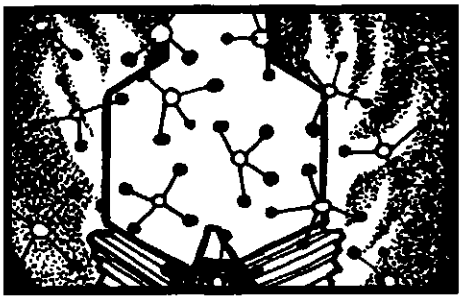

The Challenge of Deep Ocean Drilling for Natural Gas Hydrate

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SUMMARY

Large reservoirs of natural gas hydrate have been sampled extensively by past DSDP, ODP, and other scientific ocean drilling. Gas hydrate is an ice-like solid consisting of gas molecules, commonly methane, trapped in a cage of water molecules. Global estimates of the methane content of natural gas hydrate are very large, potentially enormous. Such large quantities of gas hydrate could be important as a clean energy source, as a control in global climate, and as a factor in seafloor slumps and slides. Gas hydrate occurs only in water depths greater than about 600 m at temperate latitudes, but occurs on land and in shallow water in the Arctic. The formation mechanisms of gas hydrates are only partly understood. Gas hydrate appears to be formed usually by migrating fluids carrying biologically generated methane upward to regions of sufficiently low temperature and high pressure where the hydrate is stable. Quantitative aspects of this formation model need testing, however, and questions remain about the sources and sinks for methane, and the amount that can reach the atmosphere. In Canada, gas hydrates are found on most of its continental margins, notably on the continental slope off Vancouver Island and in the Mackenzie Delta-Beaufort Sea region. A drilling program off Vancouver Island would examine gas hydrates in a well-studied accretionary sedimentary wedge; such sediments appear to be the most common environment in which hydrates are found globally. Drilling for gas hydrate offshore in the Canadian Arctic, perhaps using an alternative drilling platform, would complement a current onshore Arctic gas hydrate drilling program in the permafrost environment. The Arctic land and shallow sea hydrate are important because such hydrate is especially susceptible to global climate change.

RÉSUMÉ

De vastes réservoirs d'hydrate de gaz naturel ont été amplement échantillonnés par le DSDP, l'ODP et d'autres programmes de forage scientifiques. L'hydrate de gaz est un solide semblable à la glace, constitué de molécules de gaz, généralement du méthane, piégées dans une cage de molécules d'eau. Les estimations des volumes planétaires d'hydrate de gaz naturel sont très grandes, voire énormes. De telles quantités d'hydrate de gaz pourraient s'avérer important comme source d'énergie, comme tampon de régulation du climat de la planète, et comme facteur dans les mouvements et les glissements de terrains des fonds marins. Sous l'eau, les hydrate de gaz n'existent qu'à des profondeurs de plus de 600 m aux latitudes tempérées, mais ils existent sur terre et en eaux peu profondes dans les régions arctiques. Le mécanisme de formation des hydrates de gaz n'est que partiellement élucidé. Il semble que l'hydrate de gaz se forme généralement par la migration ascendante de fluides porteurs de méthane biologique vers des zones de température suffisamment basse et de pression suffisamment élevée, là où l'hydrate est stable. Cependant, les aspects quantitatifs de ce modèle de formation doivent être vérifiés, et certaines questions demeurent sans réponse quant aux sources et aux pièges du méthane, et à la quantité pouvant atteindre l'atmosphère. Au Canada, on trouve de l'hydrate de gaz sur la plupart de ses marges continentales, notamment sur la pente continentale au large de l'île de Vancouver de même que dans la zone du delta du Mackensie-mer de Beaufort. Un programme de forage au large de l'île de Vancouver permettrait d'étudier les hydrates de gaz au sein d'un biseau sédimentaire d'accrétion bien étudié; il semble que ce type de sédiments soit l'environnement le plus commun où l'on trouve des hydrates de gaz sur la planète. Le forage de prospection en mer pour l'hydrate de gaz dans l'Arctique canadien, peut-être avec une autre plate-forme de forage, permettrait de compléter un programme de forage sur les hydrates de gaz en cours dans une région arctique du continent, dans un environnement de pergélisol. L'hydrate de gaz des terres de l'Arctique et des mers peu profondes est important à cause de sa susceptibilité aux changements climatiques planétaires.

INTRODUCTION

One of the great achievements of the Ocean Drilling Program (ODP) and its predecessor the Deep Sea Drilling Project (DSDP) has been sampling and measuring the massive reservoir of gas hydrates — essentially frozen methane, CH_4 — beneath the seafloor. Herein use of the word "hydrate" or "hydrates" unmodified always means gas hydrate(s). The importance of understanding gas hydrates was recognized as soon as the enormous size of the methane reservoir became evident. Global order-of-magnitude estimates (*e.g.*, Kvenvolden, 2000) indicate that hydrates store about 600,000 Tcf (trillion cubic feet) of methane gas or 10,000 Gt (gigatonnes, 10^{12} kg) of organic carbon. This is approximately double the amount contained in conventional hydrocarbons such as oil, gas, and coal (Fig. 1). This huge reservoir of carbon must be considered an important element in the global carbon cycle and the ocean-atmosphere system.

As an energy source, the possibility of tapping into even a small portion of this immense methane reservoir is enticing. Methane burns cleanly with no pollutants except CO_2, and the lowest level of that for any hydrocarbon. Recovery of methane from natural gas hydrates presents a formidable technical challenge, however. Hydrates usually occur as fine crystals throughout the sediments, and the greatest volumes are distributed in deep water (more than 600 m) over thousands of

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square kilometres. Thus, it is unlikely that their commercial potential will be realized in the near future.

Methane release from hydrates may have an important role in controlling global climate, because methane is a strong greenhouse gas. Because the stability of hydrate depends on temperature and pressure, changes in ocean water-bottom temperature or in sea level can perturb the hydrates, as can changes in air temperature for Arctic land hydrate. A major release of methane to the atmosphere could result in an even more enhanced warming trend, a positive feedback. Such a scenario has been suggested as the trigger that produced the termination of previous ice ages (Nisbet 1990; Kennett *et al.,* 2000). It also may have been the mechanism that caused a sudden extraordinary 2-3°C warming of global temperature at about 55 Ma, as inferred from deep-sea sediment cores (Dickens *et al.,* 1997a).

The distribution of a number of prominent slides and slumps on continental slopes appears to be correlated to the presence of gas hydrate deposits (Paull *et al.,* 2000). Examples are found in the Beaufort Sea (Kayen and Lee, 1991), on the east coast of the United States (Booth *et al.,* 1994), and on the Norwegian margin of the Voring Sea (Bugge *et al.,* 1987). The sediments may have been destabilized by the buildup of a gas layer beneath the hydrate, perhaps because of rapid sedimentation, an increase in water temperature, or a drop in sea level. The presence of hydrates may also pose a hazard in the production of conventional hydrocarbons, especially now that offshore exploration is moving to deeper waters where hydrates are common.

Deep sea gas hydrates have an application as a heat flow mapping tool (Ganguly *et al.,* 2000). Because the depth to the base of the hydrate stability field (which can be detected seismically as discussed below) is strongly temperature dependent, it provides a method of mapping the seafloor thermal regime in some critical areas. Such thermal data are important, for example, in mapping the maximum depth extent of major thrust earthquakes in subduction zones, and for modelling of metamorphic processes in accretionary sedimentary prisms.

Bacterial activity is responsible for both the low-temperature anaerobic (oxygen-free) production of methane and, to a major degree, for its consumption near the seafloor and conversion to CO_2. Such bacteria are part of the new evidence collected by ODP that vast microbial populations live 750 m or more below the seafloor. As much as two-thirds of the microbes on the Earth are deeply buried in oceanic sediment and crust. Bacteria in deep-sea sediments may account for ~10% of living biomass on Earth (Wellsbury and Parkes, 2000). An understanding of this population, which includes those bacteria related to hydrates, is important not only to answer fundamental questions about the distribution of life on Earth, but also to quantify the parameters intimately involved in the global carbon cycle and in global climate change.

The Integrated Ocean Drilling Program (IODP) to begin in 2003 has organized its major scientific objectives into three major themes: 1) the deep biosphere and the sub-seafloor ocean; 2) environmental change, processes, and effects; and 3) solid earth cycles and geodynamics. Marine gas hydrates are involved in all three themes. Hydrates are produced by deep microbial action, and they play an important role in climate change. Closely linked to fluid flow in sediment prisms, they are an important element of the geodynamics of subduction zones. It is for these reasons that the study of gas hydrates was selected as one of the eight major initiatives of the IODP. This initiative crosses all themes, and requires a collaborative and integrated approach across a wide range of disciplines.

WHERE ARE GAS HYDRATES FOUND?

Much of what we know about gas hydrates has been determined over the past 20 years in drilling by the DSDP and ODP, in drilling programs off the continental margins of Guatemala, Mexico, Japan, Chile, Oregon/Vancouver Island, and the United States east coast (for comprehensive location information, see Kvenvolden, 2000). Gas hydrates occur in many environments, but the majority of widespread bottom simulating reflectors and inferred gas hydrate are found in clastic accretionary prisms. Hydrates are found on land only in Arctic permafrost conditions, where they have been drilled in Siberia and in the Mackenzie Delta (Dallimore *et al.,* 1999).

Distribution of Gas Hydrates Below the Seafloor

Hydrates are found in continental slope environments in the upper few hundred metres below the seafloor. The stability of gas hydrates depends mainly on temperature and pressure, and to a lesser extent on the composition of the enclosed gas and the water salinity. The base of the hydrate layer is a sharp phase boundary, representing the change between sediments containing frozen methane hydrate above the boundary and gas-saturated water or free gas bubbles below. This phase change produces a sharp acoustic contrast, particularly for underlying sediments containing free gas that significantly reduces their seismic velocity. Hydrates are most commonly detected beneath the seafloor through the presence of a strong seismic reflection (called a bottom simulating reflector or BSR) from the phase boundary. During the ODP, the BSR has been penetrated and studied in some detail on the Chile margin, Cascadia margin, and Blake Ridge on the Atlantic continental margin of the United States. Hydrate was recovered above the BSR, and sonic logging confirmed much reduced seismic velocities below the BSR owing to the presence of free gas (*e.g.,* Westbrook *et al.,* 1994; MacKay *et al.,* 1994; Holbrook *et al.,* 1996). However, the pressures and temperatures did not precisely correspond to the expected conditions at the hydrate/free gas interface. These small discrepancies may prove to be significant in understanding the

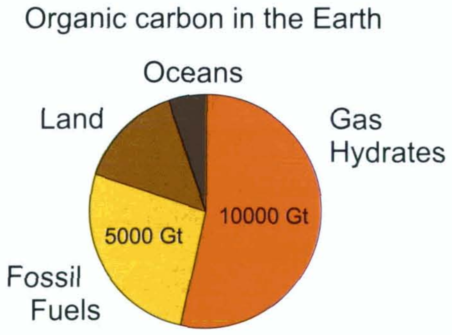

Figure 1 Estimates of total carbon stored in gas hydrates are more than double that stored in conventional hydrocarbons such as oil, gas, and coal (from Kvenvolden, 1993).

basic formation processes of hydrate (Ruppel, 1997).

Marine Gas Hydrates off Western Canada

ODP drilling during Leg 146 (Westbrook *et al.*, 1994) was key in determining the concentration of hydrate on the Vancouver Island continental margin. The primary estimators are seismic velocity, electrical resistivity, and core pore fluid chlorinity. Vertical seismic profiling in the drillhole and downhole sonic logging detected the high-velocity hydrate layer above the BSR (MacKay *et al.*, 1994), consistent with results of velocity analyses from multichannel seismic data near the drill sites (Yuan *et al.*, 1996, 1999). In the 100-m interval above the BSR, seismic velocities were 150-200 m per second faster than the "reference" seismic velocity (the velocity of sediments containing no hydrate) as determined from the seismic analyses. These velocity data give hydrate concentrations of 15-20% of the sediment pore space (Fig. 2). Comparable results were obtained from downhole measurements of resistivity (Hyndman *et al.*, 1999), which increases with the presence of gas hydrate. Resistivities at the hydrate site were compared with those at a reference site, to give estimated hydrate concentrations of 30% of the pore space (Fig. 2). These concentrations are among the highest determined for any margin worldwide.

With the hydrate concentration calibrated by ODP drilling results, the distribution of hydrate can be inferred from the presence of the BSR on seismic reflection data (Fig. 3). On the Vancouver Island continental slope, hydrates were mapped over an area of 20 km by 300 km (Spence *et al*, 2000; Hyndman *et al*, 2001) (Fig. 4). Here, they store an estimated 200 Tcf of methane gas: enough to fulfill the natural gas requirements in Canada for about 40 years, at present rates of consumption.

The areas of greatest hydrate concentration may be at cold seeps, which are sites where large volumes of fluid and gas are vented into the water column. Near Sites 889/890 on ODP Leg 146, venting sites were detected seismically as prominent zones of amplitude blanking extending upwards from the BSR (Fig. 5; Riedel *et al.*, 2001; Riedel *et al.*, in press). The location of the vent sites appears to be controlled by faulting in the sediments; in Figure 5, each blank zone is located where the dip of the sediments changes sharply. Vent Site 1 is associated with a seafloor topographic feature: a roughly circular mound with a diameter of about 300 m. This vent site was the target of a sediment piston coring program in July 2000. Massive hydrate was recovered in four cores at sub-seafloor depths of 3-6 m. This exciting find represented the first recovery of gas hydrate in Canadian waters.

Vent Site 1 was subsequently examined by the Canadian remotely operated vehicle ROPOS in September 2000. Like other cold seeps such as those off Oregon (Suess *et al.*, 1999), widespread carbonate precipitates and specific vent biota (clams and tubeworms) tolerant of high methane or sulphide environments were found.

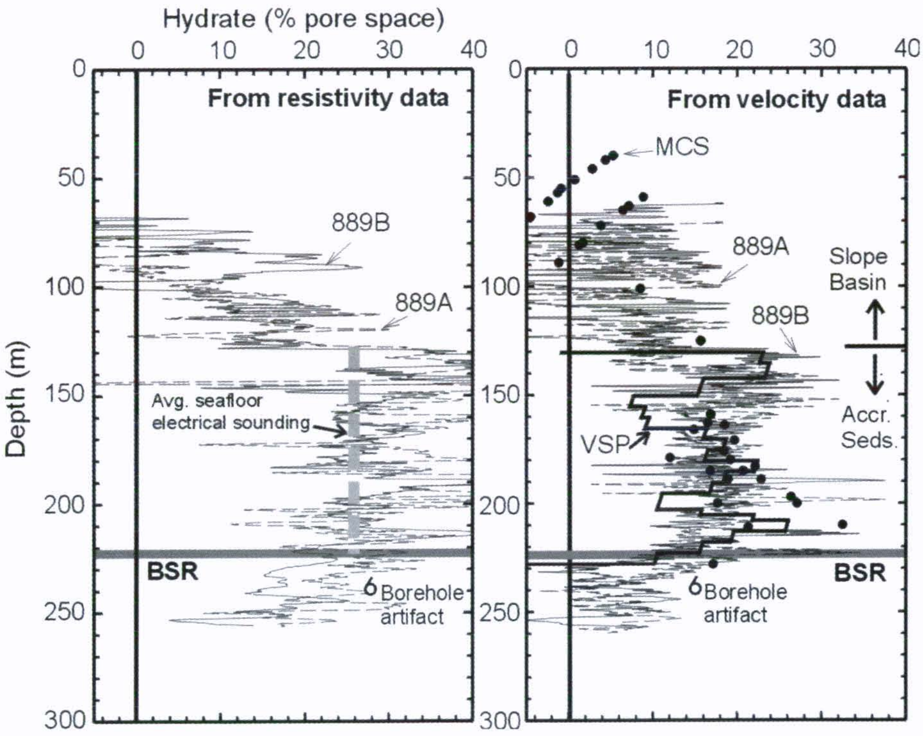

Figure 2 Hydrate concentration at ODP Site 889/890 estimated from log resistivities and core salinities (**left**) and velocity data including downhole logs, vertical seismic profiling (VSP), and multichannel seismic (MCS) velocity analyses (**right**).

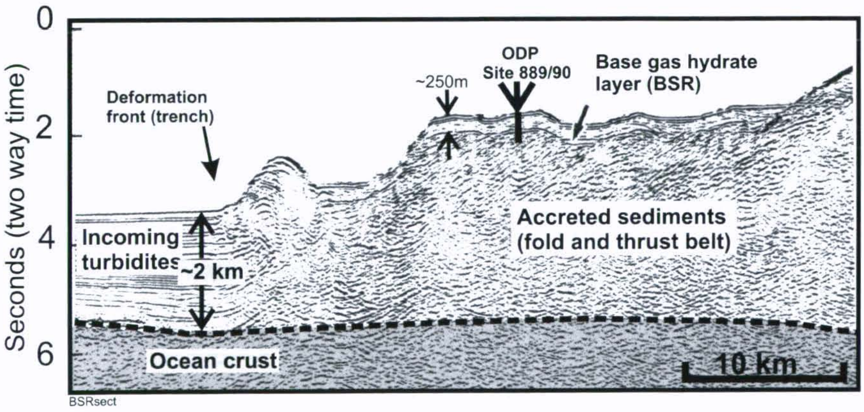

Figure 3 Line 85-02, a multichannel seismic section across the Vancouver Island continental slope. The bottom simulating reflector (BSR) can be identified over a distance of about 30 km. The location of the line is shown in Figure 4.

Arctic Canada

More than half of the petroleum exploration wells in the Arctic islands are inferred to contain gas hydrate, while well-log responses consistent with hydrates are found in about one-fifth of the wells in the Mackenzie Delta (Fig. 6). In 1998, the Mallik 2L-38 research well was drilled in the Mackenzie Delta in the first detailed borehole investigation of gas hydrate beneath permafrost (Dallimore *et al.*, 1999). As a collaborative effort among researchers from North America and Japan, the well was drilled to 1150 m and included extensive scientific, coring, and production studies. Based on cores and downhole logging, an interbedded gas hydrate succession was estimated to extend from 897 m to 1110 m. Gas hydrate concentrations were calculated using both electrical resistivity logs and seismic velocity logs (P-wave and S-wave). Estimates were as high as 80% of the pore space in some intervals, with an average of about 40% over the gas-hydrate-bearing sections. A second hydrate research well, with a greater emphasis on production testing, is planned in 2002 in the Mallik region in a collaboration among Canadian, Japanese, American, and German researchers. As discussed below, an important complement to this land drilling would be ocean drilling for hydrate beneath the adjacent Beaufort Sea.

HOW ARE GAS HYDRATES FORMED?

Although gas hydrates are found on nearly all continental margins, they are most common in subduction zone environments where thick accretionary sediment prisms occur and where extensive fluid expulsion is produced from the thickening and tectonic compaction of the sediments. A few occurrences of hydrate, such as those in the Gulf of Mexico and the Alaska North Slope, have thermogenically generated hydrocarbon components, formed from high temperature breakdown of organic matter. Typically, the dominant gas is overwhelmingly methane (>95%), produced through the bacterial decomposition of organic matter. At some locations, such as Cascadia, the total organic content in the sediments is modest (<1%) while the estimated hydrate concentrations are very large (15-20%). The primary mechanism for concentrating the methane into gas hydrates is postulated to be upward fluid flow (Hyndman and Davis, 1992). That is, methane generated over a large volume of sediments is carried upward, either as dissolved gas within the fluid, or as gas bubbles formed where the pore waters are saturated. The methane converts to hydrate as the fluid moves into the stability field several hundred metres below the seafloor (Fig. 7).

The formation and dissociation of hydrates are dynamic processes, owing to the dependence of gas hydrate stability on temperature and pressure. Rapid sedimentation, tectonic uplift, or an increase in bottom water temperature alters temperature and pressure, and causes the base of hydrate stability to move upward. Hydrate below the new stability base will thus dissociate to gas-saturated water and free gas bubbles, which are in turn carried upward to reform as hydrate at shallower levels. This is another important mechanism to concentrate methane into hydrate above the BSR (von Huene and Pecher, 1999).

Recent mathematical models have been developed for the formation of deep sea hydrate through upward advection and diffusion. Using physical and thermodynamical arguments, Rempel and Buffett (1997) estimated that it takes

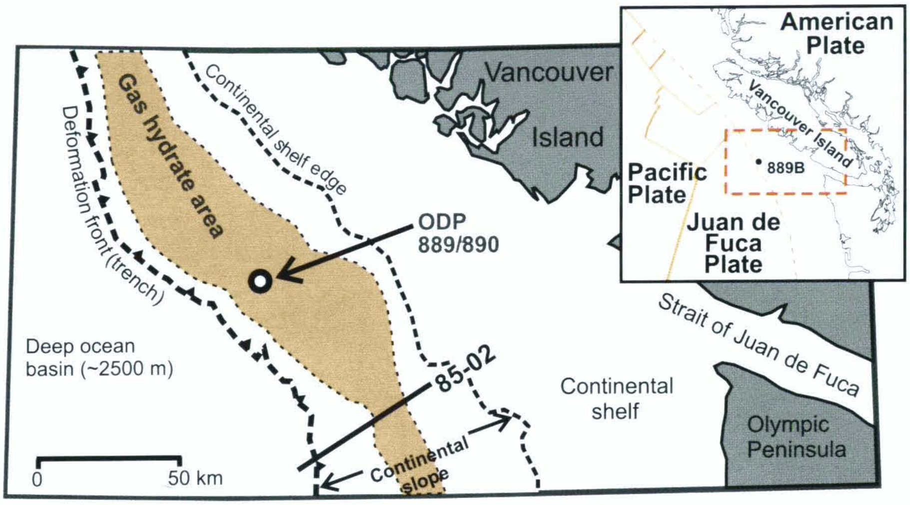

Figure 4 The area on the Vancouver Island continental margin where gas hydrate is found covers about 50% of the mid-continental slope region. Inset map top right shows location and approximate plate boundaries, dashed where uncertain.

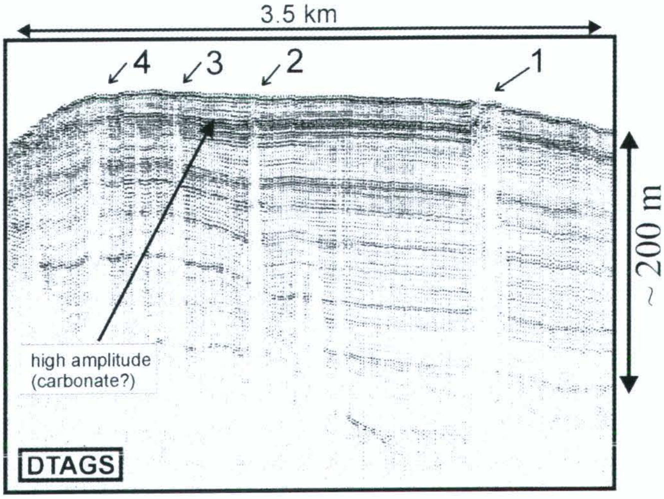

Figure 5 Stack of five near offset traces from DTAGS (Deep Tow Acoustic/Geophysics System) in the vicinity of ODP sites 889/890, Vancouver Island continental slope, showing four blank zones of reduced seismic amplitude (numbered 1-4).

approximately 100,000 years to form hydrate concentrations of 1% of the pore space, for a nominal fluid flow velocity of 1 mm per year. The dependence of hydrate formation on rates of fluid and methane flux was demonstrated by Xu and Ruppel (1999). When the methane flux becomes too small, the base of hydrate is predicted to be above the base of the hydrate stability field. Assuming that the top of the free gas represents the BSR, this provides a possible explanation why the BSR is commonly found deeper than the base of the stability field, as observed in north Cascadia and at the Blake Ridge.

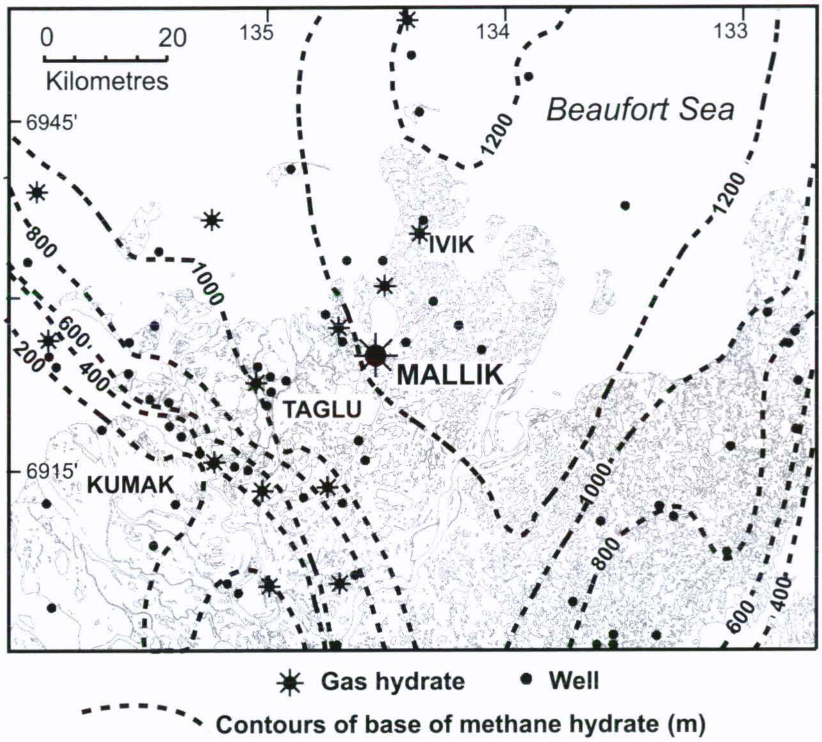

Figure 6 Map of part of the Mackenzie Delta region showing the calculated depth to the base of the methane hydrate stability zone. About one-fifth of the wells in the Mackenzie Delta have well-log responses indicating gas hydrate (after Dallimore *et al.*, 1999).

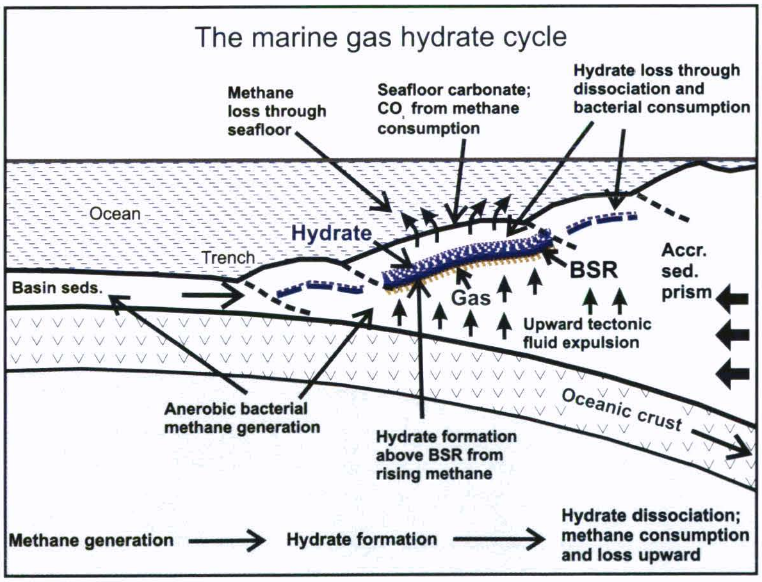

Figure 7 Formation model indicating processes in the marine gas hydrate cycle, in which gas hydrate is formed through removal of the methane carried by upward migrating pore fluids.

WHAT ARE SCIENTIFIC GOALS FOR GAS HYDRATE DRILLING?

The continental slope off **Vancouver Island** is one of the most completely studied accretionary prism environments. Within this region, there have been comprehensive geophysical site surveys and previous ODP drilling during Leg 146 to provide downhole logs, core analyses and pore fluid geochemistry. Drilling by IODP on this margin could address many of the remaining problems on the fundamental nature of gas hydrate deposits, from the production and consumption of methane to the formation and dissociation of hydrate. By examination of microorganisms found deep beneath the seafloor, a drilling program could determine how methane generation is related to, or depends on, microbial activity and on the organic carbon source material, and ultimately could help to quantify the rate at which gas is generated in the sediments. The critical role of fluid flow in hydrate formation could be addressed by quantifying the rates of fluid flux and gas migration through the sediments, using new tools developed in the Ocean Drilling Program. Such quantitative measurements are required to test recent models of hydrate formation and to estimate the size and distribution of gas hydrate reservoirs. To understand the potential impact of methane hydrate on global climate, a drilling program could examine the processes by which methane is lost from the reservoir, including (a) the environmental conditions for hydrate dissociation, (b) the rates of methane consumption by bacterial activity (oxidation) and the rates of carbonate formation, (c) the amount of methane lost through the seafloor to the water column, and (d) the geochemical processes occurring during gas migration to the atmosphere.

In the **Canadian Arctic** an important complement to the Mallik land drilling noted above would be ocean drilling for hydrate beneath the adjacent Beaufort Sea. High-latitude drilling would be particularly significant in order to examine the role of Arctic hydrate in climate change. Climate studies indicate that Arctic regions are most strongly affected by climate changes, and that extensive warming in the Arctic is predicted over the next 25 years. In this region sea level transgression results in the flooding of permafrost-bearing low-lying land areas, so that the newly flooded surface warms from very cold land temperatures to warmer near-freezing temperatures of the ocean. This warming propagates downward and dissociates deep gas hydrate. Offshore drilling will provide the baseline for this important mechanism of free gas methane generation and its movement to the atmosphere.

In the Arctic Ocean, IODP alternative drilling platforms will be required to study hydrates found in association with permafrost environments. Formation mechanisms of Arctic gas hydrate are even less well understood than those of marine environments at lower latitudes. Because extensive drilling by the hydrocarbon industry has already occurred in the Beaufort Sea as well as Mackenzie delta, these regions are very suitable for examining technical problems associated with drilling and producing gas from hydrate deposits. An important part of the 1998 Mallik land-based gas hydrate research well (Dallimore *et al.,* 1999), and the continuing program planned for 2002, is the technology of hydrate gas production.

Off the **East Coast of Canada,** interest and activity in hydrate research have been limited, but the geohazard implications of marine hydrates may be significant as conventional oil and gas exploration and development move to deep water (Taylor *et al.,* 1979). The industry and research communities must determine the hazard to drilling where shallow gas hydrate is found. Hydrate can be destabilized by temperature or pressure changes associated with the drilling itself. A second important implication is the effect of hydrate on the stability of the seafloor beneath development and production structures, including drilling structures, pipelines, anchors, cables, and production hardware.

IODP CANADA AND GAS HYDRATES

A comprehensive study of marine gas hydrates must integrate a wide range of disciplines from regional geophysics, downhole measurements and sampling, geochemistry and microbiology, and seafloor geological observations. An understanding of hydrates must involve an examination of the entire gas hydrate system, namely how and where hydrate-derived methane is produced and how and where it is lost. Careful sampling is required to examine the physical, chemical and biological properties of sections with and without hydrate, especially close to the seafloor and to the BSR, because these regions are the most vulnerable for methane dissociation and potential impact on global climate.

Additional field surveys will aid in site selection, and provide the regional context or setting to extend results beyond the drill hole. Off Vancouver Island, extensive seismic surveys have already been carried out; these include multichannel and single-channel reflection seismic, ocean-bottom seismometer and high-resolution deep-towed seismic data. Additional surveys at vent sites where hydrate has been recovered are planned with the deep-towed multichannel reflection system (DTAGS) of the United States Naval Research Laboratory. Detailed heat flow surveys, and bottom geological-geochemical studies also have been carried out in the region. New seafloor survey methods are being developed to complement the seismic techniques and provide alternative estimates of the concentration and distribution of deep sea hydrates. Specifically, these new survey methods focus on (a) continuous profiling of electrical resistivity to depths of several hundred metres (Yuan and Edwards, 2001), and (b) measurement of seafloor compliance, or displacement of the seafloor in response to varying pressures, *e.g.,* due to surface waves or internal waves in the ocean (Willoughby and Edwards, 2000).

Because seafloor gas hydrates are difficult to collect and preserve, special tools are required to make *in situ* measurements, and to preserve samples. To recover hydrate at ambient temperature and pressure, Pressure Core Sampler systems have been developed by ODP. Although they require further work, one sampler was successfully used on the Blake Ridge (Leg 164) for recovery of sediment core containing hydrate (Dickens *et al.,* 1997b). Another sampler tool is the Hyperbaric (Gas Hydrate) Autoclave Coring Equipment (HYACE), which is under development with ODP as a collaborator. This tool includes a system for nondestructive physical and chemical analyses while maintaining pressure and controlled temperatures, once samples are

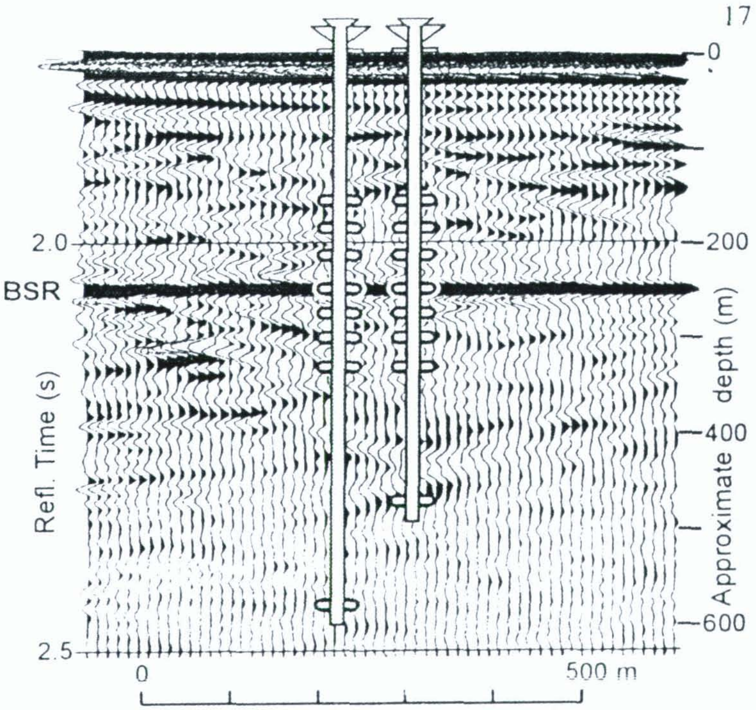

Figure 8 Advanced CORK downhole observatory system showing numerous packer levels, eight per borehole, superimposed on a multichannel seismic reflection section from a location near ODP Site 889/890.

returned to the ship.

ODP work has shown that Logging While Drilling (LWD) is required for high-quality physical properties: seismic velocity, electrical resistivity, porosity, density, and shear wave velocity. Hydrates and underlying free gas are especially susceptible to drilling and borehole disturbance, so rapid measurement using LWD is important. Shear wave velocity seems to be a particularly sensitive indicator of hydrate. Combined with careful conventional downhole logging, LWD may provide estimates of velocity and resistivity both within hydrate zones and at reference sites where no hydrate or gas is found.

The long-term deployment of sealed-hole hydrogeological observatories can be used to monitor downhole pore pressure and permeability, and thus fluid and methane flux. Since 1991, ODP has installed some 20 CORK (Circulation Obviation Retrofit Kit; see Davis and Becker, 2001) observatories in mid-ocean ridge, ridge flank, and subduction zone environments. CORKs seal holes at the seafloor, and allow monitoring of formation pressure and temperature over a period of years. The CORK can also determine the effect of gas hydrate and gas on the mechanical properties of the enclosing sediment, by monitoring pressure variations associated with tidal loading at the seafloor (Davis and Becker, 1998).

Advanced CORKs or ACORKs, still under development, incorporate multiple seals and provide the means to monitor pressure and temperature and to sample fluids at a number of isolated levels. Using osmotic samplers, the ACORK permits continuous time-series sampling of pore fluids above and below the BSR. The full internal diameter of the ACORK liner also can accommodate special tools for post-drilling downhole experiments. For example, innovative two-hole experiments could be designed (Fig. 8). Crosshole hydrogeology observations could determine rates of fluid flow (including pressure gradients, permeabilities, and storage parameters), while crosshole tomography could determine the 2-D distribution of seismic and electrical properties.

CONCLUSIONS

Gas hydrate occurs in many environments, but the majority of widespread bottom simulating reflectors and inferred gas hydrate are found in clastic accretionary prisms, including subduction zones. Indeed it is likely that the subduction zone gas hydrate environment dominates in the contribution of marine hydrate to the global carbon reservoir, and in the role of marine gas hydrate in global climate change. In a comprehensive study of marine gas hydrates, we need to understand the gas hydrate system from methane production to consumption, as well as the upward migration of methane and its concentration into hydrate above the base of the stability field. An integrated multidisciplinary program is required, involving geological, geophysical, geochemical, and biological studies. Ideal locations, extensive geophysical and geological surveys and studies, and previous drilling make drilling off the Canadian west coast, and in the Beaufort Sea off the Mackenzie Delta, attractive future IODP drilling and measurement sites. The proposed drilling would take good advantage of the improved drilling techniques and new tools offered by the Integrated Ocean Drilling Program to begin in 2003.

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