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IODP EXPEDITION 311: CASCADIA MARGIN GAS HYDRATES
SITE U1329 SUMMARY

Site U1329 (Scientific Prospectus Site CAS-05D) is at the eastern end of the southwest-northeast trending, margin-perpendicular, transect of sites occupied during this expedition and is located closest to shore (65 km) at a water depth of ~946 mbsl. The location of this site is interpreted to be at the eastern limit of gas hydrate occurrence on the Northern Cascadia Margin.

The objectives of coring and downhole logging at this site are tied to completing the transect of scientific drill sites across the Northern Cascadia Margin to further constrain models for the formation of marine gas hydrate in a subduction zone acretionary prism. The depth to the BSR rapidly becomes shallower around this site and is only half the depth (~125 mbsf) than at Site U1327 (~225) mbsf. At this eastern end-member site of gas hydrate evolution in the acretionary prism, the objectives include (a) characterizing the distribution of gas hydrate, (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 and controlled-source EM.

Five holes were occupied at Site U1329 (CAS-05D). Hole U1329A was dedicated to LWD/MWD measurements to a total depth of 220 mbsf. Hole U1329B consisted of only one missed mudline APC core to 9.5 mbsf. Hole U1329C was continuously cored (17 APC, 5 XCB, 3 PCS cores; 99.3 % recovery) to 189.5 mbsf, and was terminated before the target depth of 220 mbsf when the PCS cutting shoe broke off and was left in the bottom of the hole. The PCS was deployed three times in Hole U1329C and four APC temperature measurements were made (APCT and APC3). Swell from a passing low pressure system resulted in ship heave that was too high for wireline logging or coring operations and we waited four hours for the weather to improve. With a forecast for improving weather the following day, we decided to abandon Hole U1329C to drill a dedicated logging hole. Hole U1329D was drilled from the seafloor to 201.0 mbsf, which included another 1.5 hr of suspended operations due to excessive ship heave, and a single XCB core was taken to 210.5 mbsf. Hole U1329D was wireline logged with the triple-combo and FMS-sonic tool strings. The triple-combo and the first pass of the FMS-sonic were logged to 209 mbsf. The second pass of the FMS-sonic only reached 171 mbsf. Hole U1329E was a special tool hole to 127.1 mbsf where five APC cores were taken for high resolution microbiological and geochemical studies with two additional APC temperature measurements. Three DVTP probe deployments were also conducted. Five pressure cores were taken (3 PCS, 1 HRC, and 1 FPC) separated by drilled intervals.

Site U1329 is located near the foot of a relatively steep slope, and sedimentation at this site is dominated by slope processes. The stratigraphy at Site U1329 was divided into three lithostratigraphic units. Unit I (0 – 37.18 mbsf in Hole U1329C, 0 – 33.31 mbsf in Hole U1329E) is characterized by fine grained detrital sediments (clay and silty clay), locally interbedded with coarse grained sediments. Authigenic carbonates are abundant in some cores from Unit I, including the location of dolomite in Holes U1329C and U1329E, which coincides with changes in pore water Ca and Mg profiles suggesting dolomite formation is an ongoing process. The sedimentation rate in Unit I appears to be relatively rapid at about 10 – 12 cm/k.y. The boundary between lithostratigraphic Unit I and II is defined by the first occurrence of diatom ooze. Lithostratigraphic Unit II (37.18 – 135.60 mbsf in Hole U1329C, 33.31 – 125.95 mbsf in Hole U1329E) is characterized by a high abundance of biogenic silica (mainly diatoms). The sedimentation rate within Unit II appears to increase, relative to Unit III, from about 4 to 10 cm/k.y. The boundary between lithostratigraphic Unit II and III is marked by a conglomerate, composed of partly lithified and lithified rounded clasts supported by a silty clay matrix. The conglomerate at the base of Unit II corresponds to an unconformity between upper Miocene and Pleistocene sediments (no sediments preserved from 2–6.7 Ma) that also can be traced seismically for several kilometers along line 89-08. The unconformity is not clearly seen in the higher-frequency seismic data crossing line SCS CAS05C-01-04. Lithostratigraphic Unit III (135 mbsf–TD) is characterized by fine grained (clay to silty clay) detrital sediments with only a few coarser interlayers from turbiditic deposits. The input of detrital sediments from turbidites, however, is more obvious deeper in the section with the presence of non-marine diatoms. In the lowermost part of Unit III, a breccia deposit marks a major change in deposition, possibly representing a debris flow. The sediments in lithostratigraphic Unit III were deposited at a low sedimentation of rate of ~0.8–2.8 cm/k.y.

The biostratigraphy at this site was established by the analysis of diatoms. These analyses showed an interval of Quaternary sediments from the surface to about 35 mbsf that corresponds to Lithostratigraphic Unit I. The age of lithostratigraphic Unit II was shown to range from 0.3 to 2.0 Ma. This interval showed an abundance of diatoms and resting spores suggesting a depositional environment typical of a coastal shelf area with upwelling. The sediments of this interval may also have been transported to this site from the shelf by turbidites. Sediments deeper than 137 mbsf, near the contact between lithostratigraphic Unit II and III, contain diatoms of only late Miocene age (> 6.7 Ma), thus the Pliocene at this site is completely missing representing about 4 m.y. of missing sediment, which was likely eroded.

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 downhole logged section at Site U1329 was divided into three “Logging Units” based on obvious changes in the LWD/MWD and wireline gamma ray, density, electrical resistivity, and acoustic transit-time measurements. Logging Unit 1 (0-130 mbsf), which corresponds to lithostratigraphic Units I and II is characterized by low electrical resistivities and densities. Logging Unit 2 (130-183 mbsf) is characterized by a small increase in resistivity and density compared to logging Unit 1. The top of logging Unit 2 corresponds to the bottom of lithostratigraphic Unit II, which was identified as an unconformity separating Pleistocene from Upper Miocene sediments. Logging Unit 3 (183 mbsf-TD) is characterized by an abrupt increase in electrical resistivity, density, and P-wave velocity; indicating an increasingly consolidated formation with lower log-derived porosities. Logging Units 2 and 3 correspond to lithostratigraphic Unit III.

Variations in physical properties apparently do not correlate well with the identified lithostratigraphic and logging units. Index property analyses of porosity and bulk density as well as gamma-density data from the MST show an anomalously uniform trend throughout most of the section cored from 25–180 mbsf. A slightly different trend is observed in the upper 25 mbsf where porosity rapidly decreases to values as low as 55%, coincident to the depth where rapid changes in the core derived shear strength and electrical resistivity occur. Except for the top 15 mbsf, the magnetic susceptibility record shows extremely low and uniform values of less than $50*10^{-7}$ SI. Grain density appears to have a general downhole decreasing trend crossing all lithostratigraphic boundaries starting from values of ~ 2.8 g/cm^3 near the seafloor to ~2.6 g/cm^3 at 175 mbsf, but this trend reverses below this depth and again reaches values as high as ~ 2.8 g/cm^3. This deep increase in grain density and associated increase in bulk density occurs near the top of logging Unit 3, which is characterized by a sudden increase in electrical resistivity and drop in porosity. Analysis of the LWD/MWD density logs from this site yielded sediment porosities ranging form about 65% near the seafloor to about 23% at 220 mbsf.

Infrared (IR) imaging of the recovered core was used to assist in immediate gas hydrate detection on the catwalk. At this site, core IR temperatures did not show any significant cold-spot anomalies from gas hydrate dissociation that could be related to the presence of gas hydrate in the recovered core. In situ temperature measurements with the APC3, APCT and DVTP tools indicated a temperature gradient of 72 ± 4 °C/km and a seafloor intercept of 3.34 ± 0.34°C. This impies a heat flow of 68-84 mW/m^2 for measured thermal conductivities of 1.0-1.1 W/mK. This is consistent with the regional heat flow across the northern Cascadia margin (predicted to be ~72 mW/m^2 here) but higher than the heat flow measured at Site 889 during ODP Leg 146, indicating that heat flow at this site in not affected by sedimentation and fluid expulsion.

In total six PCS deployments were made, three in Hole U1329C and three in Hole U1329E. Out of the six deployments, two runs did not recover sediment under pressure and all other runs retrieved sediments under pressure, although at measured surface pressures approximately half the expected in-situ hydrostatic pressure. It was concluded that the tool is sealing only when a certain differential pressure is reached, not at the in-situ pressure of the cored interval. All PCS cores that were successfully retrieved under pressure were degassed and subsamples of the recovered gas were analyzed on the ship and additional subsamples were taken for shore-based isotope studies. In addition to the PCS, one HRC and one FPC were deployed in Hole U1329E. A full core at near in situ pressure was recovered by the HRC that revealed 10 cm high velocity zones indicative of gas hydrate. The FPC deployment recovered a core without pressure. The degassing of the four PCS cores from this site that were recovered under pressure showed variable gas concentrations with depth. PCS Core U1329C-7P (55.6–56.6 mbsf) and Core U1329E-7P (73.5–74.5 mbsf) from within the predicted depth of the methane hydrate stability zone, had total pore space methane concentrations of 79 and 85 mM, respectively, which would equate to a gas hydrate pore volume concentrations of less than one percent for both core samples. PCS Core U1329E-10P (125.0–126.0 mbsf), from near the base of the predicted methane hydrate stability zone for this site, had a methane concentration of 107 mM, which falls near the value for a saturated methane pore volume at this depth, with no gas hydrate or free gas. The deepest PCS core (Core U1329C-23P; 154.61–155.6 mbsf) was taken at a considerable depth below the base of the gas hydrate stability zone. This deep PCS had total pore space methane concentration of 322 mM, which suggests a potential pore volume free-gas saturation of 4.2%. A potential gas release during the coring operation may cause this to be an overestimate, yet it still supports the presence of free gas below the BSR at this site.

Interstitial water (IW) analyses were carried out on samples from Hole U1329C with additional high-resolution sampling in the top 15 mbsf of Hole U1329E to capture the sulfate/methane interface (SMI). Interstitial water salinities decreases from ~34 to ~30 at a depth of ~50 mbsf but remains almost constant at values of around 30.5 until near the bottom of the cored section in Hole U1329D. The deepest water samples from this site (>180 mbsf), show a sharp drop in salinities ranging from 22 to 28. A distinct chlorinity minimum (~15 mM decrease relative to the rest of the trend) is observed at the projected depth of the seismically inferred BSR. Assuming that this chlorinity minimum is the result of gas hydrate dissociation during core recovery and handling, the observed chlorinity minimum would equate to ~2% in-situ pore-space filling of gas hydrate. The strong decrease in chlorinity and salinity below 180 mbsf are coincident with the pronounced increase in electrical resistivity in the LWD/MWD downhole logging data in logging Unit 3 and suggests communication with a deeper sourced fresher fluid. The Ca and Mg depth profiles reflect carbonate and dolomite formation in the shallow section (SMI – 60 mbsf), but also suggests the commingling with a deeper-sourced fluid over a depth range from 60 mbsf to the BSR.

Organic geochemical studies at Site U1329 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 PCS degassing experiments. The predominant hydrocarbon gas found in the cores from Site U1329 was methane, however, we did see an increase in ethane concentrations in the void gases collected from stratigraphic section overlying the projected depth of the BSR. This increase in ethane concentrations near the BSR can also be seen in the plot of the C_1/C_2 void gas ratios. Other studies have shown void gas ratios (such as C_1/C_2) can be elevated in a gas hydrate with the preferential selection of ethane into the gas hydrate structure. But the observed increase in the C_1/C_2 ratio below the projected depth of the BSR may be more indicative of a methane enriched free-gas accumulation. In general, the C_1/C_2 ratios were generally high, suggesting a microbial origin for the observed methane. The samples collected from deeper than 180 mbsf at this site also exhibited significant increases in C_2-C_5 concentrations, which suggests the influence of a potential thermogenic hydrocarbon source.

Microbiological subsampling was routinely carried out on cores recovered from Hole U1329C. On each core run, perfluorocarbon tracers (PFT) were continuously metered into the drilling fluid and additional fluorescent microspheres were deployed on selected cores 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.

When considering the primary research objectives of this site, one of the most important features is its location on the relatively steep slope and the observation that sedimentation at this site is dominated by both slope turbidite deposition and erosional processes. The presence of thick turbidite sequences, including the presence of non-marine diatoms in the startigraphic section is a testament to the history of slope dominated processes. The occurrence of a significant depositional hiatus or erosional event that juxtaposes Miocene with Pleistocene sediments at this site further documents the complex depositional history of this margin. The deepest core and downhole logging penetrations at this site also revealed even a more complex geologic history with unique high resistivity, low porosity, conglomerate deposits that may represent thick debris flows.

Geochemical analysis of core recovered gas samples and interstitial fluids have also documented a relatively complex fluid regime for this site. The relatively low interstitial fluid chlorinities observed near the seafloor may reflect paleoceanographic changes in seawater salinity. However, the more rapid Cl concentration decrease with depth strongly suggests the communication with a deep-seated, fresher fluid, especially below 140 mbsf. For the most part, the geochemical analysis of gases from this site reveal a similar story as the analysis of the interstitial fluids with most of the cored section dominated by a simple methane gas-rich system. But near the bottom of the cored section we appear to see the influence of a deeper hydrocarbon source.

Identifying gas hydrates and supportive physical evidence of the BSR at this site remains an elusive goal. The BSR is subtle at this site and is located only ~10 m above a prominent unconformity, which results in a complicated reflectivity pattern. The pre-coring LWD/MWD and conventional wireline log data were used to identify and further characterize potential gas hydrate and related free gas occurrences at each site occupied on this expedition. The presence of gas hydrate is generally characterized by increases in measured electrical resistivities and acoustic velocities. The relative lack of notable resistivity or acoustic downhole log anomalies at this site supports a general inference of very low to no gas hydrate occurrence at this site. The lack of either visual observations of gas hydrate or the occurrence of IR detected thermal anomalies along the recovered cores also supports the assumption that this site contains little to no gas hydrates. However, the geochemical analysis of interstitial fluids from near the depth of the predicted BSR may suggest the presence of a small amount of gas hydrate, with minimum dissolved chloride concentration at about 125 mbsf, coincident with the depth of the BSR. The HRC core taken from 114.6 mbsf, which contained high-velocity layers, also suggest the presence of gas hydrate at these depths. In addition, the relative increase in ethane concentrations immediately above the depth of the BSR may indicate the presence of gas hydrate. Degassing experiments of three PCS cores that were collected from within the zone of predicted methane hydrate stability zone appear to confirm that this site contains very little gas hydrate if any. However, a PCS core from 188.5 mbsf in Hole U1329C does suggest the occurrence of a free-gas phase. The presence of free gas at greater depth below ~160 mbsf may also be supported by a distinct change in seismic reflection character in the low-frequency seismic data of line 89-08. In contrast to the shallower section of the seismic line above 1.5 s TWT, no clear reflection can be identified below and seismic frequency also is strongly reduced.

As noted, this site was intended to characterize the eastern limit of gas hydrate occurrence on the Northern Cascadia Margin, and establish an understanding of the geologic controls on the occurrence of gas hydrates along the transect of sites established during this expedition. All of the objectives set for Site U1329 are considered fulfilled.