) detrital sediments with intervals of turbidite deposited silty/sandy interlayers, but diatoms are absent and other biogenic components are rare. The frequent occurrence of turbidites might indicate times of active tectonism. Below 30.4 mbsf, abundant soft sediment deformation and dipping strata show that tectonism is more active at the westernmost end of the transect drilled during this expedition. Authigenic carbonate cement and a carbonate concretion also are present in lithostratigraphic Unit II. Soupy and mousse-like textures indicative of gas hydrate occurrence were observed throughout this unit. The lithostratigraphic Unit II/III boundary is marked by the appearance of diatoms, although their abundance is low. Lithostratigraphic Unit III (146.30-271.40 mbsf in Hole U1326C) is characterized by fine grained (clay to silty clay) detrital sediments with few, thin silty/sandy turbidite interlayers. We interpret this interval as mixed hemipelagic-turbiditic deposition. Soupy sediment textures related to the presence of gas hydrates are also present in lithostratigraphic Unit III.

Pre-coring LWD/MWD logging was conducted at Site U1326 to direct special tool deployments, such as the PCS, HRC, and FPC pressure cores. The stratigraphic section logged at Site U1326 was divided into three "Logging Units," based on obvious changes in the LWD and wireline gamma ray, density, electrical resistivity, and acoustic measurements. The three identified logging units do not correspond to the defined lithostratigraphic units. Logging Unit 1 (0-72 mbsf in Hole U1326A) is characterized by a resistivity trend that steadily increases from around 1 oh-m near the seafloor to about 1.5 oh-m at the bottom of the unit. This increase in resistivity with depth is matched by an increase in density. This unit shows only a few small resistivity "spikes" (e.g., at about 52 and 60 mbsf in the LWD logs) that may be attributed to gas hydrates. Logging Unit 2 (72-240 mbsf in Hole U1326A) is characterized by uniform density with depth and it includes a prominent high resistivity section from 72 to 107 mbsf in Hole U1326A, with peaks above 40 oh-m. This interval of high resistivity also includes a number of alternating, thin intervals of very low resistivities. These high and low resistivities likely correspond to intercalated layers that have high and low gas hydrate concentrations, respectively. The P-wave velocities measured by wireline logging in Hole U1326D show highly variable values (between 1750 and more than 3000 m/s) in the same high resistivity interval. The high values of P-velocity are consistent with high concentrations of gas hydrate. The top of logging Unit 3 (240-300 mbsf in Hole U1326A) is marked by an increase in density, which remains constant down to 300 mbsf. The background resistivity also increases slightly and displays a clear peak reaching 5 Ω·m in the interval 255-261 mbsf. This resistivity peak could be due to gas hydrate or free gas. Free gas seems more likely, as this interval is located below the BSR depth at this site estimated from seismic reflection data at 234 mbsf. On the other hand, the P-wave velocities are at least 1700 m/s in this unit and there is no sign of the low velocities as expected in a free gas zone.

LWD/MWD derived RAB images from Hole U1326A also indicate the presence of gas hydrate in the high resistivity interval observed in Logging Unit 2, with gas hydrate-rich layers alternating with low-resistivity layers that likely contain little or no gas hydrate. When the RAB images are examined in greater detail, they also show apparent stratigraphic layers in the interval from 50 to 300 mbsf uniformly dipping to the NNE with dips between 45 and 85 degrees. This is in agreement with the WNW-ESE strike of the uplifted ridge penetrated by Hole U1326A.

The Archie interpretation of water saturations from electrical resistivity log data yielded evidence for relatively shallow gas hydrate occurrences at this site within the depth interval from about 50 to 100 mbsf, with inferred water saturations as low as 20%. This interpretation is in general agreement with the freshening of the pore waters observed in sand layers at Site U1326. The infrared (IR) core images taken on the catwalk reveal cold anomalies due to gas hydrate dissociation, which give an independent map of gas hydrate occurrence and concentrations. In some cases IR imaged cold temperature anomalies correlate with layers of high resistivity. In other cases, however, cold intervals in the IR images are harder to correlate to high-resistivity peaks in the wireline or LWD/MWD logs because of incomplete core recovery and intra-site geologic variability.

Cold temperature anomalies were observed at a wide range of depths from 70-250 mbsf, and catwalk sampling was conducted based on these scans. Many IW samples were taken based on IR data to extend the chlorinity anomaly database available for calibrating IR data as a proxy for gas hydrate saturation. We note that the maximum depth of observed IR anomalies is deeper than the anticipated BSR depth of 230 mbsf. The possibility that gas hydrate is present to at least 250 mbsf was confirmed by IR core imaging and interstitial water chlorinity analysis. It was also suggested that the chlorinity anomaly associated with gas hydrate may actually extend to a depth as great as 270 mbsf at this site. This apparent

conflict between the depth of the BSR and the observed occurrence of gas hydrate can be explored with a closer examination of gas hydrate stability condition at this site. Because of difficult weather conditions throughout the duration of the coring operations at this site, we deployed only four temperature tools. For the most part, all of the data from the temperature tool deployments were degraded to some extent. At this time we have extrapolated the temperature data from Site U1325 to estimate temperature conditions at Site U1326. With a surface temperature of ~3.03°C and a geothermal gradient of ~6.0°C/100m, yields an estimated depth to the base of the methane hydrate stability zone for Site U1326 of ~250 mbsf. A predicted methane hydrate stability zone depth of 250 mbsf would help explain most of the deeper IR and chlorinity inferred gas hydrate occurrence, but the several isolated anomalies below this depth requires further post-cruise consideration.

At Site U1326, only one PCS core (Core 311-U1326C-12P) was recovered successfully under pressure and investigated by controlled shipboard degassing experiments. This core was taken at a depth of 84.2 mbsf. The degassing of this single PCS core yielded 21.0 liters of gas, which was determine to be equivalent to a pore space gas hydrate saturation of 40%, which is in close agreement with the gas hydrate saturations estimated from the Archie resistivity calculations in the same interval.

This site was selected to further characterize the occurrence of what could be the tectonically youngest gas hydrate occurrence on the Northern Cascadia Margin, considering it's location within the most western portion of the deformation front. Hydrocarbon headspace gas measurements from Holes U1326C and U1326D, show that methane is the dominant hydrocarbon gas within the cored interval at this site. Although the C_{2+} hydrocarbon void gas concentrations were less than 125 ppmv for all samples, their relative abundance and distribution were valuable for describing the gas hydrate system at Site U1326. Low concentrations of ethane within the interval from ~35 to ~72 mbsf were determined to be directly associated with two recovered gas hydrate samples. With greater depth, ethane concentrations returned to the near surface concentrations close to the depth of the seismically inferred BSR. Iso-butane concentrations were also elevated within the same interval, which may indicate the presence of a Structure II gas hydrate. The occurrence of more complex hydrocarbon gases generally indicates the contribution of a deeper gas source. The salinity and chlorinity profiles at this site also point to a deeper fluid source with a chloride concentration higher than seawater, indicative of low temperature diagenetic reactions in the deeper parts of the site. Except for the difficulties experienced with pressure coring and special temperature tool deployments, all of the objectives set for Site U1326 were considered fulfilled.