IODP Proposal Cover Sheet

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Title:	IODP proposal 553-Full2 “Cascadia Gas Hydrates”
Proponent(s):	Michael Riedel, Roy D. Hyndman, Earl E. Davis, Tim S. Collett, Douglas Bartlett, Ken Takai, Miriam Kastner, George D. Spence, and Scott R. Dallimore
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Contact Information:

Contact Person:	Michael Riedel		
Department:	Natural Resources Canada		
Organization:	Geological Survey of Canada – Pacific		
Address	9860 West Saanich Road, Sidney, BC, V8L 4B2		
Tel.:	250-363-6885	Fax:	250-363-6565
E-mail:	mriedel@NRCan.gc.ca		

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Abstract: *(400 words or less)*

This addendum to the IODP proposal 553-Full2 is to outline outstanding operations not carried out during IODP Expedition 311, undertaken from August 25 to October 28, 2005. Expedition 311 was a light version of the originally submitted proposal. Only standard drilling, coring and logging operations at five of the originally proposed six sites were carried out. Operations included drilling Sites U1325 (CAS-02B), U1326 (CAS-03C), U1327 (CAS-01B), U1328 (CAS-06A), and U1329 (CAS-05D). Proposed Site CAS-04B in the deep Cascadia Basin has not been drilled and is proposed for the Phase-II operations. Additional long-term monitoring experiments in two closely spaced wells using Advanced Circulation Obviation Retrofit Kit (ACORK) instruments (at Site CAS-01C) and distributed (fibre-optic) temperature sensing (DTS) cables are proposed. Additional geophysical testing with the modular formation dynamics tester (MDT) as well as a walk-away Vertical Seismic Profile is proposed for Phase-II.

This addendum describes the main results of Expedition 311 as they relate to Phase-II operations and also outlines technical details and specifications to the two instrument packages proposed for long-time monitoring and the MDT-tool for specific gas hydrate studies.

Proposed Sites:

Site Name	Position	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
CAS-04B	048 33.461 N 127 09.934 W	2600	500	0	500	Reference location of Expedition 311 transect. Site will provide important reference information about the sediments that do not contain gas and/or gas hydrate. A-Hole; LWD, B-Hole coring, C-Hole: tools hole
CAS-01C	048 41.682 N 126 51.630 W	1250	600/400	0	600/400	Dual ACORK Site. Near U1327 and U1328. Long-time monitoring experiment and link to NEPTUNE cable observatory. A-Hole: 600m, B-Hole 400m

Introduction

IODP Expedition 311 produced significant results from the first phase of a proposed two-phase gas hydrate drilling program based on IODP proposal 553-Full2. This addendum updates the original proposal based on the initial results of Expedition 311, and the results of recent surveys, analyses, and other developments. It also summarizes the new opportunities for long-term monitoring borehole instruments provided by the NEPTUNE cable observatory and outlines the operations not yet carried out during the first phase of this effort. Expedition 311 was a shortened version of the originally submitted proposal, but it carried out the critical initial component of drilling, coring and logging operations at five of the originally proposed six sites across the margin, i.e., Sites U1325 (CAS-02B), U1326 (CAS-03C), U1327 (CAS-01B), U1328 (CAS-06A), and U1329 (CAS-05D) (**Figure 1**). Reference Site CAS-04B in the Cascadia Basin was not drilled and is proposed for Phase-II. Expedition 311 provided critical constraints on the distribution of gas hydrate across an accretionary sedimentary prism, i.e., from the first formation to the subsequent final dissociation. The proposed second phase expedition concentrates on downhole measurements and experiments, and on borehole long-term recording instrumentation including: a dual-hole ACORK (Advanced Circulation Obviation Retrofit Kit) deployment for measurements of pressure, permeability and other formation characteristics, and for long term monitoring; the MDT tool (Modular Formation Dynamics Tester) for formation pressure and permeability etc.; and formation temperatures (using distributed fiber-optic Temperature Sensing [DTS] cables). An exceptional opportunity is provided by the NEPTUNE deep sea cable system that will be deployed around the northern part of the Juan de Fuca plate starting in 2007.

NEPTUNE cable observatory and connection to Phase-II operations

The NEPTUNE Stage I Juan de Fuca cable observatory system plans its main cable/node installation around the northern part of the Juan de Fuca plate in the summer of 2007 with the first community experiments/sensors being installed in mid-2008. The recently approved plan for the NEPTUNE Canada array has the cable routed along the transect of the X311 drill sites across the N. Cascadia Margin with a branching unit at Site U1327 (CAS-01B) that will allow the deployment of a node and extension cables to the holes in this region. The NEPTUNE project offers a unique opportunity to augment the scientific objectives of proposal 553-Full2 by linking the borehole instruments and a range of other instruments to the cable system for long-term, real-time, high data bandwidth monitoring. The cabled system, with high power and high data bandwidth, allows interactive experiments to be performed in and around the boreholes, not just basic monitoring observations. A financial support for seafloor broadband seismometer development, installation, and connection to the cable has recently been approved by NEPTUNE in Canada. The seafloor seismometer and other instrumentation now in development should meet many of the development needs for NEPTUNE recording of IODP downhole installations.

Review of Expedition 311 results relevant to Phase-II operations

Much work and interpretation of the Phase I Expedition results are yet to be done, but some very important conclusions are evident in the initial analyses. In accretionary sedimentary prisms, the occurrence of gas hydrate appears to be controlled by several key factors. The concentration and vertical distribution of gas hydrate changes significantly as those factors vary in the sediments along the margin. They are: (1) fluid/gas upward advection rates, that may be episodic, (2) local methane solubility linked with pore water salinity, and (3) availability of suitable host material (especially coarse-grained sediments). In a simple regional model for gas hydrate formation in an accretionary margin (e.g., Hyndman and Davis, 1992), upward fluid and gas flow will result in most hydrate being formed where methane first moves into the stability field just above the BSR. The highest concentrations of gas hydrate are expected to occur near the base of the gas hydrate stability zone, with concentrations gradually decreasing upward as a result of pervasive fluid advection from overall tectonically driven fluid expulsion. The results of Expedition 311 show first, that much of the upward fluid and gas flow is not pervasive, but focused by complex structures resulting in complex distributions of gas hydrate. Gas hydrate concentrations occur at variable depths above the BSR. Secondly, there is an important additional local overprinting factor of gas hydrate being preferentially concentrated in the coarser sediments. The widespread gas hydrate–related BSRs in this and other clastic accretionary prisms are interpreted to require some gas hydrate just above the BSR as a gas barrier, and some gas hydrate was inferred from the new data just above the BSR in all but the most landward site. However, only at Site U1325 are the greatest hydrate concentrations in the 50 m near the BSR. At Site U1326 on the first ridge, and at Site U1327 on the mid slope, the largest concentrations of gas hydrate were observed well above the BSR at a depth of ~100 mbsf, where gas hydrate deposits several tens of meters thick have concentrations locally exceeding 80% of the pore volume. This depth may represent the point where the amount of methane in the pore fluid exceeds the local methane solubility threshold (**Figure 2**). An extreme case of local focusing of fluid and methane is the cold vent Site U1328 where very high gas hydrate concentrations were found at shallow depth. Beds of massive gas hydrate occur within the top ~40 mbsf with concentrations exceeding 80% of the pore space, probably as a result of focused upward fluid/gas migration (Expedition 311 Scientists, 2005).

The gas hydrate deposits found showed strong lateral heterogeneity (i.e., at Site U1327) that needs further investigation. This heterogeneity must be taken into account in the design of the ACORK and other experiments, especially the distance between the adjacent boreholes and the depth-location of packers and screens, although the originally proposed basic concept and objectives remain the same.

Accurate and precise formation temperatures are fundamentally important data from IODP boreholes, for example for comparison of the formation temperatures at the BSR with various hydrate stability fields (dependent on hydrocarbon composition and pore fluid salinity), for heat flow determination, and for local and regional upward fluid flux determinations that may be episodic. It proved very difficult to obtain reliable and accurate formation temperatures on Expedition 311, in spite of considerable effort and the use of several different instruments

(**Figure 3**). This was in part due to the generally rough weather (the Phase I Expedition was late in the good weather window), but much more accurate and detailed temperature data are of high priority. The proposed installation of continuous DTS temperature measurement cables in Phase II boreholes for long-term recording should meet the need for accurate and very detailed temperature data.

Outline of DTS temperature device and proposed deployment

Measurement of the undisturbed formation temperatures is critical to assessing the base of the gas hydrate stability field (and relation to gas composition, pore fluid salinity, and sediment-hydrate chemical interactions), variations in the geothermal properties of gas hydrate intervals, and determination of both localized and regional fluid flow regime. An innovative application of a fibre-optic cable technique for the measurement of borehole temperatures was successfully applied at the 2002 Mallik gas hydrate research well program in arctic Canada. Distributed temperature fibre-optic sensor cables were installed in three wells outside the casing string (Henninges et al., 2003). The data acquisition system used at Mallik allows the collection of high-resolution temperature measurements allowing for determination of both short-term variations due to fluid flow and the long-term equilibrium temperatures. The observation of temperature changes over long time periods are extremely important to the overall question of pervasive and/or fault related fluid flow, and to the relation between fluid expulsion and flow associated with large earthquakes.

A new marine deployment-technology for the DTS cables was developed and used with the JOIDES Resolution during the 2004 Nankai trough campaign (Fukuhara et al., 2005). The DTS cables are attached to drill pipe and deployed with a seafloor data storage and communication unit. The drill pipe is severed near the seafloor and remains in the ground. The formation appears to close in on the pipe and no cementing is required. During the Nankai trough campaign a 1.5 month long data series was obtained allowing detailed temperature analyses after the circulation and drilling temperature disturbances had decayed. It was found that adequate approach to equilibrium formation temperatures were reached after about 30 days. This DTS cable system will require further minor modifications to connect it to the NEPTUNE cable observatory. The cable system is an important opportunity to remove the need of subsequent ROV dives for battery power supply replacements, and will allow much longer observations.

A-CORK instrumentation

Advanced CORK Installations

The safest and most efficient approach appears to be to insert the ACORK strings into LWD holes drilled immediately prior to ACORK operations. A short section of casing with a small re-entry cone is drilled in to stabilize the hole for LWD operations, and to allow re-entry. Precise spacing of the CORK screens will be determined from the nearby coring results, and refined by the LWD data which will be available within 2-3 hours of recovery of the LWD tool string. This strategy proved successful during Leg 196. Among the many benefits of the ACORK design is that the full internal diameter of the casing is available for post-drilling downhole experiments and monitoring tools. Fluid sampling and hydrologic monitoring can take place independently on the outside of the casing. Since the casing strings can be sealed at the bottom, the holes can be re-entered at any time, without the requirement to maintain a pressure seal at the top of the hole. Candidates for sealed-hole monitoring sensors include seismometers, tilt meters, thermistors, and a continuous fiber-optic temperature sensor. Clamped seismometers or hydrophone strings can be used for active oblique seismic experiments, and possibly electromagnetic sensors for cross-hole imaging. The hole collapse and sediment filling experienced during Leg 146 and in similar formations elsewhere suggest that collapse of the formation around the casing will provide excellent coupling for high-quality down-hole seismic data, and added insurance of hydrologic isolation of the hydrologic ports. Downhole electromagnetic recording and strain instruments to be attached to the NEPTUNE cable are also being examined, but these instruments may require dedicated holes.

Primary Goals and Observational Strategy

ACORKS provide the opportunity to obtain the critical information on permeability and pore pressure, including transients, required to understand and model fluid expulsion and hydrate formation in accretionary prisms. A closely-spaced pair of ACORK instrumented holes each with seven packer elements and screened ports is proposed at Site CAS-01C near Site U1327. The two holes will first provide information on the degree and scale of heterogeneity in the distribution of hydrates. Secondly, the hole pair will allow cross-hole hydrologic testing, with each screened port used for either monitoring or pumping. Only with separate pumping and monitoring points can formation storage and transmission parameters be independently constrained. The geometry offered by the distribution of multiple intervals in the pair of holes also allows permeability heterogeneity and anisotropy to be assessed. At the expected hydraulic diffusivity of the order of the order of 5 x 10^{-3} m^2 s^{-1}, and a reasonable testing period of a few days, the hole spacing should be of the order of 50-100 m. Multiple packers and ports located above and below the level of the base of gas hydrates will also provide key information about the pressure gradient that drives vertical fluid flow. Further constraints will be added by drilling to and setting the deepest monitoring ports at different depths. With these data, rates of flow can be estimated using the vertical profile of permeability, constrained by the pumping experiments outlined above and the tidal loading response as described below.

Another important function of the multiple ports above and below the base of gas hydrates is to monitor pressure variations associated with tidal loading at the seafloor and earthquake-related transients (Davis et al., 1995; 2000). The instantaneous response depends primarily on the ratio of the bulk moduli of the matrix and the interstitial fluid. The matrix modulus will be influenced by hydrates if there is bonding between the sediment grains and the hydrate, and by high pore-fluid pressure if effective stresses are reduced significantly. Boundaries (such as that created at the base of hydrate stability) serve as a source for diffusive propagation of pressure. The distance over which this time dependent propagation occurs depends on the permeability of the matrix and the effective viscosity of the fluid. With multiple levels of monitoring possible with the Advanced CORK installations, we anticipate being able to learn much about the concentrations of hydrate and gas, the formation-scale permeabilities, and the matrix mechanical properties above and below the base of hydrate stability.

CORK Operations and Technical Considerations

ACORKs are now a proven technology, although improvements are still being made. The configuration deployed at the Nankai accretionary prism is well suited to the study of hydrates. Time required for installation can be estimated at this stage with reasonable confidence, given the experience at Nankai. Approximately 72 hours are required in addition to the time required for LWD for each of the two holes. Additional time may be required for installation of instrumentation inside the casing following the installation of the bridge plug.

Outline of Modular Formation Dynamics Tester (MDT) tool

The proposed Schlumberger MDT tool has the capability of providing critical formation properties, especially insitu permeability, and formation pore fluid sampling at frequent depth intervals. It is a wire-line deployed tool with a dual packer assembly which allows controlled testing of formation properties over a 1 m active interval. Each test can contain several cycles of pressure draw down and pressure build up to induce micro-fracturing of the formation and the effect of fracturing on permeability. The MDT tool was very successfully deployed during the Mallik 2002 gas hydrate drilling program in the arctic (Dallimore et al., 2002). In situ fluid and gas samples can also be carried out. The MDT tool can add substantial information to the overall understanding of the formation of marine gas hydrates and the dissociation behavior of natural gas from a marine gas hydrate reservoir. Although the ACORK experiment provides information about fluid flow and permeability in time at a single site, a series of MDT tests along the proposed transect would provide information about the spatial variability of those parameters. A new deployment-technology was developed that runs the MDT tool directly at the bottom of the drill string. This does not require the use of a larger-diameter pipe as proposed earlier.

Outline of basin reference site and other geophysical operations

The complete Cascadia transect, as originally proposed, included drilling and logging of Cascadia Basin reference Site CAS-04B. This Site has been approved by EPSP in preparation for Phase I. Operations include LWD logging as well as coring of the proposed 400 m sediment interval. The cored sediments will be analyzed in an identical manner as done during Expedition 311. However, no gas hydrate or significant amounts of free gas are expected at this reference location.

A walk-away Vertical Seismic Survey (VSP) experiment also was part of the original proposal but could not be carried out in the limited time for Phase I. During Expedition 311 two zero-offset VSPs were conducted and yielded high-quality data about the P-wave velocity at Site U1327 and u1328. However, no information about the S-wave filed was obtained. This will be done by the walk-away VSP deploying multi-component geophones in the boreholes and shooting the seismic source along a transect away from the drill-site. A second operating vessel is required for this operation. It is anticipated that this can be provided the Pacific Geoscience Centre, Geol. Survey of Canada, using the CCGS John P. Tully.

Discussion

Although much needs yet to be done in the details of the science program, instruments, and operations, the planning for Phase II of the N. Cascadia gas hydrate program is in a mature state. Several of the most important downhole instrumentation and measurements have been used previously in the Nankai accretionary prism and elsewhere (ACORK and DTS) and in the Mallik gas hydrate drilling in the Canadian arctic (DTS and MDT). There are a number of additional important opportunities in other instrumentation and long-term measurement that will require additional work prior to the Phase II operations, but these are in addition to the core systems and are not essential to the primary objectives. The NEPTUNE cable routing has been announced; it will go to the area of this IODP transect and should be ready to connect to the borehole instrumentation in 2007-2008. There is little doubt that the proposed N. Cascadia Hydrate Phase II Expedition has very high probability of success and has exceptional potential.

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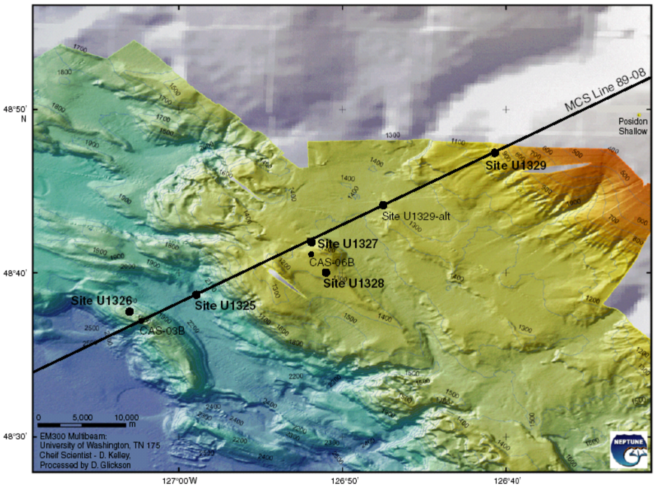
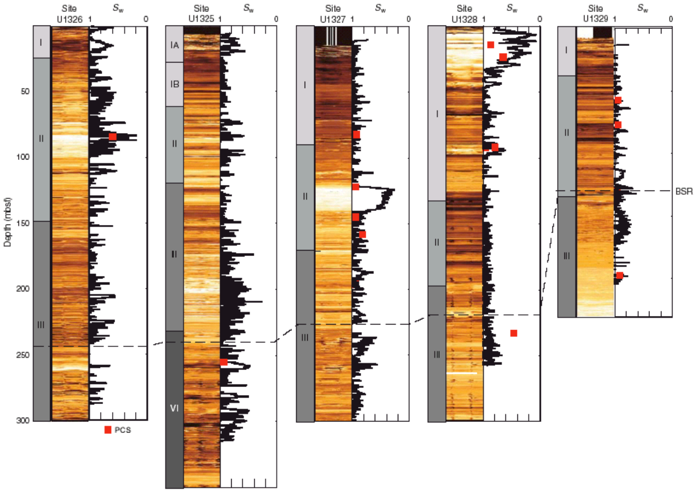


Figure 1. Multibeam bathymetry map along the transect across the accretionary prism offshore Vancouver Island (courtesy of D. Kelly and J. Delaney, University of Washington and C. Barnes, C. Katnick, NEPTUNE Canada, University of Victoria).

Figure 2. Summary of Expedition 311 pore water saturations derived from LWD data using Archie's relation. Also shown are lithostratigraphic units and LWD RAB resistivity images and location of the BSR.



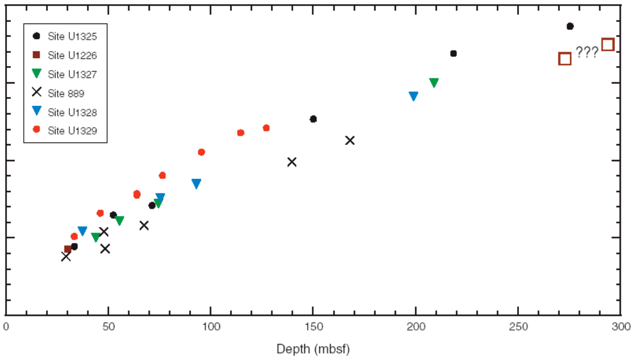


Figure 3. All reliable in situ temperature measurements from X311. Data from Leg 146 Site 889 are also included. Two DVTP measurements (open squares) at Site U1325 were of marginal quality due to heave conditions.