Integrated Ocean Drilling Program (IODP) Proposal

GAS HYDRATE ON THE CASCADIA MARGIN

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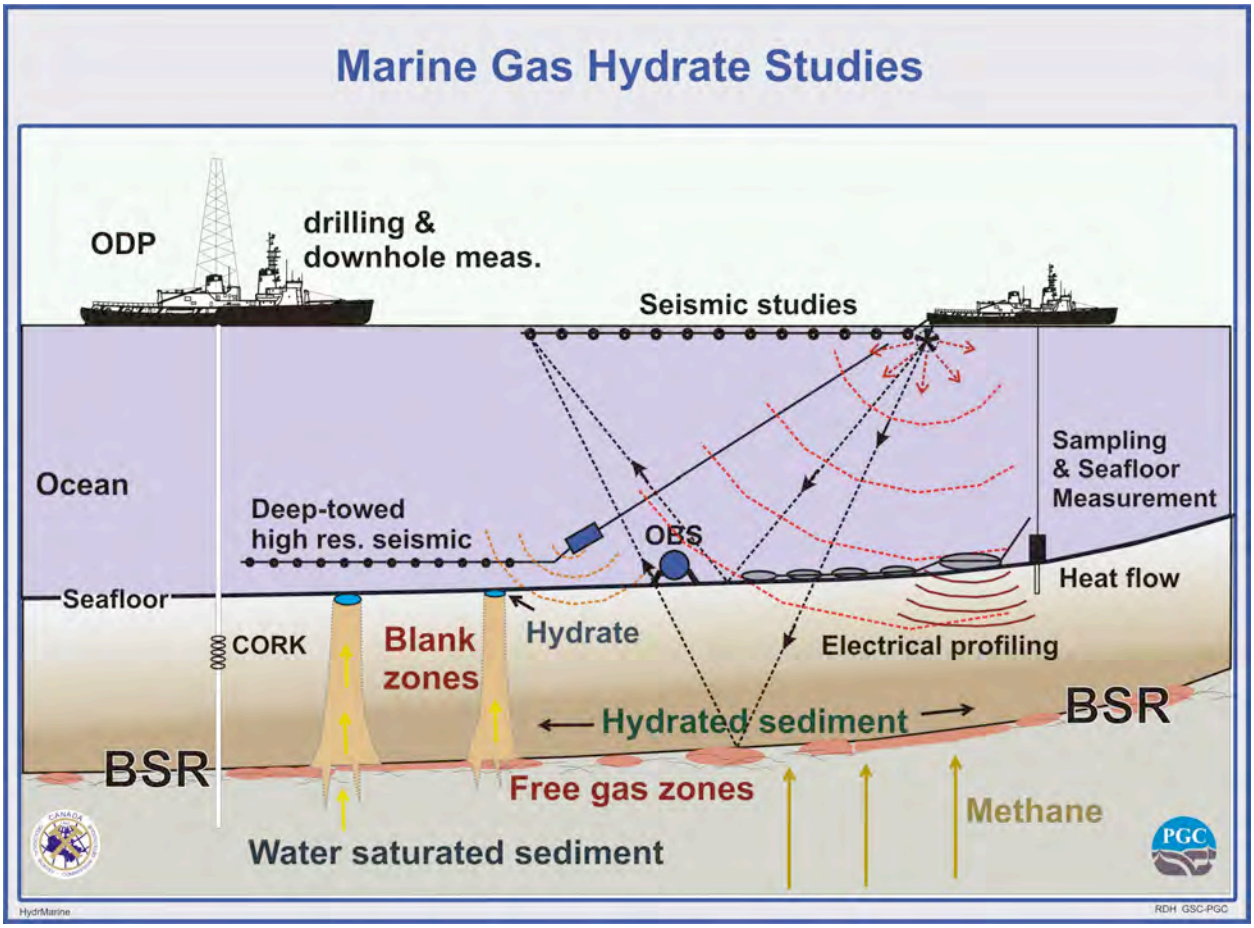

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ABSTRACT

This proposal is for an IODP program to constrain models for the formation of deep sea gas hydrate in subduction zone accretionary prisms. The objectives include the deep origin of the methane, its upward transport, its incorporation in gas hydrate, and its subsequent loss to the seafloor. The main attention is on the widespread seafloor-parallel layer of dispersed hydrate located just above the base of the stability field (~250 m below seafloor). Such layers may make up the largest volume of hydrate globally. In the model, methane is carried upward through regional grain-scale or small-scale fracture permeability, driven by the tectonic consolidation of the accretionary sedimentary prism. Also important is the focussing of a portion of the upward methane flux into localized plumes or channels to form concentrations of near-seafloor hydrate. The amount of hydrate in local concentrations near the seafloor is especially important for understanding the response of marine hydrate to climate change. Long-term monitoring in the boreholes, especially over a strong earthquake concentration (Nootka fault), will assist in determining the role of strong shaking in the sediment consolidation, episodic upward fluid transport, and hydrate formation. The proposal is for drilling, downhole measurements, and long-term recording at a transect of sites across the Northern Cascadia large accretionary prism, from the first indication of hydrate just landward of the deformation front, to the upper continental slope where hydrate is no longer stable. The sites will track the history of methane in an accretionary sedimentary prism from: (1) its production by mainly microbiological processes (and to a lesser degree thermal processes) over a thick sediment vertical extent, (2) its upward transport through regional or locally focussed fluid and free gas, (3) its incorporation in the regional hydrate layer above the BSR or in local concentrations at or near the seafloor (and how the methane gets to near the seafloor without forming hydrate at greater depth), to (4) methane loss from the hydrate by upward diffusion, or eventually by the base of the stability field moving upward to the seafloor as the water depth shoals landward though sediment tectonic thickening, and (5) methane oxidation and incorporation in seafloor carbonate, or expulsion to the ocean.

The proposal builds on the previous Cascadia hydrate drilling of Leg 146 in the area that included hydrate Sites 889-890 and deep sea reference Site 888, on more recent Leg 204 off Oregon, as well as previous hydrate drilling elsewhere. The recent Mallik II hydrate drilling program in the Canadian arctic provided important testing of a number of new measurement technologies. Previous drilling mainly addressed the nature and distribution of hydrate occurrence. A series of important new technical developments in measurement and borehole recording have made achieving the new objectives of tracking the formation to the dissociation of hydrate now very feasible. Further technical developments are in progress, so the discussion here may be modified to take advantages of new technologies. Borehole instrumentation is developing rapidly. Important facilities for this proposal include, (1) the now well-developed CORK monitoring of downhole pore pressure, permeability, and thus upward fluid flow, (2) Modular Formation Dynamics Tester (MDT), (3) Log-While-Drilling (LWD), (4) Distributed Temperature Sensors (DTS), (5) Infrared (IR) imaging of the recovered core, and (6) Pressure Core Barrel sampler for hydrate, free gas, and fluid recovery under insitu conditions. Long-term monitoring of the boreholes may be facilitated by the proposed NEPTUNE seafloor cable system.

The area on the continental slope off Vancouver Island is one of the most completely studied of accretionary prism gas hydrate, together with Hydrate Ridge on the central Cascadia continental slope. There are detailed and comprehensive site surveys and other field studies, including: very extensive seismic reflection surveys (conventional MCS, 3D MCS, high resolution surveys, deep-towed DTAGS, and OBSs), heat flow, electrical sounding, seafloor compliance, piston coring, swath bathymetry, and acoustic imaging. The Lithoprobe program has allowed close integration of marine and land geophysical and geological data, and continuity of geological structure from marine to land. The previous Cascadia and other hydrate drilling has been analysed and interpreted, and the hydrate formation theories have now been developed into quantitative models that may be tested by an IODP program.

INTRODUCTION

This proposal is for an IODP program on the northern Cascadia margin to constrain models for the formation of deep sea gas hydrate in subduction zone accretionary prisms. Natural gas hydrate occurs beneath some continental slopes and in arctic permafrost areas. The

arctic occurrences can have very high concentrations, but appear to contain less total hydrate than marine occurrences. Recent studies have indicated that the largest occurrences of gas hydrate may lie in nearly horizontal layers several hundred metres beneath the seafloor of continental slopes, especially in the large subduction zone accretionary sedimentary prisms. Such hydrate and underlying free gas produce the ubiquitous BSR. Hydrates do occur on passive margins, but they are less common and appear usually to contain lower concentrations. The importance of deep sea gas hydrates is highlighted by the Japanese second $70 Million, 5-year government-industry program, and large research and survey programs of U.S.A., India, Korea, Canada, Germany, and several other countries.

The two marine hydrate areas that have received the most detailed scientific study, including previous drilling by ODP, are the Blake Ridge region off eastern U.S.A. (a passive margin setting), the Cascadia margin off Oregon and Vancouver Island (subduction zone accretionary prism). Other hydrate drilling on an accretionary prism has been off SW Japan (by JNOC/JAPEX). The Blake Ridge has a widespread bottom-simulating reflector (BSR) but the hydrate concentrations are relatively low. Very important new information for arctic hydrate has been obtained from the Mallik I and Mallik II drilling in northern Canada (Dallimore et al., 1999, 2002; also see Mallik and ICDP web sites). The very high concentrations encountered at the Mallik site (up to 80% pore volume) suggest that such arctic deposits may be the first to be exploited for energy. However, the total amounts in such occurrences appear to be less than the total in marine hydrate. If our conclusions for the distribution and concentration of most hydrate are correct, accretionary prism hydrate is the most important both for the long-term energy potential of hydrate, and for the role that natural gas hydrate plays in climate change. The larger clastic sedimentary prisms (including Cascadia, S.W. Japan, Alaska, S. Chile, and Makran) make up approximately 20 % of the total of subduction zone margins.

Within accretionary prisms, the largest amount of hydrate appears to occur in a very widespread layer located just above the BSR (e.g., Trehu et al., 2002). However, also important is the focussing of a portion of the upward methane flux into localized plumes or channels to form concentrations of near-seafloor hydrate. The amount of hydrate in the widespread layer above the BSR (~200 m below seafloor), compared to that in local concentrations near the seafloor is especially important for understanding the response of marine hydrate to climate change. Near-seafloor hydrate will respond much more quickly to ocean temperature changes

compared to hydrate several hundred metres below the seafloor. For the region of ODP Site 889/890, Taylor et al. (2002) calculated that a 30 m thick hydrate deposit lying at the base of the stability field would dissociate due to seabed warming in approximately 8000 years. Near-seafloor hydrate could dissociate much more quickly, and be much more responsive to human-induced global warming (e.g., Wood et al., 2003). It remains a puzzle how methane can get to near the seafloor without forming hydrate at deeper levels.

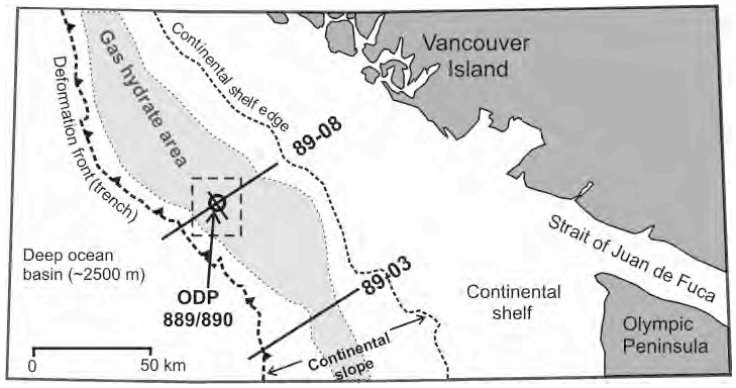

Figure 1. General location of proposed drilling transect near previous ODP Site 889/890. A BSR is present on about 50% of the mid-continental slope (shaded area).

Off Vancouver Island a hydrate BSR occurs in a 30 km wide band parallel to the coast beneath much of the continental slope **(Figure 1)**. The hydrate is concentrated in a layer 50-100 m thick, just above the base of the hydrate stability field, which is located 200-300 m below the seafloor. The hydrate concentrations reach about 30% of pore space base upon seismic velocity and electrical resistivity data. The surveys and studies that have been carried out, and the evidence for the presence and content of gas hydrate have been summarized in two recent comprehensive review articles (Hyndman et al., 2001; Spence et al., 2000).

Models for formation of wide-spread gas hydrate layer

A general model for deep sea gas hydrate formation by removal of methane from upwardly expelled fluids was developed earlier for this area (Hyndman and Davis, 1992). Mainly biogenic methane, inferred to be produced over a thick sediment section, is carried up to form hydrate when it enters the stability field. The hydrate concentration is predicted to be greatest just above the BSR as is usually observed. Subsequently a model has been proposed for how free gas and resulting BSR will be formed as the base of the hydrate stability moves upward due to, post-Pleistocene seafloor warming, uplift, and sediment deposition (Westbrook et al., 1994; Paul and Ussler, 1997; von Huene and Pecher, 1998). Physical and mathematical models have been developed for the formation of hydrate involving upward methane advection and diffusion (e.g., Xu and Ruppel, 1999; Rempel and Buffett, 1997, and others).

Testing these models and determining the appropriate model parameters requires: (1) accurate definition of the vertical distribution of hydrate and gas, (2) accurate formation temperatures to define the base of the stability field, (3) physical and fluid chemical data, and downhole measurements and recording, that define the vertical advection rates of fluids and of methane, (4) better calibration of the effect of hydrate and gas concentrations on velocity, resistivity, and other physical parameters for interpretation of both downhole data and seafloor measurements and surveys, (5) determination of the sediment pore pressure and permeability that drive the upward advection.

Recently evidence for focused fluid/gas flow and gas hydrate formation has been identified at at least two sites on the Vancouver Margin. The first site is an active cold vent field associated with near-surface hydrate close to ODP Site 889/890 that has been focus of intense research (e.g. Riedel et al., 2002). Studies include high-resolution bottom profiling, 3D seismic surveys, piston coring and ocean-bottom video surveying and sampling with the remotely operated vehicle ROPOS. These vents represent fault-related conduits for focused fluid and/or gas migration associated with massive hydrate formation within the fault zone and represent therefore the opposite mechanism to the widespread fluid-flow. It is so far unknown how important these cold vents are in the total budget of fluid flow in an accretionary prism. Drilling at the vent field would help to constrain the significance of fault-related fluid and/or gas flow. The second site is located in Barkley Canyon at shallower water depth around 800 m and hosts massive gas hydrate outcrops. Some of these outcrops have been accidentally dredged by a fish boat in summer 2000, and an estimated 1.5 t of gas hydrate was brought to the surface in the fishing net (Spence et al., 2001).

<u>The role of earthquake shaking on fluid expulsion and hydrate formation</u>

There may be important time variations in fluid expulsion and hydrate formation, especially the influence on fluid expulsion and hydrate formation of very strong shaking. Most of the fluid expulsion could occur as a consequence of the megathrust earthquake rupture located immediately beneath the continental slope hydrate deposits. Magnitude ~9 thrust earthquakes occur approximately every 600 years on this margin, with the last event 300 years ago. In order to look at the effects of strong shaking we need to find a location with more frequent large (but not megathrust) earthquakes. The Nootka transform fault that extends beneath the accretionary

prism approximately orthogonal to the margin of central Vancouver Island provides an ideal opportunity (**Figure 2**). It generates M>6 events approximately at intervals of 20 years and M>4 every 4 month. Accelerations are estimated to occur at 1% g every 3 – 12 month and 5 % g every 2 – 10 years.

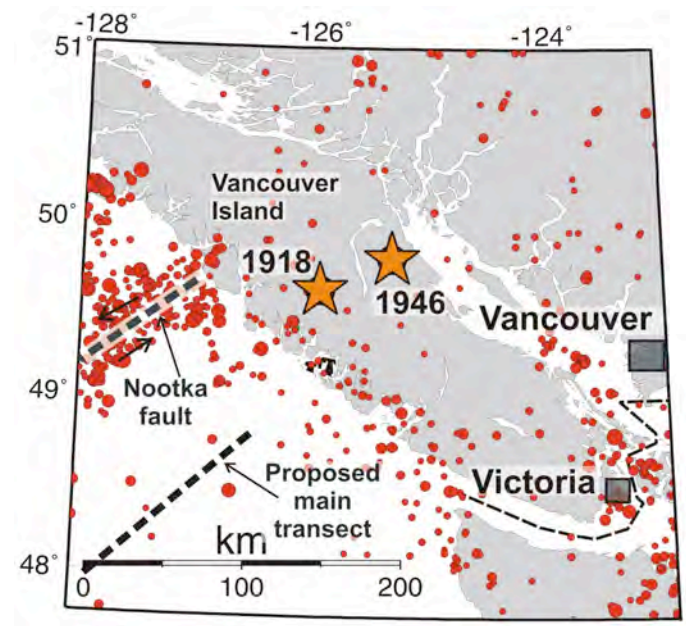

Figure2. Nootka fault seismicity.

This part of the proposal involves only one site, with the key installation of an ACORK to monitor time variations in pore pressure and fluid flux associated with earthquake shaking. The NEPTUNE seafloor cable observatory system proposed for the Juan de Fuca plate may provide an ideal method for long-term monitoring (see NEPTUNE web site http://www.neptune.washington.edu/).

SCIENTIFIC GOALS

The proposal follows the goals for gas hydrate drilling of the ODP Gas Hydrates Program Planning Group, i.e., (1) Study the formation of natural gas hydrate in marine sediments; (2) Determine the mechanism of development, nature, magnitude and global distribution of gas hydrate reservoirs; (3) Investigate the gas transport mechanism, and migration pathways through sedimentary structures, from site of origin to reservoir; (4) Examine the effect of gas hydrate on the physical properties of the enclosing sediments, particularly as it relates to the potential relationship between gas hydrates and slope stability; (5) Investigate the microbiology and geochemistry associated with hydrate formation and dissociation.

These scientific goals are an expansion of the latest achievements of ODP Leg 204, dedicated to study gas hydrates at Southern Hydrate Ridge (Trehu et al., 2002). Leg 204 was entirely focused on the specific structure of Hydrate Ridge and has only limited potential for applications at different continental margins.

The objectives of this proposal are to test gas hydrate formation models and constrain model parameters, especially models of hydrate concentration through upward fluid and methane transport. These objectives require:

(1) High quality data on the vertical concentration distributions of gas hydrate and free gas, and variation landward in the accretionary prism.

(2) Estimates of the vertical fluid and methane fluxes through the sediment section, as a function of landward distance from the deformation front.

The objectives can be achieved by, and only by, ODP type drilling. However, close integration of the drilling and downhole results with regional geophysical and geological data is required. The study will concentrate on the contrast between dispersed pervasive upward flow and focused flow of fluid and methane in fault zones (**Figure 3**). The pervasive permeability may be on a grain scale, on a centimeter scale (the scaly fabric observed in previous ODP clastic accretionary prism cores), or in closely spaced faults. Strong and continuous BSRs may occur only in coarser clastic accretionary prisms, i.e., muddy silt or coarser, where grain or other small-scale permeability allows pervasive upward expulsion. In muddy, low permeability sediments, fluid expulsion may be focused in discrete faults so hydrate does not form a continuous layer. The massive hydrate sampled on a Central America DSDP Leg (Mathews, 1986), may represent hydrate

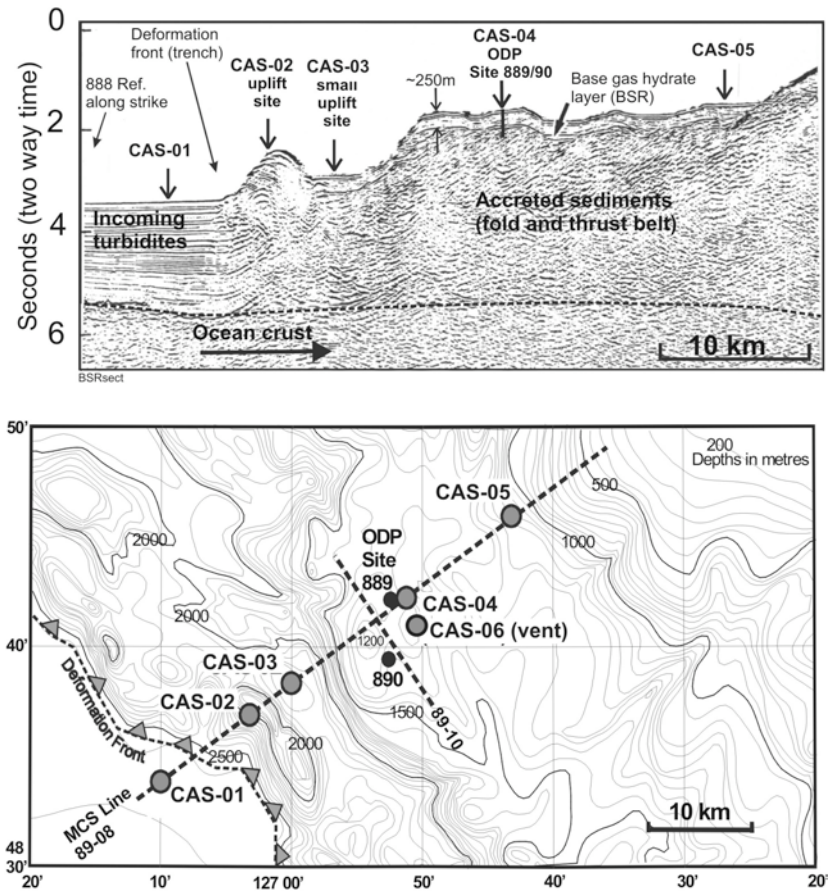

Figure 3. (Top) Seismic section showing proposed sites. (Bottom) Bathymetry of continental slope and locations of proposed ODP Sites.

formed in a fault zone that channeled repeated fluid expulsion. The lack of a BSR in the fine grained muddy northern Barbados prism, and the presence of a BSR in the sandy southern prism (e.g., Westbrook et al. 1994) may reflect this difference.

On the proposed transect (**Figure 3**), there appears to be almost no current underthrusting of sediments. The whole 2-3 km thick incoming sediment section is being scraped off at the deformation front by thrusts that extend down to near the top of the ocean crust (e.g., sections shown in Hyndman et al., 1994; and large scale in ODP Leg 146 Volume). This configuration simplifies consolidation and fluid expulsion modeling. We note that in many accretionary prisms, underthrust sediments may be an important source of fluid and methane, and there may have been underthrusting on this part of Cascadia margin in the past.

GEOCHEMISTRY

Geochemical measurements of the gas hydrates, pore fluids, and sediments within and below the gas hydrate stability zone (above and below the BSR) are essential to meet the outlined objectives. In addition to characterizing gas hydrate and free gas depth distribution and geochemistry, critical chemical and isotopic measurements summarized below will provide information on conditions of gas hydrate formation, relation to organic matter content and type, and the nature and temperature of fluid-rock reactions. Continuous long-term monitoring of these parameters after drilling would as well be performed to gain insights into the kinetics of methane hydrate formation and dissociation and methane fluxes in response to environmental perturbations. The chemical and isotopic data are necessary for the understanding of: a) the origin of the methane and other hydrate gases, b) the mode of formation of the methane hydrate, c) the source of the fluids carrying the gases sequestered in the gas hydrates, and if more than one source the ratio of sources, and testing which of the hypotheses of gas hydrate formation outlined in the proposal applies to this region. Representative samples will be recovered under in situ conditions with the ODP Pressure Core Sampler (PCS) to quantify gas concentrations in the hydrate-bearing zone and below the BSR.

Based on extensive previous geochemical studies, especially since ODP Leg 146, the most critical measurements include: a) chloride concentrations and isotope ratios in the gas hydrates and pore fluids in order to determine the mode and rate of formation of gas hydrate and the fluid source, from greater depths or from the in situ pore fluid (Ransom et al., 1995; Spivack

et al., 2002), b) two to three geothermometers (i.e. Fournier and Potter, 1979; Kharaka and Mariner, 1989), c) carbon isotope ratios of dissolved inorganic carbonate along with oxygen and hydrogen isotopes of the gas hydrate structural water and pore water (i.e. Kastner et al., 1998), d) chemical and isotopic compositions of the hydrocarbons in the hydrate, and of the dissolved and free gases , e) pore fluid pH, and sulfate, sulfide, ammonium, and alkalinity concentrations (i.e. Borowski et al. 1997) and minor and trace elements concentrations and corresponding isotope ratios characteristic of fluids from a deeper source, such as Li, B, and Sr (i.e. Kastner et al., 1995a, b), f) sediment mineralogy and geochemistry, and g) amount and type of organic matter.

The samples will be recovered under in situ conditions. The hydrate and free gas samples will be handled in the laboratory using the manifold used on ODP Leg 204, and the pore fluids will be recovered under anaerobic conditions. The analyses will utilize the extensive experience and results obtained primarily since ODP Leg 146, and particularly during Leg 204 (described in shipboard preliminary results, Trehu et al., Proc. ODP Init.Rep. 204, in preparation, and references therein).

Monitoring borehole fluids and *in situ* experiments:

Continuous monitoring in situ will help constrain methane fluxes, record in situ concentrations through the methane hydrate stability zone (MHSZ) and fluctuations in response to environmental perturbations. The monitoring will be conducted in multiple isolated horizons by packers (Advanced CORK concept) that will be chosen based on observations of methane hydrate distribution within the MHSZ, with emphasis on across the BSR and uppermost section of the sediment column, near the sediment-seawater interface. Controlled borehole in situ cooling and heating experiments are also proposed for direct observations on the kinetics of gas hydrate formation and dissociation.

MICROBIOLOGY

The proposed microbiology/molecular biology experiments are needed to help determine over what depth range biogenic methane is produced, how rapidly methane is lost from hydrate and by what mechanism. The microbiology studies will also determine what microbes are associated with the gas hydrates, which microbes directly take up methane, which microbes are responsible for other anaerobic processes within the gas hydrate environment and to determine

whether any groups of microbes associated with anaerobic methane oxidation can be cultured in the lab for eventual physiological and biochemical studies.

In recent years it has been demonstrated that specific groups of microbes belonging to both the archaeal and the bacterial domains of life exist on and adjacent to gas hydrates in diverse marine sediments and in anoxic waters of methane seep environments within the Black Sea (Bidle et al., 1999; Boetius et al., 2000; Hinrichs et al., 1999; Kastner et al., 2000; Lanoil et al., 2001; Michaelis et al., 2002; Orphan et al., 2002; Valentine, 2002). The two principal archaeal phylogenetic groups have been designated ANME-1 and ANME-2 and are closely related to methanogenic archaea within the order methanosarcinales. They are both frequently associated with sulfate-reducing bacteria which belong to the Desulfosarcina/Dsesulfococcus group, in an apparent syntrophic relationship. 14C-methane labeling studies and secondary ion mass spectrometry indicate that the ANME microbes are able to directly take up methane (Michaelis et al., 2002; Orphan et al., 2002). Presumably they pass on incompletely oxidized intermediates of methane oxidation to their sulfate-reducing bacteria partners. The presence and activity of these and other microbial groups will be ascertained as part of this project.

The techniques to be used will include sterile anaerobic sediment core subsampling (Parkes et al., 1995), direct microscopic counts of microbial abundance (Cragg, 1994), 16S ribosomal DNA community analyses (Bidle et al., 1999, Carson et al., 2003), fluorescence in situ hybridization (FISH) abundance measurements (Boetius et al., 2000), lipid biomarker studies (Hinrichs et al., 1999), assorted anaerobic metabolic rate measurements (most importantly methane oxidation and sulfate reduction; Hanson et al., 1998; Reeburgh, 1982), and the cultivation of novel methanogens, sulfate-reducing bacteria and consortia of microbes capable of anaerobic methane oxidation. The later will depend on culturing systems similar to that described by Nauhaus et al. (2000) which Kastner and Bartlett already have in operation.

DATA REQUIRED TO ACHIEVE OBJECTIVES

A. <u>Hydrate and Free Gas Concentrations</u>

- Sonic log and VSP, incl. Offset
- Resistivity log, incl. LWD; density and porosity logs, incl. LWD
- Core pore fluid chemistry, chlorinity; core fluid isotopes; headspace gas sampling
- Pressure core sampler, Infra-red imaging

- LWD RAB tool for complete structural imaging of hydrate occurrence

B. Upward Fluid Expulsion

Both total fluid expulsion since deformation front, and present rate.

- porosity loss in sediment section since deformation front, from logs and core
- constraints of models of sediment accretion that give model fluid expulsion rates
- geochemical tracers in core pore fluid
- permeability from core and downhole meas., incl. CORK
- pore pressure inferred from logs, esp. LWD
- pore pressure measured by Advanced CORK

C. Relation of top of gas and base of hydrate to stability field:

- downhole DTS and D-V and CORK high resolution temperatures.
- as above, accurate definition of top of gas and base of hydrate, and their vertical conc. profiles.

NEW TOOLS AND TECHNIQUES

1) LWD

LWD is required for high quality insitu physical properties (e.g. Moore et al., 1995; Myers et al., 2003). Accurate formation physical properties from downhole logs are essential for model constraints and to provide calibration of field geophysical data (especially P and S wave velocity, electrical resistivity, density, porosity). The new Resistivity-at-the-Bit (LWD-RAB) tool makes lateral resistivity measurements and is an ideal tool to study the occurrence of gas hydrate. During ODP Leg 204, this tool was successfully deployed and provided insitu information about concentration and distribution of gas hydrates (disseminated in pore space or concentrated along cracks/faults). It also allows estimates of the stress-orientation and insitu strength of gas hydrate bearing sediments (Goldberg et al., 2003). It is essential that the log data extend to sufficient depth below the BSR to obtain background velocities, resistivities and porosities well below where they are affected by the hydrate and free gas. LWD provides the best opportunity to obtain the required high quality data.

2) CORK

CORKs are a very important recent ODP technology development (e.g., Davis et al., 1992). The CORK allows recording instrumentation to be left in boreholes after the hole has been hydraulically sealed and the drill ship has left. Through borehole seals, pressure recording and pump testing, it is possible to determine and monitor downhole pore pressure and to estimate permeability, and thus fluid flow (at multiple depth intervals for the Advanced CORK). Accurate formation temperatures also can be obtained after the borehole drilling disturbance has decayed, especially at the base of the hydrate and top of the free gas. Mechanical and hydrologic properties of the hydrate-bearing sediment matrix above and the gas-bearing interstitial fluid below the phase boundary (BSR) can be determined from the response to tidal loading and seismic ground motion as a function of distance away from the boundary. Such measurements are also very complementary to the seafloor compliance method for estimating the concentration of hydrate (see details below). A single site with a dual hole is proposed for the CORK experiment.

3) CONVENTIONAL WIRE-LINE LOGGING

A comprehensive program is required, with special attention to well-calibrated P- and S-wave velocity data and electrical resistivity (e.g. Collett, 2001). The logs have numerous applications in the proposed study, but especially calibration of the field seismic and electrical surveys. Density and porosity logs through the hydrate and gas zones may allow estimation of the no-hydrate, no-gas velocity and resistivity references with depth; hydrate has a similar density to pore water and the very small amounts of free gas have only a negligible effect. Thus, density and porosity versus velocity and resistivity relations may be used to give approximate reference velocities and resistivities through the hydrate and gas zones. Other log combinations may give additional information (see Guerin et al., 2002, 2003).

4) VSP (Vertical Seismic Profiling)

VSPs provide relatively low spatial resolution but high absolute accuracy velocity data, (e.g., McKay et al. 1994, for Cascadia). Shear wave velocities also may be obtained (e.g., Pecher et al., 1997) for comparison with amplitude-versus-offset (AVO) multichannel seismic refection data inferences on Poisson's Ratio. VSPs are also critical for estimating the amount of free gas below the base of the hydrate stability field. VSPs with spatial resolution of about 1 – 5 meter fill

the spatial gap in imaging the hydrate-bearing sediments between measurements in the decimeter range from the sonic logs to measurements with MC seismic data on the 10's of meter scale.

5) PCS, HRC and FPC

The pressure core barrel (PCS) was used very successfully for the first time to sample gas hydrate on the Blake Ridge (Leg 164, Dickens, et al., 1997) and at Hydrate Ridge (Leg 204, Milkov et al., 2003). It allows accurate determination of the concentration of hydrate and free gas present insitu, which have proven to be very difficult to determine reliably by any other method. During Leg 204 two new techniques of pressure coring were tested to acquire hydrate-bearing sediments under insitu pressures. The HYACE Rotary corer (HRC) and Fugro Pressure Corer (FPC), developed under the European HYACINTH project were successfully deployed. The up to 1 m long cores taken by the HRC/FPC can be transferred into specialized chambers under full pressure. Controlled hydrate dissociation experiments can then be performed with continuous measurements of physical properties (Schultheiss et al., 2003).

6) DTS (Distributed Temperature Sensors) and DV (Davis-Villinger) probe

Measurement of the undisturbed formation temperatures is critical to assessing the base of the gas hydrate stability field, 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 technique for the measurement of borehole temperatures has been successfully applied at the 2002 Mallik gas hydrate research well program. The geothermal program, led by a research group from GeoForschungsZentrum Potsdam (Henninges et al., 2003), installed distributed temperature fibre-optic sensor (DTS) cables in three wells outside the casing string. The DTS system has the capability to measure formation temperatures over the entire cable length with a minimum sampling interval of 0.25 m and an accuracy of 0.3°C. The Data acquisition system allows the collection of high-resolution temperature measurements at up to 7 second intervals allowing for determination of equilibrium temperatures and also observation of temperature changes over long time periods that are extremely important to the overall question of pervasive and/or fault related fluid flow. The installation of DTS cables will be complemented by measurements with the DVTP (Davis-Villinger temperature probe), DVTPP (Davis-Villinger Temperature/Pressure Probe), and the APCT (Advanced Piston Coring Temperature tool) temperature probe at frequent depth intervals during drilling. The DVTP/APCT probes were last successfully used during Leg 204 (Trehu et al., 2003) and gave

valuable information for calibrating the base of hydrate stability. It is also proposed to use the APCM and PCSM methane tools to monitor temperature, pressure and conductivity changes in the core headspace from the time the core is cut through its ascent to the rig floor. This data is important for any gas hydrate related analyses of the recovered core.

7) MDT (Modular Formation Dynamics Tester)

The Schlumberger MDT tool has a dual packer assembly, which allows controlled testing of formation properties over a 1 m active interval. A test can contain several cycles of pressure draw down and pressure build up to induce micro-fracturing of the formation. Direct measurement can be made of in situ permeability of the formation pressure régime. The MDT tool was successfully deployed at the Mallik 5L-38 research well in the Mackenzie Delta in 2002. It was the first controlled small-scale production test of a gas hydrate reservoir using the pressure drawdown technique (Dallimore et al., 2002). In situ fluid and gas samples can also be carried out. The use of the MDT tool would 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. While the CORK 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 spatial variability of those parameters. The MDT tool has not been used as part of an ODP Leg so far and needs further modification and development but it is expected that this technology will be available at the time of actual drilling.

8) ODP Standard Core Measurements

<u>Core Physical Properties</u>, velocity, resistivity, density, porosity, grain size and configuration, and permeability (as a function of confining pressure), and geotechnical properties.

<u>Core Pore Fluid and Gas Chemistry and Isotopes</u>.

Detailed and high quality measurements are required of core pore fluid and gas chemistry and isotopes (e.g., Kastner et al., 1995a,b) as indicators of hydrate, model constraints on hydrate formation, and as tracers of advective fluid transport, e.g., near seafloor sulphate gradients (Borowski et al., 1997) and Lithium concentrations (Torres et al., 2003).

<u>Infra-red (IR) imaging of the recovered core</u>

IR imaging for gas hydrate studies is a new technique that has been tested during ODP Leg 199 and got implemented in the regular core-analyses flow on ODP Leg 204 (Long et al., 2003). IR imaging proofed to be the fastest and most reliable tool to determine the presence of any gas

hydrate in the recovered cores on the catwalk during Leg 204. IR imaging was also used to estimate the type of hydrate occurrence, i.e. disseminated, or occurrence in veins or nodules. IR imaging on Leg 204 was done automatically on all cores with a track-mounted IR camera and a complementary hand-held camera for detailed analyses.

SUPPORTING DATA AND RESULTS

The supporting data available for the area include very extensive and comprehensive site survey geophysical data and the core and downhole measurements from ODP Leg 146. Some of the more important are:

1. Ocean Drilling Program Leg 146

Two hydrate sites were drilled to address questions of hydrate formation associated with advective fluid expulsion in an accretionary prism (Westbrook et al., 1994): (a) Site 889/90 on the continental slope off central Vancouver Island, in an environment of inferred diffuse upward flow, (b) Site 892 on the upper slope off Oregon, in an environment of focused fluid flow in a thrust fault zone. Several other sites were drilled, including a reference in Cascadia Basin off southern Vancouver Island. The diffuse flow site 889/890 and the reference site are most relevant to this proposal. The CORK measurements in Hole 892 also provide input information on the deployment and analysis of CORKs in this environment. The Leg 146 program provided: (a) Extensive site survey data (the part acquired before Leg 146 is in ODP site survey data bank; earlier large scale multichannel seismic sections are included at back of ODP Volume 146; also see Proposal for ODP drilling Leg 146 (Proposal #317E, 1988, and addenda 1989; 1990), and previous safety review; (b) Conventional downhole log data, including velocity, resistivity, density, porosity. Core physical properties data, including velocity, resistivity, porosity, density data; (c) Detailed pore fluid chemistry and isotopes (Kastner et al., 1995a,b); (d) Estimates of hydrate and gas concentrations from velocity and resistivity increase relative to a no-hydrate, no-gas references; (e) Extensive probe and BSR depth heat flow data (and numerical thermal models at several scales).

2. Detailed and comprehensive seismic data:

A map with all seismic surveys located in the vicinity of ODP Sites 889/890 is shown in **Figure 4**. (a) Conventional multichannel seismic reflection; a regional survey in 1985 and site survey lines for ODP Leg 146 in 1989. Summaries are given in Hyndman et al. (1994; ODP

Volume), and Hyndman (1995). Seismic velocities and porosities were studied by Yuan et al. (1994), and detailed seismic studies of the hydrate and BSR, including full wave inversions, by Yuan et al. (1996; 1999).

(b) 3D seismic survey; a regional MC 3D seismic survey (4 km by 10 km grid) was conducted in 1999 in the vicinity of ODP site 889/890 (Riedel, 2001). In addition to the MC data, two high-resolution 3D SC grids were acquired over the vent-field (Riedel et al., 2002). Other regional high resolution closely spaced single channel and short-offset multichannel surveys were reported by Fink and Spence (1999) and Mi (1998). (c) Three OBS surveys were carried out in 1996, 1997 and as part of the 1999 3D survey in cooperation with T. Minshull (Cambridge Univ., 1996) and K. Louden (Dalhousie Univ. 1997/1999). (d) DTAGS deep-towed multichannel seismic system survey carried out by NRL in 1997 in the area of ODP Site 889/890 (Gettrust et al., 1999; Hannay and Walia, 1999). (e) High resolution surveys were carried out in 1997 and 1999 in the area of ODP Site 889/890 by the German ship SONNE with the special parasound 4 kHz sub-bottom profiling system (Zuehlsdorff, et al., 2002).

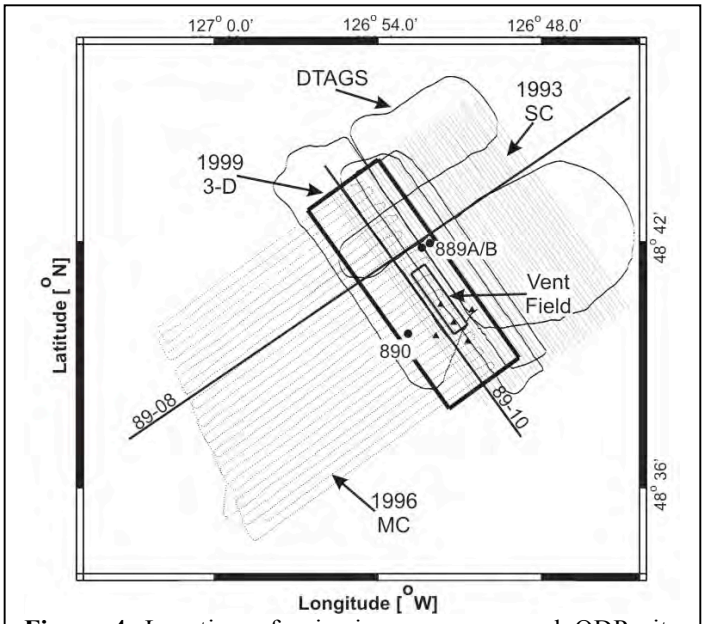

Figure 4. Location of seismic surveys around ODP site 889/890. Triangles indicate location of OBSs during the 3D survey in 1999.

3. Cold Vent studies.

The vent site has been investigated over the last 5 years including 3D seismic imaging, piston coring and ROV-based bottom video observations and seafloor sampling (Riedel et al., 2002, Novosel et al., 2003). Several seismic blank zones were observed in the seismic data (**Figure 5**) over a frequency range from 20 Hz to 4 kHz, where the degree of blanking increases with seismic frequency. The blank zones range from 80 m to several 100 m in width. The blank zones represent conduits for fluids and gas migrating upward. Blanking of the seismic energy is believed to be mainly the result of increased hydrate formation in lenses within the faults. The blanking effect is enhanced locally due to scattering at carbonates at the seafloor. One blank

zone, almost circular with a diameter of about 400 m, has a distinct seafloor expression. It shows the characteristics of a mud/carbonate mound, and is probably associated with free gas expulsion. Massive hydrate was found at several sites by piston coring within this blank zone at depths of 1 – 8 m below the seafloor. Increased methane concentrations of up to 8 times the ocean background levels were measured in water samples taken above an active area (Solem et al., 2002). However, venting appears to be strongly episodic. Pore fluid alkalinity gradients from piston cores were converted to sulfate gradients, from which the amount of methane and related fluid flux were calculated (Solem et al., 2002). The calculated methane flux varies from between 10-19 mol/m^{2}ky outside to values between 32-60 mol/m^{2}ky inside the vent. Assuming full methane saturation the maximum methane flux inside the vent corresponds to a fluid flux of about 1mm/yr. Preferred site locations are either within blank zone 1 or 4, which are the largest and most studied vents.

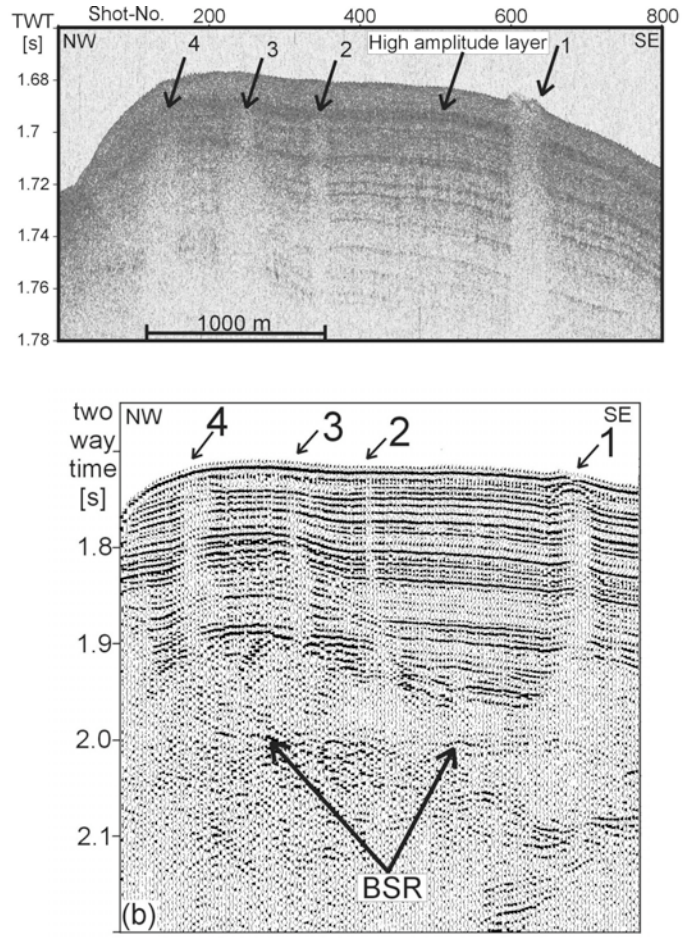

Figure 5. Seismic signature of the cold vents (blank zones) from (a) 3.5 khz subbottom profiler, (b) single channel seismic data. Blank zone 1 (Bullseye vent) is active, zones 2 – 4 are inactive.

4. Hydrate concentrations at Site 889/890

The primary estimators of hydrate and free gas concentrations used so far in this area are the velocity, resistivity and core pore fluid chlorinity. The presence of gas hydrate in the sediments increases the seismic velocity and electrical resistivity relative to a no-hydrate/no-gas reference (as estimated from ODP Site 888 and regional seismic MC studies). The velocity and resistivity data give consistent concentration estimates of about 20% of pore space over a range

of 100 m above the BSR (**Figure 6**). Hydrate concentrations estimated from the velocity increase are however about 5% lower than estimates using electrical resistivity. Only about 0.5% free gas in the pore space is present below the BSR as derived from the VSP data. In a recent paper Hyndman et al. (2001) summarize results at Site 889/890 and MC seismic studies. Details about specific models used to calculate hydrate concentrations can be found e.g. in Hyndman and Spence (1992), Yuan et al. (1996, 1999), Desmons (1996), Hyndman, (1997), and Hyndman et al. (1999).

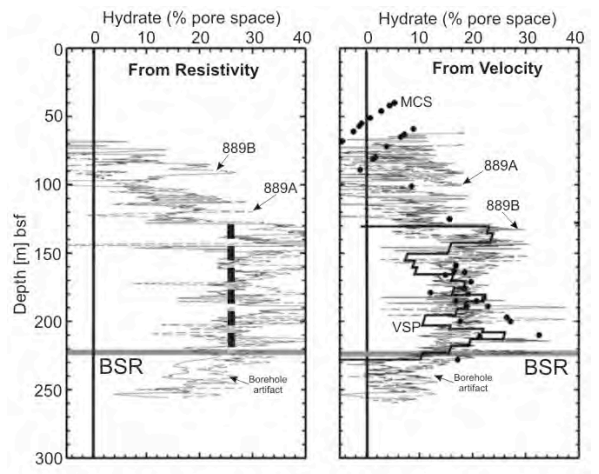

Figure 6. Hydrate concentration from resistivity and seismic velocity. Dashed thick line is from electrical sounding (see below).

HYDROLOGIC OBSERVATORIES; EXPERIMENTS AND LONG-TERM MONITORING.

Advanced CORK Installations

Long-term borehole monitoring can be used to address almost all of the goals of this proposal and listed by the Gas Hydrates PPG. In particular, CORK instrumentation can help to (a) define the vertical distribution of hydrate and underlying free gas, (b) estimate the vertical fluid and methane flux, and (c) determine the effect of gas hydrate and gas on the mechanical properties of the enclosing sediment (see K. Becker and E.E. Davis, 1998; report on: Workshop on Advanced CORKS for the 21st Century). Since 1991, twenty CORKs have been deployed to study the hydrogeology of mid-ocean ridge axes (Juan de Fuca Ridge), ridge flanks (of the Juan de Fuca Ridge, Mid-Atlantic Ridge, and Costa Rica Rift), and subduction zone accretionary and non-accretionary prisms (Cascadia, Barbados, Mariana, Nankai, and Costa Rica). These experiments have been highly successful with one unfortunate exception, ODP Site 889 drilled during Leg 146, and the location of the experiment proposed here. The failure at this site was due to excessive heave (installation was attempted during rough seas in late fall), and to rapid filling of the hole. The former problem serves as a reminder that the new program in the Northeastern Pacific must be scheduled in the summer 4-5 months.

In late 1997, a JOI/USSSP-sponsored workshop was held to discuss goals for downhole hydrologic instrumentation; following these discussions, a follow-up meeting was held at ODP to outline an engineering strategy for achieving these goals. Results of these meetings are summarized in Becker and Davis (1998). At the workshop, it was concluded that a means to monitor pressure and temperature, and to sample fluids at multiple isolated levels in formations of interest was essential. The proposed configuration for Site CAS-04 (ODP Site 889) is illustrated in **Figure 7.** The systems will be similar to those designed, constructed, and deployed at the Nankai accretionary prism during ODP Leg 196 (Mikada et al., 2002). These were built around a sealed casing (built in modules at the rig floor), with external annular packers that hydrologically isolate discrete intervals. For pressure monitoring and fluid sampling, these intervals are accessed through screened ports and small-diameter lines (also external to the liner) connected to a seafloor landing module. The landing module will house pressure gauges, sampling/testing ports, data loggers, and batteries. The inside diameter of the liner will be sufficient to allow use of a mud-motor and under-reamer for deployment of the packer/screen/liner string.

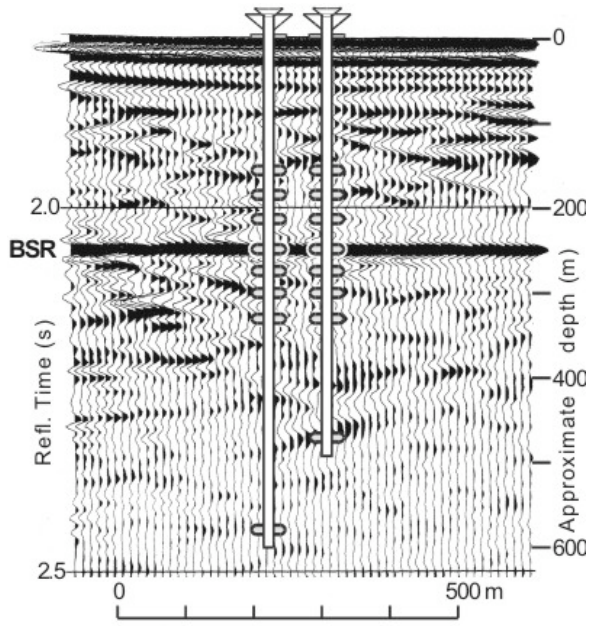

Figure 7. Schematic CORK dual-hole installation at proposed Site CAS-04 9odp Site 889).

The safest and most efficient approach is to insert the CORK strings into LWD holes drilled immediately prior to CORK operations. A short section of casing with a small reentry cone will be drilled in to stabilize the hole for LWD operations, and to allow reentry, so the LWD and CORK operations can be completed sequentially in the same hole. Precise spacing of the screens and packers 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 Advanced CORK design is that the full internal diameter of the liner will be available for post-drilling downhole experiments and monitoring tools. Fluid

sampling and hydrologic monitoring take place independently on the outside of the liner. Since the casing strings will be sealed at the bottom (compared to being sealed at the top as in the case of the original CORK configuration), the holes can be re-entered at any time with a wireline deployed from an oceanographic ship, without the requirement to maintain a 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 (DTS). 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 suggest that collapse of the formation around the liner will provide excellent coupling for high-quality down-hole seismic data, and added insurance of hydrologic isolation of the hydrologic ports.

Primary Goals and Observational Strategy

A closely-spaced pair of instrumented holes is proposed for the area of previous ODP Site 889, each with seven packer elements and screened ports. The two holes will first provide information on the degree and scale of heterogeneity in the distribution of hydrates (LWD and CORK). Secondly, the hole pair will allow cross-hole hydrologic testing, with each screened port used for either monitoring or pumping. Active hydrologic experiments in single holes have been carried out in Cascadia and Barbados CORKs (Sites 892 and 949; Screaton et al., 1995; 1997). However, tests using the same interval for pumping and monitoring are not ideal. The importance of cross-hole experiments is well recognized in terrestrial hydrology, and it has been highlighted by the ODP Hydrogeology Program Planning Group (Ge et al., 2002; 2003); 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 anticipated hydraulic diffusivity of the order of the order of 5×10^{-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 hydrates will also provide key information about the pressure gradient that drives vertical fluid flow, and further constrains 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 tidal loading response

as described below.

Another important function of the multiple ports above and below the base of hydrates will be to monitor pressure variations associated with tidal loading at the seafloor (see Davis and Becker, 1994; Davis et al., 1995; Davis et al., 2000 for examples of tidal response in single intervals). The spacing has been chosen from the likely diffusion path length at dominant tidal frequencies, given our best estimate of the hydraulic diffusivity and other parameters. The frequency-dependent response of formation pressure to tidal loading depends in a complex way on the elastic and hydrologic properties of the rock matrix and the interstitial fluid (Wang and Davis, 1996). The instantaneous response depends primarily on the ratio of the bulk moduli of the matrix and the interstitial fluid (the load imposed by the ocean is born by the least compliant constituent). The matrix modulus will be influenced strongly by hydrates if any physical bonds develop between the sediment grains and the hydrate, and by high pore-fluid pressure if effective stresses are reduced significantly. The fluid modulus will be influenced strongly by the presence of free gas (Wang et al., 1998). Boundaries (such as that created at the base of the zone 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. Tidal and barotropic loads are known to occur over a wide range of frequencies (periods from 6 hours to 15 days; Davis et al., 2000). With this broad range of frequency, and the 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.

A primary part of the instrument string deployed inside the liner will be a thermistor cable. Accurate down-hole temperatures will allow a number of critical questions to be addressed, the first and most obvious being the precise temperature at the gas/gas-hydrate boundary. The distribution of thermistors along the cable will be optimized to determine this, as well as the temperature gradients both immediately and well above and below the boundary. Gradient variations will contain key information about possible advective heat transport, the influence of hydrate and gas on thermal conductivity, and thermal transients associated with uplift, post-glacial bottom-water temperature change, and hydrate formation/dissociation. Information will also be contained in the manner and rate of decay of the thermal perturbation

associated with drilling.

Operations and Technical Considerations

Advanced CORKs are now a proven technology, and the configuration deployed at the Nankai accretionary prism is ideally suited to the study of hydrates. We will work closely with the IODP engineering group to determine the optimal configuration, but only minor differences are anticipated. Time required for installation can be estimated at this stage with reasonable confidence, given the experience at Nankai (with due consideration of the difficulties encountered and considerable time lost to problems arising from strong currents, deep penetration, and unstable formation, and under-reamer failure during Leg 196). We have allocated 72 hours beyond 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.

There are many parallels between this Advanced CORK program and that underway at the Nankai accretionary prism. That project is a collaborative one with research, engineering, post-drilling operations, and funding shared among ODP, NSF, JAMSTEC, and GSC; we plan a similar distribution of effort for this one.

COMPLEMENTARY SEAFLOOR SURVEY TECNIQUES

1. Seafloor electrical profiling

Seismic velocities from multichannel and OBS seismic studies have been the primary data available for field estimates of deep sea gas hydrate concentrations and for mapping of their distribution. However, electrical resistivity is another parameter that is very sensitive to gas hydrate, because electrically resistive hydrate replaces conductive seawater in the pore spaces. A new seafloor electrical system for continuously profiling the electrical resistivity of gas hydrate sections to depths of several hundred meters was developed and may be a powerful method for mapping deep sea gas hydrate (Edwards, 1997). Several surveys giving data to depths in excess of 300 m have been conducted in the proposed drilling area near ODP Site 889/890. Initial interpretation has yielded resistivities in agreement with those from the downhole logs (**Figure 6**). Comparison of these field results with downhole electric log data is an important objective of the new drilling proposal. A related experiment is the possibility of using cross-well electrical imaging (Yu and Edwards, 1997), using the two holes proposed for CORK at CAS-04.

2. Seafloor compliance

The change in compliance of sediment due to gas hydrate is another method for detecting and estimating hydrate concentrations, as noted above for the CORK experiments. The elastic moduli, especially the shear modulus, are increased by the hydrate cementation. Ocean surface gravity waves and longer period infra-gravity waves induce time varying pressure fields on the seafloor that deforms the sediment and causes correlated vertical acceleration. Differential acceleration and pressure are recorded by a sea floor gravimeter and a precision seafloor pressure gauge. Compliance is obtained from the transfer function between these measures as a function of frequency, given the known dispersion relationship for gravity waves. Large measured seafloor displacements are indicative of low rigidity and result in corresponding high measured compliance. The depth of penetration depends on the wavelength and corresponding frequency of the gravity waves; 0.01 to 0.5 Hz sense structures to about 200 m. Successful data have been obtained from six sites near ODP Site 889/890 (Willoughby and Edwards, 1997). This method has significant potential as an independent field method for estimating seafloor hydrate concentration. Comparison with downhole data is part of this proposal.

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ODP Site Description Forms:

Page 1 - General Site Information

Please fill out information in all gray boxes

New [x] **Revised** [ ]

Section A: Proposal Information

Title of Proposal	Gas Hydrate on the Cascadia Margin
Proposal Number:	
Date Form Submitted:	April 01, 2003
Site Specific Objectives (Must include general objectives in proposal)	First Site along transect in deep ocean basin. This Site will provide necessary important reference information about the sediments that do not contain gas and/or gas hydrate.
List Previous Drilling in Area:	ODP 146, Site 888,889,890

Section B: General Site Information

Site Name: (e.g. SWPAC-01A)	CAS-01	If site is a reoccupation of an old DSDP/ODP Site, Please include former Site #	Area or Location:	Deep Basin offshore Vancouver Island
Latitude:	Deg: 048	Min: 34	Jurisdiction:	Canadian
Longitude:	Deg: 127	Min: 10	Distance to Land:	115 km
Priority of Site:	Primary: X	Alt:	Water Depth:	2600 m

Section C: Operational Information

	Sediments. What is the total sed. thickness? 2.5 km	Basement
Proposed Penetration (m)	500	
General Lithologies:	Holocene to Pleistocene, interbedded gray to dark greenish gray clayey silts, and gray to dark gray fine- to medium-grained sands (from Site 888)	
Coring Plan (circle):	***1-2-3-APC*** VPC* ***XCB*** MDCB* PCS ***RCB*** Re-entry HRGB ** Systems Currently Under Development*	

Logging Plan:	Standard Tools		Special Tools	LWD
	Triple-Combo Neutron-Porosity x Litho-Density x Natural Gamma Ray x Resistivity-Induction x	FMS-Sonic Acoustic x FMS x	Borehole Televiewer [ ] Geochemical [ ] Resistivity-Laterolog [ ] High Temperature [ ] Magnetic/Susceptibility [ ]	Density-Neutron x Resitivity-Gamma Ray x

Estimated days:	Drilling/Coring: 6	Logging: 2	Total On-Site: 8
Hazards/ Weather	*List possible hazards due to ice, hydrocarbons, dumpsites, cables, etc.*		*What is your Weather Window?* Summer

Instructions:

Please fill out these forms for each site that you are proposing to drill, including as much detail as possible. The following table describes the purpose of each page, what information is needed, and when each page should be submitted.

Page	Information needed	Used By	When to submit	Contact for more information
1	General Info. about proposals, site location and basic operational needs	JOIDES Office, Data Bank, Logging Group, ODP/TAMU, SSP, PPSP	When submitting preliminary proposal and when updating site information.	JOIDES Office email: joides@whoi.edu www: http://www.whoi.edu/joides/
2	Information regarding site survey data available and to-be-collected	JOIDES Office, Data Bank, SSP, PPSP	When submitting full proposal and when updating site survey information	Site Survey Data Bank email: odp@ldeo.columbia.edu www: http://www.ldeo.columbia.edu/databank/
3	Detailed Logging Plan	JOIDES Office, Logging Group, ODP/TAMU	When submitting full proposal and when updating logging plan	ODP-LDEO Wireline Logging Services email: borehole@ldeo.columbia.edu www: http://www.ldeo.columbia.edu/BRG/brg_home.html
4	Lithologic Summary	JOIDES Office, Data Bank, ODP/TAMU, PPSP	When proposal is placed on Drilling schedule, prior to PPSP review.	Site Survey Data Bank email: odp@ldeo.columbia.edu www: http://www.ldeo.columbia.edu/databank/
5	Pollution and Safety Hazard Summary	JOIDES Office, Data Bank, ODP/TAMU, PPSP	When proposal is placed on Drilling schedule, prior to PPSP review.	Site Survey Data Bank email: odp@ldeo.columbia.edu www: http://www.ldeo.columbia.edu/databank/

ODP Site Description Forms:

Please fill out information in all gray boxes

Page 2 - Site Survey Detail

New x **Revised**

Proposal #:	Site #: CAS01	Date Form Submitted: April 01, 2003

	Data Type	SSP Requir-ements	Exists In DB	Details of available data and data that are still to be collected
1	High resolution seismic reflection		No	Primary Line(s): Location of Site on line (SP or Time only) Line 99-01 Crossing Lines(s):
2	Deep Penetration seismic reflection		yes	Primary Line(s): Location of Site on line (SP or Time only) ODP Leg 146 pre site survey line 89-04 (Shot 340), 89-08 Crossing Lines(s):
3	Seismic Velocity†		yes	From Site 888: At seafloor around 1500 m/s increase to about 2000 m/s at 500 mbsf
4	Seismic Grid			
5a	Refraction (surface)			
5b	Refraction (near bottom)			
6	3.5 kHz			Location of Site on line (Time)
7	Swath bathymetry			
8a	Side-looking sonar (surface)			
8b	Side-looking sonar (bottom)			
9	Photography or Video			
10	Heat Flow		Yes	From Site 888, shipboard analyses showed a heat flow of 73 mW/m^2 at the seafloor.
11a	Magnetics			
11b	Gravity			
12	Sediment cores			
13	Rock sampling			
14a	Water current data			
14b	Ice Conditions			
15	OBS microseismicity			
16	Navigation			
17	Other			

SSP Classification of Site:	SSP Watchdog:	Date of Last Review:
SSP Comments:		

X=required; X*=may be required for specific sites; Y=recommended; Y*=may be recommended for specific sites; R=required for re-entry sites; T=required for high temperature environments; † Accurate velocity information is required for holes deeper than 400m.

ODP Site Description Forms:

Page 3 - Detailed Logging Plan

New [x] **Revised** [ ]

Proposal #:	Site #: CAS-01	Date Form Submitted: April 2003
Water Depth (m): 2600	Sed. Penetration (m): 500	Basement Penetration (m):

Do you need to use the conical side-entry sub (CSES) at this site? Yes ☐ No ☒

Are high temperatures expected at this site? Yes ☐ No ☒

Are there any other special requirements for logging at this site? Yes ☐ No ☒

If "Yes" Please describe requirements:_____

What do you estimate the total logging time for this site to be: 2 days

Measurement Type	Scientific Objective	Relevance (1=high, 3=Low)
Neutron-Porosity	Tool is used to characterize porosity-depth function at this reference site. Important for control of sediment thickening, porosity reduction during accretion-process.	1
Litho-Density	Density is a proxi for porosity, combined with Neutron porosity	1
Natural Gamma Ray	Tool is used to define lithology (clay-content)	1
Resistivity-Induction	Resistivity is a key proxi to characterize the occurrence of hydrate. At this reference Site, this will define the baseline of no-hydrate/no gas.	1
Acoustic	Acoustic logs are (together with resistivity) primary tools to characterize the occurrence of gas hydrate. At this reference Site a baseline for no hydrate/no gas will be defined	1
FMS	FMS is an important tool to study formation of hydrates and as a general tool for lithology description and log-control (break-outs).	1
BHTV	Not used	
Resistivity-Laterolog	Not used	
Magnetic/Susceptibility	Not used	
Density-Neutron (LWD)	LWD is a key tool to characterize gas hydrates. This Site forms a no hydrate/no gas baseline for the other sites with hydrate occurrence.	1
Resitivity-Gamma Ray (LWD)	LWD is a key tool to characterize gas hydrates. This Site forms a no hydrate/no gas baseline for the other sites with hydrate occurrence.	1
Other: Special tools (CORK, PACKER, VSP, PCS, FWS, WSP	Use of DVTP	1

For help in determining logging times, please contact the ODP-LDEO Wireline Logging Services group at:

borehole@ldeo.columbia.edu
http://www.ldeo.columbia.edu/BRG/brg_home.html
Phone/Fax: (914) 365-8674 / (914) 365-3182

Note: Sites with greater than 400 m of penetration or significant basement penetration require deployment of standard toolstrings.

ODP Site Description Forms:

Please fill out information in all gray boxes

Page 4 - Pollution & Safety Hazard Summary

New x **Revised**

Proposal #:	Site #: CAS-01	Date Form Submitted: April 01, 2003

1	Summary of Operations at site: (Example: Triple-APC to refusal, XCB 10 m into basement, log as shown on page 3.)	Triple APC to refusal, XCB and RCB if needed LWD (Hole A), Coring/logs (Hole B) as shown on page 3
2	Based on Previous DSDP/ODP drilling, list all hydrocarbon occurrences of greater than background levels. Give nature of show, age and depth of rock:	ODP Leg 146, Site 888 Generally methane (from headspace) concentrations were below 10000 ppmv in the upper 500 mbsf. In the upper 500 mbsf no evidence for ethane was found, below 500 mbsf, C1/C2 ratio drops from 10^6 to about 10^3.
3	From Available information, list all commercial drilling in this area that produced or yielded significant hydrocarbon shows. Give depths and ages of hydrocarbon-bearing deposits.	
4	Are there any indications of gas hydrates at this location?	No
5	Are there reasons to expect hydrocarbon accumulations at this site? Please give details.	No
6	What "special" precautions will be taken during drilling?	
7	What abandonment procedures do you plan to follow:	None
8	Please list other natural or manmade hazards which may effect ship's operations: (e.g. ice, currents, cables)	
9	Summary: What do you consider the major risks in drilling at this site?	The sediments can be gas-rich, cores can expand significantly after recovery and may cause uncontrolled breaks/explosion of cores on the catwalk. Minor concentration of H_2S gas may be encountered.