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IODP EXPEDITION 311: CASCADIA MARGIN GAS HYDRATES
SITE U1325 SUMMARY

Site U1325 (Prospectus Site CAS-02C) is located near the southwestern end of the margin-perpendicular transect established during Expedition 311 and is within a major slope basin that developed eastward of the deformation front behind a steep ridge of accreted sediments. Bathymetry data show that the seafloor in the western part of this slope basin is relatively flat with water depths around 2200 m. Around Site U1325 the seafloor becomes gradually shallower before it rises rapidly to the east to form the plateau of the second main accreted ridge at water depths around 1200 m, on which Sites U1327 and 889 are located. A bottom-simulating reflector (BSR) is clearly visible in the eastern part of the slope basin, but it fades to the west (CDP 1180 – 1280 along MCS line 89-08). The BSR also shows the typical frequency dependent reflection strength pattern as observed at all other sites. At Site U1325 the BSR is less strong than at the core of a buried ridge of accreted sediments, which is located about 700 m west of this Site. The BSR appears to be at ~230 ± 5 mbsf based on seismic travel-time depth conversion, using an average P-wave velocity of 1636 m/s. This average velocity was determined at Site 889 to match observed travel-time depths of the BSR and VSP data. We acknowledge that this velocity may not be appropriate in this setting. However, lack of good control in seismic interval velocities from MCS semblance analyses of the lines 89-08 and PGC9902_ODP7 prohibited accurate depth migration.

The primary research objectives for this site are linked to the transect-concept of this expedition. The 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 slope basin is expected to show a different geochemical regime and related geophysical properties than the uplifted ridges of accreted sediments.

Four holes were occupied at Site U1325. Hole U1325A was dedicated for the LWD/MWD program to a total depth of 300 mbsf. Hole U1325B was spudded with the APC system but problems arose due to thick sand accumulation causing a switch to XCB core barrel for one core section and a switch back to APC. The hole was then advanced by combination of APC, XCB, and pressure coring to a depth of 206.5 mbsf. Interspersed with the XCB cores was a DVTP run at 140.5 mbsf, which yielded high quality temperature data. Five pressure cores were deployed in Hole U1325B but all attempts failed to retrieve sediments under pressure. The last run with a PCS resulted in a stuck tool, which lead to the abandonment of the hole. Hole U1325C was drilled to a depth of 188 mbsf where core recovery in Hole U1325B began to deteriorate. Coring operations resumed with the XCB system, interspersed with two pressure coring runs (one failed FPC run, one successful run with the PCS) and two DVTP deployments, deepening the hole to a TD of 304.3 mbsf. Because of degrading weather conditions, it was decided that two separate logging runs would be attempted without calipers to reduce the potential risk of damage to the tool strings. The first run included the phasor Dual Induction Tool and the Hostile Environment Gamma Ray Sonde. The second run included the Dipole Sonic Imager, the Scintillation Gamma Ray tool and the Temperature/Acceleration/Pressure tool. We were only able to lower the first tool string to 259.8 mbsf, which is 44.5 m shallower than total depth for coring, and the hole was successfully logged followed by some difficulty re-entering the drill pipe. The second tool string (sonic without the FMS) was deployed and was only able to reach a TD of 185.8 mbsf and the available hole was logged successfully. The repeat pass of the sonic tool string reached 183.0 mbsf. To ensure that a mudline core was obtained at this site, Hole U1325D was established with one APC core only (4.69 m recovery) indicating a seafloor depth of 2193.2 mbsl (2204.8 mbrf). Analyses of the pore water showed that the first core in Hole U1325C had missed the mudline by ~ 3 m.

The sediments cored at Site U1325 are mostly Quaternary in age, which is based on the examination of the diatoms from Holes U1325B and U1325C. The 304.3 m-thick sedimentary section cored at Site U1325 was divided into four lithostratigraphic units based on visual inspection of the recovered cores and analysis of smear slides. Lithostratigraphic Subunit IA (0-52.50 mbsf in Hole U1325B; 0-4.69 mbsf in Hole U1325D) is characterized by very abundant, thick, coarse grained sand layers within fine grained (clay and silty clay) detrital interlayers. The thickness of the sand layers suggests the depositional environment of a distributary channel within the slope basin with mass transport parallel to the uplifted bounding ridges. Sedimentation rate for the upper 129 mbsf of sediments (lithostratigraphic Units I, II, and upper part of Unit III) was estimated of 43 cm/k.y. This is the highest sedimentation rate calculated for any site occupied on Expedition 311. Lithostratigraphic Subunit IB (24.00-52.23 mbsf in Hole U1325B) is composed of fine grained (clay to silty clay) detrital sediments with few, thin silty/sandy interlayers from turbidites. The occurrence of only marine diatoms suggests that the terrigenious sediment flux was somehow restricted. In addition, the occurrence of abundant bioturbation and sulfide mottles suggests more hemipelagic-dominated sedimentation. Mousse-like texture related to the presence of gas hydrates is present at depths as shallow as 26 mbsf. The boundary between lithostratigraphic Subunit IA and IB is marked by a seismic horizon (unconformity) that can be traced for about 1.5 km around Site U1325. It separates undeformed, seafloor parallel slope sediments from underlying deformed and slightly faulted sediments. It is likely that at Site U1325 we penetrated a fault within lithostratigraphic Unit II near the base of the unit.

Lithostratigraphic Unit II (52.23-102.30 mbsf in Hole U1325B) is characterized by fine grained (clay to silty clay) detrital sediments with intervals of silty/sandy interlayers. We interpret the coarser interlayers as turbiditic deposits. Their frequent occurrence might indicate times of active tectonism. The boundary between lithostratigraphic Unit I and II is marked by the absence of diatoms, bioturbation, less intense sulfide mottles and a sharp decrease in the occurrence of sponge spicules. Mousse-like texture related to the presence of gas hydrate was also observed in lithostratigraphic Unit II. Lithostratigraphic Unit III (102.30-189.44 mbsf in Hole U1325B; 188.80-192.08 mbsf in Hole U1325C) is characterized by fine grained (clay to silty clay) detrital sediments with abundant sponge spicules and diatoms. We interpret this interval as mixed hemipelagic-turbiditic sediments. The presence of authigenic carbonate cement suggests that diagenetic processes are active in lithostratigraphic Unit III. Soupy and mousse-like sediment textures related to the presence of gas hydrates are present in lithostratigraphic Unit III, within the depth interval from ~120 to ~150 mbsf. The boundary between lithostratigraphic Unit III and IV is marked by the sudden decrease in diatoms. Lithostratigraphic Unit IV (197.40-206.56 mbsf in Hole U1325B; 198.40-304.30 mbsf in Hole U1325C) is characterized by fine grained (clay to silty clay) detrital sediments with few silty/sandy interlayers from turbiditic deposits. The poor recovery in this unit limits the observation of sedimentary structures; however, the appearance of several coarser grained layers indicates low-energy turbidity currents.

Pre-coring LWD/MWD logging was conducted at all sites occupied on Expedition 311 to direct special tool deployments, such as the PCS, HRC, and FPC pressure core systems. The stratigraphic section logged at Site U1325 was divided into three “Logging Units” based on obvious changes in the LWD/MWD and wireline gamma ray, density, electrical resistivity, and acoustic measurements. There is no obvious correlation between the logging units and the lithostratigraphic units. Logging Unit 1 (0-122 mbsf) is characterized by a well-defined gradual increase in density with depth and a corresponding decrease in porosity. This increase in density is matched by a corresponding increase of resistivity with depth, from about 1 ohm-m near the seafloor to about 1.5 ohm-m at 122 mbsf. The boundary between logging Units 1 and 2 corresponds to the 0.3 Ma age boundary noted in the biostratigraphy. Logging Unit 2 (122-260 mbsf) is characterized by a uniform density that averages about 1.9 g/cm^3. In contrast, the resistivity logs in Unit 2 show alternating, thin intervals of high and low resistivity, spanning the range 1-15 ohm-m. These high and low resistivities are likely to correspond to intercalated layers that have high and low gas hydrate concentrations, respectively. Logging Unit 3 (260-350 mbsf) displays a uniform background resistivity (about 1 ohm-m) and density (about 2 g/cm^3). The most striking feature of this unit is the presence of several borehole enlargements.

LWD/MWD derived RAB images from Hole U1325A suggest that gas hydrates occur concentrated in thin sand layers within the depth interval between 173-240 mbsf (Logging Unit 2). The LWD/MWD porosity and resistivity logs from Hole U1325A further show that it is very heterogeneous gas-hydrate-bearing section, composed of alternating layers of gas hydrate saturated sands and clay-rich layers with little to no gas hydrate. This interpretation is in general agreement with the marked freshening of the interstitial waters observed in sampled sand layers.

There appears to be little correlation between the core derived physical properties data and the defined lithostratigraphic or logging units. Sediment density and porosity determined from MAD analyses show a typical sediment compaction trend with depth. Slight deviations in the density and porosity profiles with depth reflect small-scale lithologic variability and generally match the downhole measured LWD/MWD data. Infrared (IR) imaging of the recovered cores was routinely carried out on the catwalk to detect and characterize the nature of gas hydrates in the cores. A large number of IR imaged cold spots were detected in the cores from Holes U1325B and U1325C and were partially subsampled for focused interstitial water analyses and microbiology studies. In many cases the IR imaged cold temperature anomalies correlated with layers of high resistivity and low interstitial water salinities and chloride concentrations, which have been shown to be associated with the occurrence of gas hydrate.

Six deployments of temperature tools were attempted at Site U1325, and all six provided useable data. Three APC3 and one DVTP deployment in Hole 1325B as well as two additional DVTP deployments in Hole U1325C occurred during times of relatively low heave and yielded excellent quality data. A linear fit to the points indicates a thermal gradient of 0.060 ± 0.003 ^{o}C/m and a seafloor intercept of 3.03 ± 0.55 ^{o}C. The temperature data indicate that the base of the methane hydrate stability zone for this site, assuming a hydrostatic pore pressure gradient and seawater salinity, is at 275 ± 25 mbsf.

Pressure coring tools were deployed seven times at Site U1325, including two PCS cores, two HRC cores and one FPC core in Hole U1325B. Hole U1325C included one FPC core from above the projected depth of the BSR and a PCS core from well below the estimated depth of the BSR. Pressure coring proved to be extremely difficult at Site U1325, with only the deepest PCS (Core 311-U1325C-10P, 256.5 mbsf) recovered successfully under pressure, which was investigated by a controlled shipboard degassing experiment. All other attempts to deploy pressure cores failed for various reasons, partially due to difficult lithologic conditions (the presence of unconsolidated fine sand) and the potential effect of adverse ship heave conditions. The degassing of Core 311-U1325C-10P yielded 2.07 liters of methane gas and may have contained small amounts of gas hydrates (0.4%) or free gas

(0.3%) depending where the base of gas hydrate stability (BGHS) is situated (see uncertainty in temperature-derived BGHS above).

A total of 92 IW samples were processed from two holes cored at Site U1325. The salinity and chlorinity profiles at this site appear to indicate an advective transport system with the occurrence of higher than seawater salinity and chlorinity, which likely comes from a deeper source (~36 and 600 mM, respectively). The chlorinity of this fluid is 7.3% above the modern seawater value, more than twice the value of the interglacial maximum ocean value (3.5%). The elevated solute concentration may instead be caused by low temperature diagenetic reactions in the deeper parts of the basin. The most plausible candidate for such a reaction is the alteration of volcanic ash to clay minerals and/or zeolites. In the zone extending from ~70 to 240 mbsf (the BSR is at ~230 ±5 mbsf), the salinity and chlorinity data show discrete excursions to fresher values indicating that gas hydrate was present in the cores and dissociated prior to processing the samples. Intense microbial activity at Site U1325 results in sulfate depletion, phosphate and alkalinity production, and significant Ca and Mg depletion in the interstitial waters of the upper 3 mbsf. At this site the sulfate/methane interface was placed between 4 and 5 mbsf, based on samples recovered from Hole U1325D.

Organic geochemical studies at Site U1325 included analysis of the composition of volatile hydrocarbons (C_1-C_5) and non-hydrocarbon gases (i.e., O_2 and N_2) from headspace gas samples, void gas samples, and gas samples recovered during the only PCS degassing experiment. With the exception of several samples that contained a large percentage of air, the void gas was almost entirely methane and a small percentage of carbon dioxide (~0.1 to 0.5%). Trace quantities of C_2+ hydrocarbons (< 5 ppmv) were present above the seismically inferred BSR (230 mbsf). With greater depth, the concentrations of ethane, propane and i-butane increased, but did not exceed 15 ppmv. The molecular ratios of methane to ethane (C_1/C_2) were the highest observed during Expedition 311. Values from where gas voids were first observed (9.1 mbsf) to the seismically inferred BSR ranged from ~61,000 to ~173,000 and showed no apparent trend with depth.

Microbiological subsampling was routinely conducted on cores recovered from Holes U1325B and U1325C. On each core run, perfluorocarbon tracers (PFT) were continuously metered into the drilling fluid and fluorescent microspheres were deployed to investigate potential drilling fluid contamination of the core. These analyses confirmed that the center of each whole-round sample remains undisturbed for microbiological subsampling. Additional IR images were taken on the cut-ends of each microbiological core section to document the thermal warming process of the core before subsampling.

At Site U1325 the pore water chemistry is distinctly different than what has been found at the other sites during this expedition, in that chlorinity and salinity increase with depth rather than decrease. This trend, attributed to a shallow, more saline sourced-fluid, is used as evidence for an advection-driven system, it also shows that this part of the basin is likely detached from the more broad-scale fluid-flow regime seen at the other sites.

Seismic data suggest that the sediments cored at Site U1325 are similar to those seen in a seafloor-parallel package of sediments on the SW side of the buried accreted ridge but they have been deformed and tilted with small offset faults associated with the uplift of the underlying ridge. Enhanced advective fluid flow from the buried accreted basin resulted in gas hydrate formation within the overlying deformed section, and preferentially in the coarser grained turbidite sequences. In contrast, the SW part of basin has relatively little deformation and postulated reduced fluid flow and therefore less gas hydrate, which also explains the lack of a strong BSR in that part of the basin.

Although the BSR is not very prominent near Site U1325, the stratigraphic section beneath the projected BSR generally shows high amplitude reflectors and up-dip amplitude truncations at the BSR, typical of free-gas being trapped beneath the BSR. Data from downhole logging and coring also revealed lateral homogeneity between the holes at this site, which is a testament to the orientation of the holes along structural strike in a NW-SE direction, avoiding the steep SW-NE dipping slope seen in the seismic data.