Marine Gas Hydrates off Canada's West Coast

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ABSTRACT

Gas hydrates are solid ice-like structures in which gas molecules (largely methane) are trapped within cages of water molecules. Gas hydrates may represent a large energy resource but may also play an important role in global climate change. On seismic sections, gas hydrates can be detected primarily by the occurrence of a bottom-simulating reflector (BSR) marking the base of the hydrate stability field. Gas hydrates were first observed in seismic data at the Northern Cascadia Margin in 1985 and have been investigated intensively over the last decade. Studies include seismic surveys, electrical resistivity and seafloor compliance studies, seafloor observations from an unmanned submersible, and Ocean Drilling Program Leg 146 drilling.

Recent research activity is concentrated around an active cold-vent field. The vent field shows several blank zones of reduced seismic reflectivity representing faults that act as conduits for upward fluid migration. They vary in size up to 100s of meters across and may contain high concentrations of hydrate. Gas hydrate was recovered by piston coring at nine sites within an active vent within the upper 10 m below the seafloor.

Massive gas hydrate outcrops at the seafloor were discovered in August 2002 in Barkley Canyon, offshore Vancouver Island. At this site hydrates were accidentally dredged by a fishing boat in summer 2000, when an estimated 1.5 tons of gas hydrate were brought to the sea surface in the fishing net. Remotely operated submersible based seafloor observations revealed widespread hydrate outcrops several meters in height in conjunction with natural oil-seeps.

Introduction

Marine gas hydrates are found several hundred meters beneath the continental slopes of many areas around the world, mainly beneath continental margins having thick sedimentary sections. The ice-like clathrate structure of methane hydrate is stable at temperatures between 10-30 ^{o}C beneath the seafloor at the pressures generated by water depths greater than about 600 m. Information on marine gas hydrates and underlying free gas has come from many sources, but mainly from seismic studies and scientific deep sea drilling. The primary indicator of marine hydrate is a bottom-simulating reflector or BSR that parallels the seafloor. Such hydrates are estimated to contain a very large amount of methane, a potential clean hydrocarbon fuel resource. Estimates of total global methane in hydrate exceed the other known combustible hydrocarbon reserves, i.e., 10^4 Gt (10^{13} tonnes) of carbon or $6{\cdot}10^5$ Tcf (trillion cubic feet) of methane (e.g., Kvenvolden, 1988; MacDonald, 1990; Kvenvolden, 1993), (*Fig. 1*).

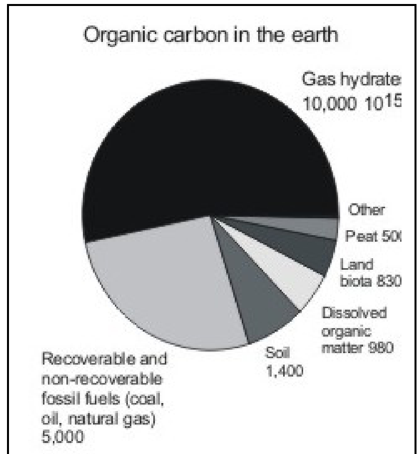

Fig. 1: Total organic carbon in the earth (from Kvenvolden, 1988).

Because methane is a very strong greenhouse gas, second in importance only to CO_2, natural gas hydrate may also play a role in climate change. Gas hydrates have also been known for many years as a problem in natural gas pipelines and as drilling hazard.

The presence of gas hydrate has been confirmed on Canada's West Coast at the

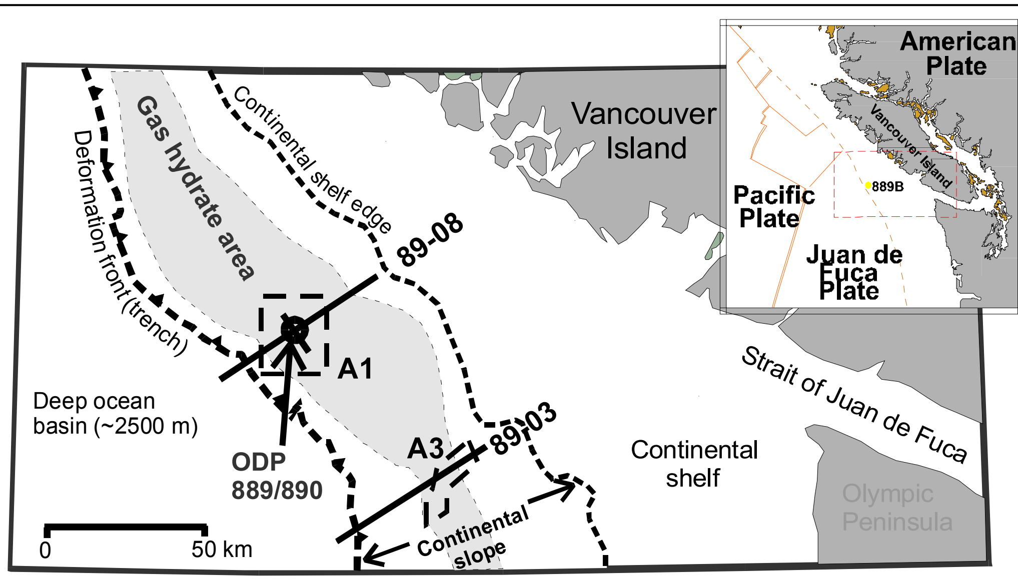

Fig. 2: Location of area with gas hydrate occurrence offshore Vancouver Island near ODP Site 889/890. A BSR is present on about 50% of the mid-continental slope (shaded area).

Northern Cascadia Margin by widespread BSRs in multichannel seismic data, scientific ODP drilling (Leg 146) and electrical sounding. After the first discovery in 1985, the area offshore Vancouver Island has been the focus of many interdisciplinary studies (*Fig. 2*); see e.g., Hyndman et al (2001) and Spence et al (2000) for a summary of those findings. Studies include 2D and 3D single and multichannel conventional and high-resolution seismic studies, Ocean Bottom Seismometer (OBS) surveys, swath-bathymetry mapping, high-resolution subbottom profiling, heat-flow studies, piston coring with geochemical and geophysical sediment analyses, ODP scientific drilling Leg 146, and ocean bottom video surveying with the remotely operated vehicle ROPOS.

Recent studies focus on a cold-vent field near ODP Site 889/890. The vent field is characterized by several seismic blank or washout zones, representing faults that act as conduit for focused fluid and/or gas flow. The vent field was imaged by 3D single and multichannel seismic surveys and was investigated in detail by piston coring and ROV video observations. Gas hydrate was recovered at the main vent within the upper 2-8 mbsf.

Regional seismic data

A wide variety of seismic surveys have been used to map and characterize the gas hydrate and underlying free gas on the Northern Cascadia Margin. The seismic systems have frequencies ranging from 20 Hz to 650 Hz with additional seafloor acoustic imagery using 3.5 kHz subbottom profilers and 12 kHz echosounders.

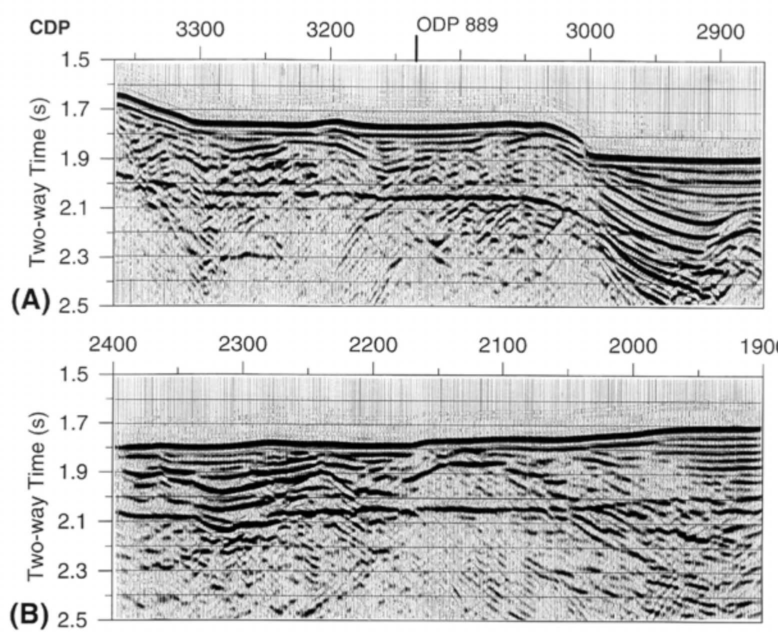

Fig. 3: Regional conventional (low frequency) MC seismic data showing strong BSR.

On regional conventional (low frequency) multichannel seismic lines, a BSR was observed in a 20-30 km wide band along much of the 250 km length of the Vancouver Island continental slope (*Fig. 3*). A BSR is generally not observed in the well-bedded slope basin sediments, but interpretations vary as to whether or not hydrate is present. On regional multichannel seismic lines a hydrate BSR is clearly observed as a generally symmetric wavelet with a reversed polarity relative to the seafloor suggesting a sharp negative impedance contrast.

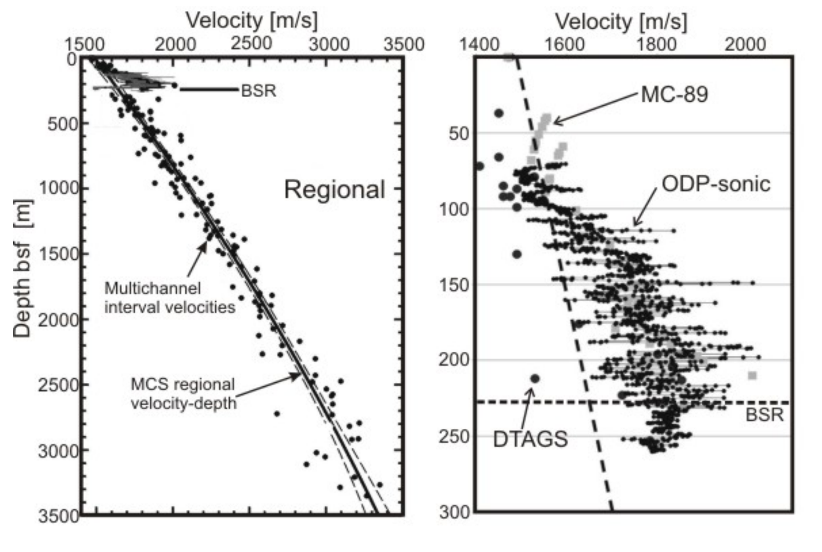

Fig. 4: Seismic Velocities from MCS semblance analyses and ODP sonic log.

Careful semblance velocity analyses were carried out down to depths of 2000 mbsf (*Fig. 4*). Above the BSR, velocities increase to nearly 1900 m/s, indicating the presence of high-velocity hydrate within the pores. By extrapolating the deeper velocities upwards, a reference velocity of sediments unaffected by either hydrate or free gas was achieved. At the BSR, hydrate produces an increase in velocity of about 250 m/s. Downhole sonic logs from ODP Site 889 (Westbrook et al., 1994) provide detailed velocity information from about 50 mbsf to the BSR at 225 mbsf. Excellent agreement with the semblance velocity results was obtained. Constraints for low velocities below the BSR, due to the presence of small quantities of gas, come from vertical seismic profiles (VSP) at Site 889 (MacKay et al., 1994).

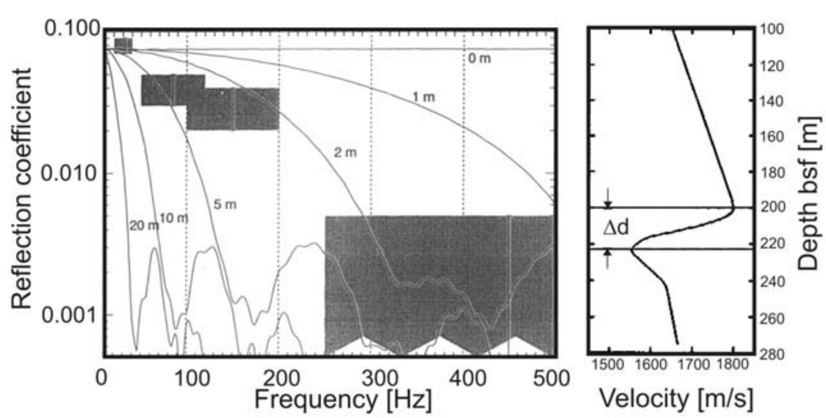

Fig. 5:. Frequency dependent nature of the BSR reflection coefficients (from Chapman et al., 2002).

Seafloor reflection coefficients are typically around 0.2, and the BSR reflection coefficients are about 30% those of the seafloor (Yuan et al, 1996).

However, multi-frequency seismic analyses showed a strong frequency dependence of the BSR reflectivity (*Fig. 5*). Modeling of this behavior inferred a thickness of the BSR of about 6 – 8 m with a strong velocity decrease of 250 m/s.

Hydrate concentrations from seismic velocities and electrical resistivity

Estimates of gas hydrate concentrations were obtained using seismic velocity and electrical resistivity. Two different models have been used to relate seismic velocity to hydrate concentration: (a) porosity reduction due to hydrate filling the pore space (Yuan et al, 1996), and (b) a time-average approach with a mixture of hydrate, water and sediment matrix (Yuan et al., 1996, 1999; Lee at al., 1993). Both models yield similar concentrations of about 10 – 25 % hydrate in the pore space (*Fig. 6*).

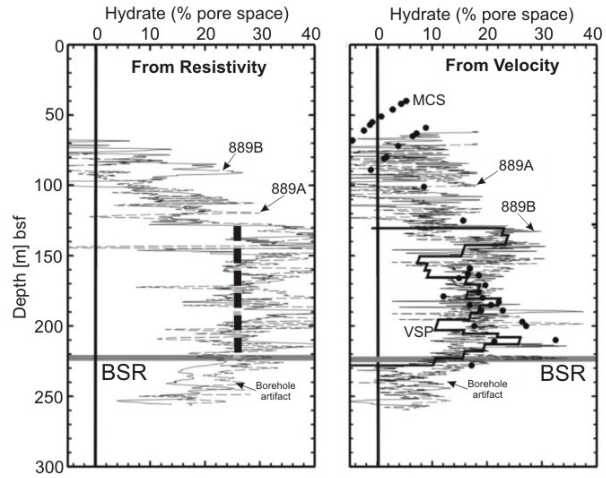

Fig. 6: Hydrate concentration from resistivity and seismic velocity. Thick dashed line is estimate from electrical sounding (see text for details).

An increase in electrical resistivity results from the formation of gas hydrate, which partially fills the pore spaces. A careful correction for lower insitu pore-fluid salinities had to be carried out prior to calculations (Hyndman et al., 1999). A simple Archie's Law model of resistivity versus hydrate then yielded hydrate concentrations of up to 30% above the BSR, which is slightly higher than the velocity estimate but is in general agreement.

Another independent constraint on hydrate concentrations was achieved from seafloor electrical sounding (Edwards, 1997; Yuan and Edwards, 2001). Several surveys giving data to depths in excess of 300 m have been conducted in the area near ODP Site 889/890. Initial interpretation has yielded resistivities in agreement with those from the ODP downhole logs.

Cold vents

Recent research activity is concentrated around an active cold-vent field in close vicinity to ODP Site 889/890. The vent site has been investigated intensively 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 (*Fig. 7*) 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 from 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 and localized. 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^2ky outside to values between 32-60 mol/m^2ky inside the vent. Assuming full methane saturation the maximum methane flux inside the vent corresponds to a fluid flux of about 1mm/yr.

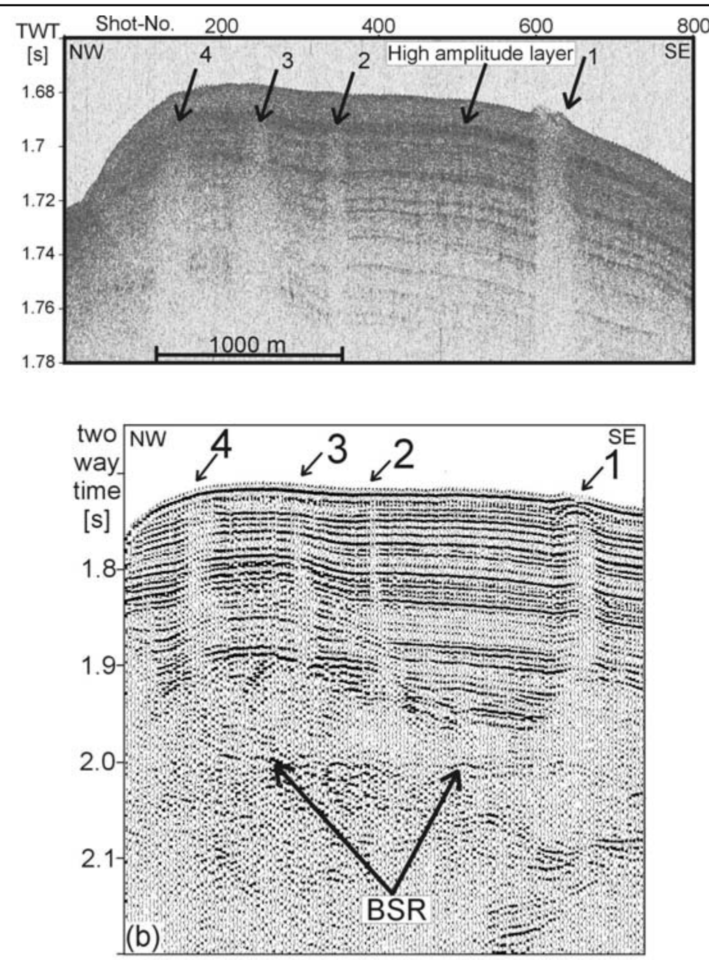

Fig. 7: Seismic signature of the cold vents (blank zones) from (a) 3.5 khz subbottom profiler, (b) single channel seismic data (20 – 180 Hz).

Gas Hydrate mounds in Barkley Canyon

Massive gas hydrate outcrops at the seafloor were discovered in August 2002 in Barkley Canyon, offshore Vancouver Island at a water depth of around 800 m using the remotely operated vehicle ROPOS. At this site hydrates were accidentally dredged by a fishing boat in summer 2000, when an estimated 1.5 tons of gas hydrate were brought to the sea surface in the fishing net (Spence et al., 2001). ROV based seafloor observations revealed widespread hydrate outcrops several meters in height in conjunction with natural oil-seeps. The hydrate outcrops are covered with an about 1 – 5 mm thin veneer of mud and are surrounded by clam colonies. First geochemical analyses of recovered hydrate pieces indicate Structure II hydrate with abundant higher hydrocarbons, indicating a thermogenic source for the gases. This site will be focus of future research.

Regional model for hydrate formation

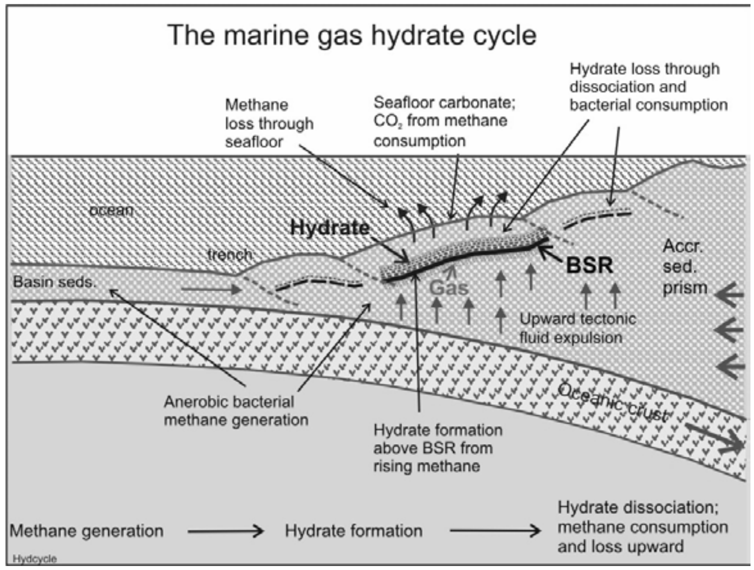

Fig. 8: Formation of gas hydrate through removal of the methane carried by upward migrating pore

The formation of substantial amounts of gas hydrate required large amounts of methane. Most deep sea gas hydrates that have been recovered contained mainly biogenic methane, i.e., produced by low temperature methanogenesis rather than by thermal gas generation. The hydrates are estimated to contain methane concentrations that are much too high to have been produced from the local sediments at the depth of the hydrate unless the organic carbon concentrations are unusually high (Hyndman and Davis, 1992; Paull and Ussler, 1997). Thus, methane produced over a considerable depth interval must be carried up to form hydrate within the stability field above the BSR. The rising fluids do not need to have methane saturation. In this fluid expulsion model, which is especially applicable to accretionary prisms, the required biogenic methane may be generated throughout a thick sediment section extending well below the BSR. This model predicts the highest concentrations of hydrate just above the BSR, decreasing upward, in good agreement with the widespread geophysical and geochemical observations for the Vancouver Island margin.

Westbrook et al. (1994), Paul and Ussler (1997), and von Huene and Pecher (1998) described another important alternative process for increasing the hydrate concentration. Upward movement of the base of hydrate stability may result from (a) incorporation and uplift of incoming sediments into the accretionary prism, (b) sedimentation, and/or (c) post-Pleistocene increase in bottom water temperature. The reduced pressure or increase in temperature cause the base of the hydrate stability to move to a lower temperature and thus upward. The lowest part of the hydrate thus dissociates to form free gas, which in turn is carried upward to reform as hydrate at higher levels. The small amount of gas that is not advected or diffused upward and remains, reduces the seismic velocity below the hydrate layer and contributes to a strong BSR.

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