Evidence for gas hydrate 'sweet spots' on the Hikurangi margin and offshore Fiordland

AR Gorman[1], IA Pecher[2], and SA Henrys[2]

[1]Department of Geology, University of Otago, PO Box 56, Dunedin, New Zealand. Telephone 64-3 455 1213, Email andrew.gorman@otago.ac.nz [2]Institute of Geological and Nuclear Sciences Ltd., PO Box 30-368, Lower Hutt, New Zealand. Telephone 64-4 570 4796, Email i.pecher@gns.cri.nz

Abstract

Within New Zealand's Exclusive Economic Zone, the continental margins adjacent to the Hikurangi Trench and Fiordland are known to contain significant quantities of gas hydrates – an ice-like solid composed of water and natural gas with huge resource potential. Current work is focussed on these regions to determine the distribution and concentrations of gas hydrate found extensively in sediment pore spaces in the upper few hundred metres of seafloor. The Hikurangi Margin, off the east coast of the North Island, has the highest economic potential of these gas hydrate deposits for future gas production because of its proximity to major population centres. The Fiordland Margin has less seismic data available, but also shows potential for resource development.

Analysis of gas hydrate deposits is primarily based on the interpretation of seismic data for the presence of bottom simulating reflections (BSRs). BSRs are reflections from thin horizons containing free gas at the base of the gas hydrate stability zone, the zone in the upper few hundred metres of the seafloor where pressures and temperatures enable solid gas hydrate to be stable. BSRs are prevalent (1) beneath structural highs and (2) at locations where dipping layers crop out at the seafloor. Both of these features are known to focus fluid flow through the sediment to the seafloor. In the methane-rich environment of the Hikurangi Margin, we presume that a substantial amount of methane is supplied to the system in regions of high fluid flow. Because an ongoing methane supply is known to be a key factor controlling gas hydrate concentration, high methane flux regions are likely to be proximal to regions of high gas hydrate concentration. These "sweet spot" locations are a focus of our work and may contain gas hydrate concentrations that are high enough for the commercial production of natural gas in the future.

Recoverable gas will depend on drilling and production technology yet to be developed. However, conservative analysis of existing seismic data from the Hikurangi continental shelf estimates recoverable gas at standard temperature and pressure (STP) to be on the order of 23 000 km^3 (813 TCF). Individual sweet spots within the province would contain on the order of 1.5 to 12.25 km^3 (0.05 to 0.43 TCF) of mathane at STP.

Introduction

Natural gas reserves sequestered within global gas-hydrate deposits have been estimated to be as much as twice the original size of all conventional hydrocarbon reserves (oil, gas, coal) combined (Kvenvolden, 1988). As conventional resources are depleted, the question must be asked, "Are gas hydrates the energy of the 21st century?"

What are Gas Hydrates?

Gas hydrate is an ice-like compound solid (a clathrate solid) composed of loosely-bound water and gas (usually methane) molecules. In marine sediments, these hydrates are stable at water depths greater than ~600 m and, typically, down to a few 10s to 100s of metres below the seafloor. Gas hydrates are of profound interest due to their evident link to global climate cycles, their affect on ocean-bottom slope stability, their risk to conventional oil and gas drilling, and perhaps most significantly to their potential as a future hydrocarbon resource.

Gas hydrates are often indirectly interpreted in marine seismic reflection data by the presence of a bottom simulating reflection (BSR) from the top of gas-charged sediments beneath the base of the hydrate stability zone. This reflection is especially evident when it cross-cuts stratigraphic or structural features in the data.

Significance of Gas Hydrates to New Zealand

Within New Zealand's Exclusive Economic Zone, the Hikurangi Margin and the margin off the coast of Fiordland are known to contain significant quantities of gas hydrates. We are currently focussing our research on the gas hydrate province on the Hikurangi Margin off the east coast of the North Island. The economic potential of these gas hydrate deposits for future gas production is highest because of their proximity to infrastructure and major population centres. Indications of large accumulations of gas hydrates have also been found on the continental margin off Fiordland and are the subject of current research at the University of Otago.

Investigating Gas Hydrates

The seismic mapping of BSR occurrences is a primary method for characterising gas hydrate distributions. However, gas hydrates were first studied by chemists and engineers, rather than seismologists, because of their formation in high pressure pipelines where they resulted in blockages (Sloan, 1990). High-pressure / low-temperature laboratory experiments, numerical simulations, and theoretical studies continue to provide complementary data to seismic investigations of gas hydrate deposits. Together, these studies play a vital role in exploring the physical nature of the substance and its relationship to surrounding materials.

The Steady State Model

Recent theoretical studies have characterised gas hydrate deposits as dynamic steady-state systems dependent on methane flux from below. In addition to the high pressure and low temperature requirements, gas hydrate is stable only in pore fluids that are fully saturated in methane. Since seafloor pore fluids are usually in communication with the overlying ocean (which is not generally saturated in methane), then methane input from below must be maintained to make up for that lost to the ocean above (e.g., Xu and Ruppel, 1999).

As a result, concentrations of gas hydrate in seafloor sediments will be highest in regions of high methane flux. This generally corresponds to regions of high fluid flow. It follows that increased concentrations of gas hydrate will occur at high-flux / high-fluid-flow localities. Such regions are therefore the focus of investigations of hydrate distributions and concentrations.

The link between BSRs, free-gas accumulations and fluid flow can be made and evaluated using seismic data (e.g., Gorman et al., 2002; Holbrook et al., 2002). In general, increased gas flux from below will result in more gas beneath the hydrate stability zone, which in turn results in a more significant BSR seismic event and higher concentrations of gas hydrate in the overlying hydrate stability zone (Pecher et al., 2001). Such a link has been documented on the Hikurangi Margin (Pecher et al., 2003) and observed on the Fiordland margin where strong BSRs coincide with features of fluid focussing.

Seismic Data Analysis

The significant portion of the seismic data available on both the Hikurangi and Fiordland is a large data set acquired as part of the France – New Zealand GeodyNZ venture of 1993 (Collot *et al*. 1996). This was acquired using a configuration that was not optimal for gas hydrate exploration (*e.g*., shelf parallel line configurations). However, several other data sets with more optimal configurations have been acquired over the last twenty years that are also being used in the analysis. These tie the large sub-optimal data sets and provide additional controls on aspects such as the density and seismic velocities of the seafloor sediments and their associated gas hydrate deposits.

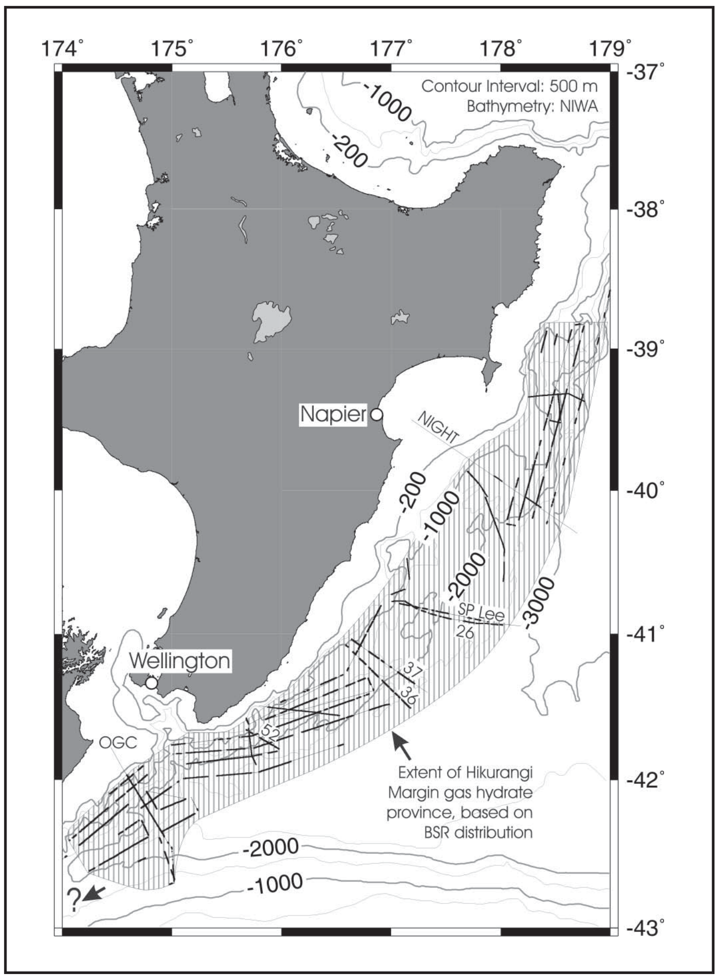

Figure 1. Seismic ship tracks (thin lines). BSR occurrences (thick lines) and the estimated extent of the Hikurangi margin gas hydrate province. Labelled lines are mentioned in the text. The eastern limit of the gas hydrate province roughly coincides with the Hikurangi trench. The southern limit is unknown due to the lack of seismic data.

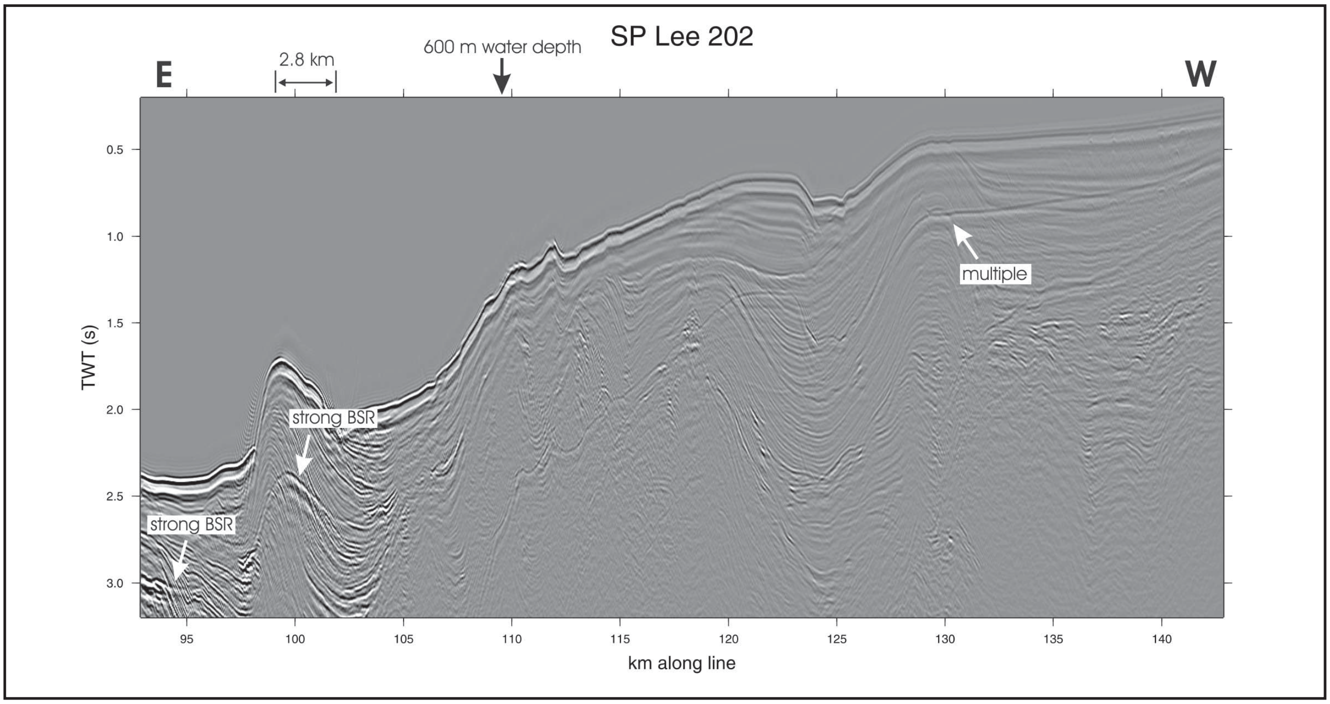

Figure 2. SP Lee line, western section. The anticline at about km 100 is analysed in Figure 4.

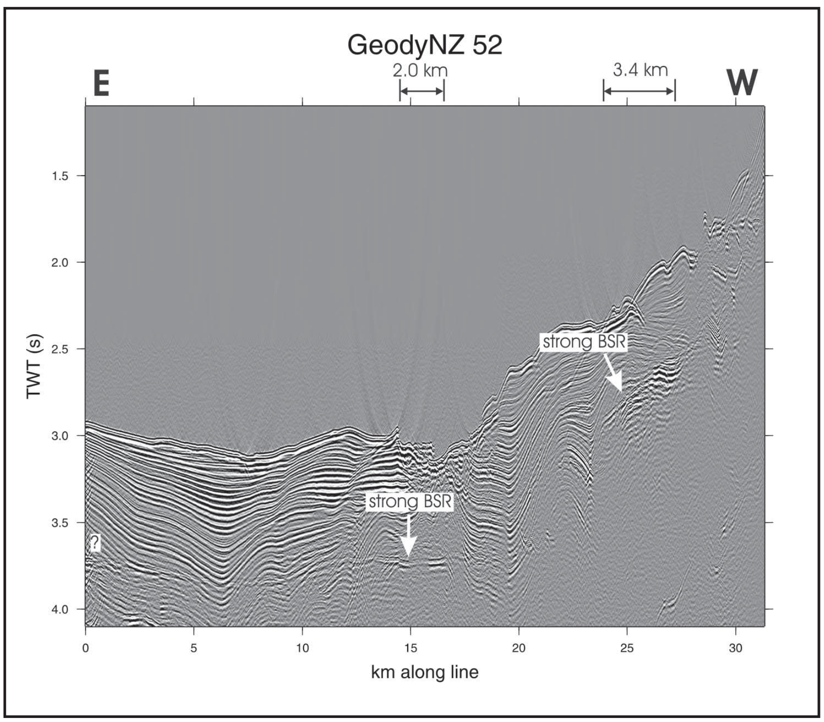

Figure 3. GeodynNZ line 52.

Quantification of Gas Hydrate and Associated Natural Gas Reserves

Figure 1 shows the distribution of BSRs on the Hikurangi Margin. Most of the region between the latitudes of Marlborough and Gisborne and in water depths from ~600 m out to the Hikurangi trench appear to contain hydrates. The shaded area in Figure 1 corresponds to roughly 50,000 km^2. Conservative input parameters suggest a resulting volume of ~230 km^3 of gas hydrate which can be translated to 23 010 km^3 (or 813 trillion cubic feet) of recoverable gas at standard temperature and pressure (STP) (Pecher and Henrys, 2003).

While the above estimate underscores the significance of the potential gas reserves from gas hydrates on the New Zealand continental margin, it is unlikely that production will become economically viable in the near future (Max, 2000). However, the fraction of these reserves that is characterised by gas hydrate "sweet spots" may be the first to become exploitable.

Gas Hydrate "Sweet Spots"

Two conditions must be observed for the seismic characterisation of a gas hydrate "sweet spot": a strong BSR and an indication of fluid focussing. A strong BSR signal is the result of free gas in the sediments beneath the gas hydrate stability zone and indirectly can be indicative of an overlying sweet spot. While the strength of the BSRs has not been quantified in New Zealand studies to date, qualitative detection of strong BSRs is straight forward (Figs. 2 and 3). High fluid flow is also required for sweet spot characterisation due to the requirement for a constant supply of methane from below to maintain the gas hydrate reservoir within the hydrate stability zone. Where both fluid pathways and high amplitude BSRs can be identified, the region can be said to be a gas hydrate sweet spot.

A systematic examination of the Hikurangi Margin seismic data has been carried out (Pecher and Henrys, 2003). In general about 10% of the gas hydrate province has the potential to contain sweet spots. Assuming that

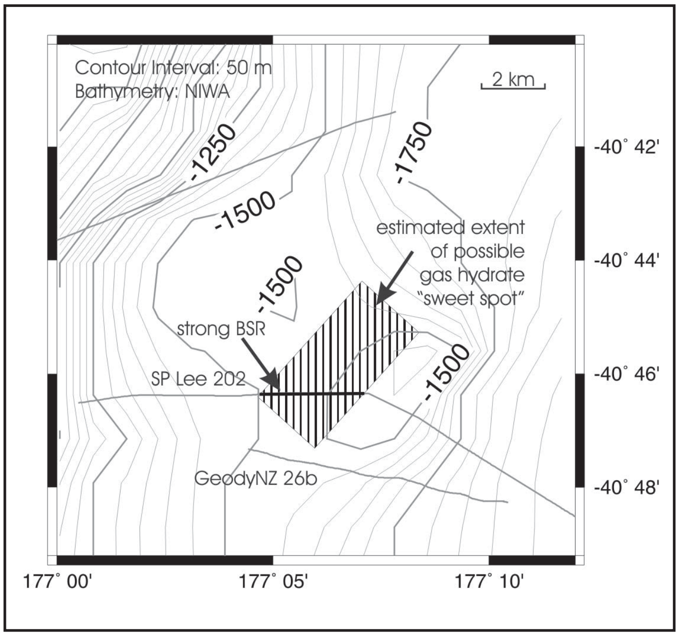

Figure 4. Bathymetry and track map of SP Lee line, around stroung BSR at km 100 (Fig. 2). The setimated extent of the gas hydrate sweet spot covers 12.2 km^2.

approximately 5000 km^2 of the margin contain sweet spots, Pecher and Henrys translate this to ~604 km^3 (~21.3 TCF) of potentially recoverable methane at STP. Individual sweet spots may be on the order of 12 to 24 km^2 in size (*e.g.*, the sweet spot seen on SP Lee, km 100; Fig. 4) which would correspond to 1.5 to 12.25 km^3 (0.05 to 0.43 TCF) of potentially recoverable methane at STP.

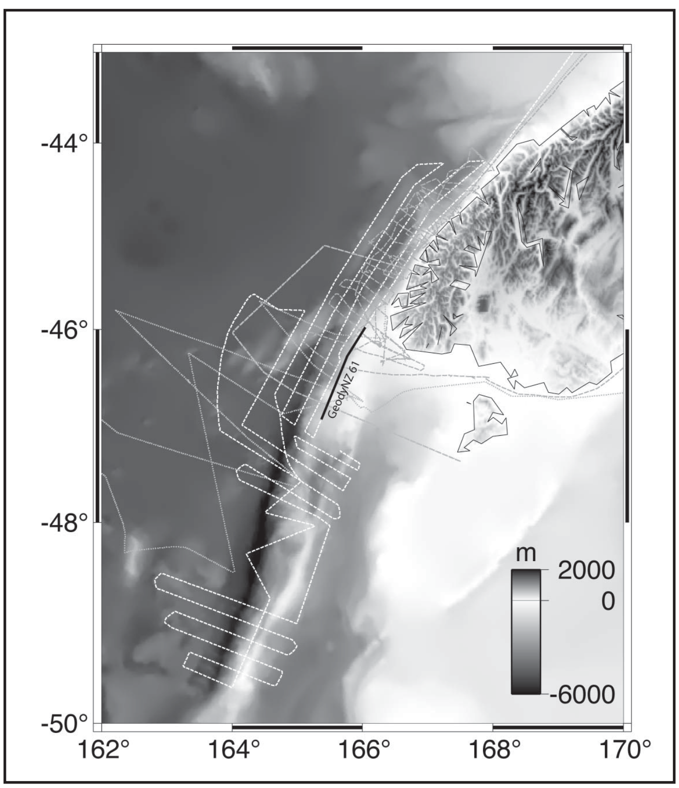

Figure 5. Seismic ship tracks from the Fiordland margin. Portion of line 61 shown in Fig. 6 is highlighted. The extent of gas hydrates on the Fiordland margin has not been delineated.

Beyond Hikurangi

The Fiordland margin is relatively unexplored for gas hydrates. However, a significant data set exisits (Fig. 5) that shows evidence of large deposits (Fig. 6). Work is currently underway to quantify the size of the resource and to plan for further more focussed investigations off the southwest coast of New Zealand.

Discussion and Conclusions

Global Context

The size of the Hikurangi Margin gas hydrate province rivals that of other major hydrate regions worldwide. The geological setting is similar to that of the Nankai Trough – a focus for the active and advanced Japanese national gas hydrate programme.

Economic Prospects

Volumes of recoverable gas will depend on drilling and production technology yet to be developed. The conservative estimates stated above suggest that the Hikurangi gas hydrate province has the potential to have more than 6 times the reserves originally estimated for the Maui gas field (3.452 TCF). However, individual gas hydrate sweet spots are likely to be much smaller.

Reserves will need to be re-assessed as drilling and production technology (especially in the Japanese sector) advance. Pecher and Henrys (2003) point out that even though gas hydrate deposits are usually in relatively deep water, the occurrence is in the shallow sea floor (upper 100s of metres) and they often occur in closely spaced clusters proximal to regions of high fluid flow through the sea floor sediments. Both of these characteristics may be exploited in the planning of drilling and production operations.

What Is Next?

Adequate characterisation of New Zealand's gas hydrate reserves requires an increase in the size of the seismic database on the Hikurangi and Fiordland margins. GNS has plans for a gas-hydrate focussed survey to study sweet spots. However, a densely spaced regional survey using seismic methods tailored for gas hydrates (higher-frequency air gun sources and closer shot spacing that conventional petroleum industry seismic) would be desirable.

In the long term, long-streamer and ocean-bottom seismometer data are needed to provide additional control on the seismic velocities of the sea floor sediments. Also, high-resolution 3-D seismic coverage of critical areas is needed. Eventually, coring of the sea floor sediments and interstitial hydrate deposits will provide "ground truthing" of the seismic interpretations made. Chemical analyses will determine the origin of the natural gas and investigate the chemical interactions of methane with the surrounding sediments, fluxing ground water, and overlying seawater.

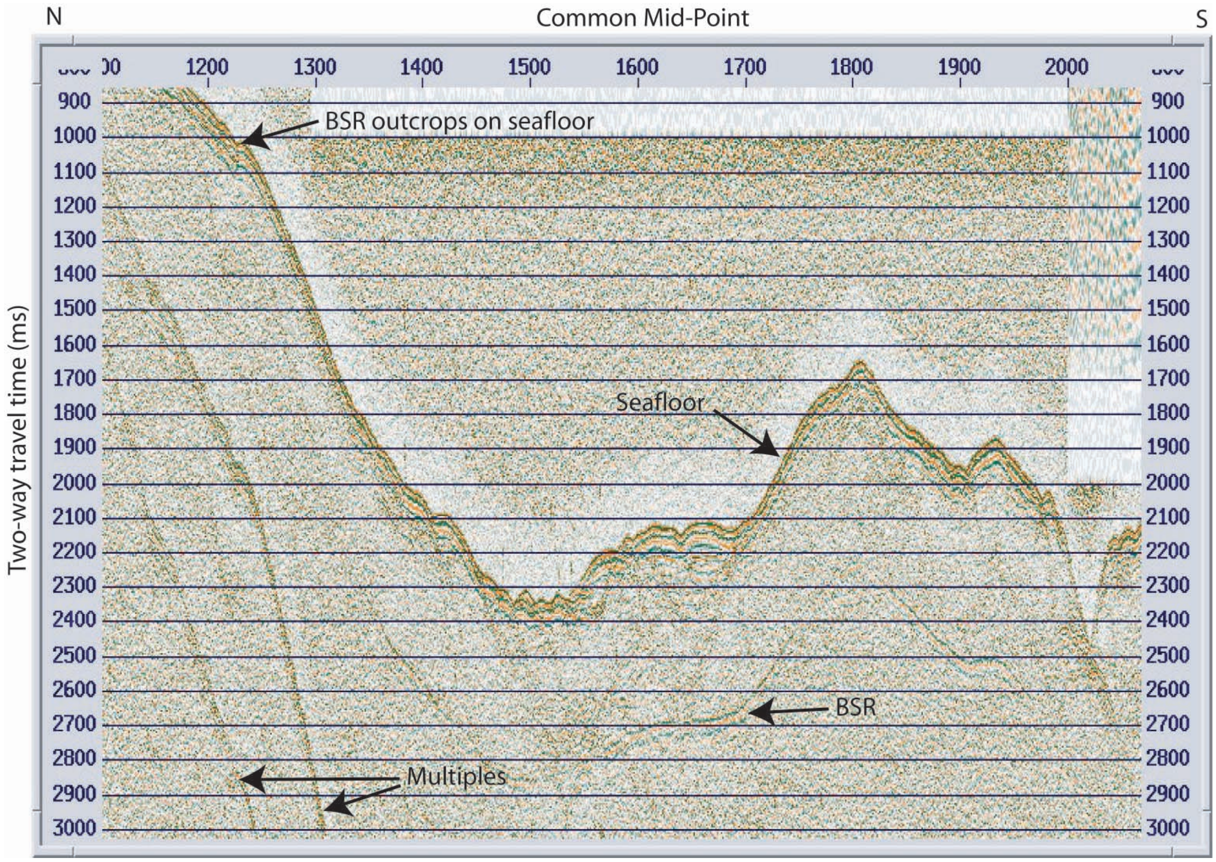

Figure 6. GeodyNZ2 line 61 (southern section). Note that the BSR outcrops at the seafloor at approximately 1 s (two-way travel time). This corresponds to approximately 750 m water depth.

New Zealand's convergent margin gas hydrates, offer a significant advantage over gas hydrates found in many other regions due to the local geology which favours fluid focussing and expulsion. This situation is similar to that found in the Nankai Trough where economic pressure for gas hydrate production is strong. For these reasons, the Hikurangi Margin is one of the best locations in the world for pioneering the production of natural gas from offshore hydrate deposits.

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Authors

ANDREW GORMAN is a lecturer in geophysics in the Geology Department at the University of Otago. His background in controlled-source seismology started in the Canadian petroleum industry, and was followed by a PhD at the University of British Columbia and postdoctoral research at the University of Wyoming.

INGO PECHER is a geophysicist with GNS, specialising in marine active-source seismology. Before joining GNS, Ingo conducted research at the Wood Hole Oceanographic Institution and the University of Texas at Austin in the US. He has a PhD and an MSc from the University of Kiel, Germany.

STUART HENRYS is a senior scientist at GNS. Special research interests include geophysical studies of plate boundary structures, gas hydrates, seismic stratigraphy, and in particular stratigraphy of the Antarctic continental margin. He has a PhD and MSc from Auckland University.