Gas hydrate “sweet spots” on the Hikurangi margin, from recently acquired multi-channel seismic data

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Abstract

The strength of bottom simulating reflections (BSRs) at the phase boundary between gas hydrates and free gas in sediments on the Hikurangi margin is known to vary significantly. BSRs appear strongest where geologic structures favour fluid migration and hence, the supply of methane for gas hydrate formation. Gas hydrate deposits are steady-state systems in equilibrium between gas supply from below and gas loss into the upper sediments and the ocean. High gas hydrate concentration, and hence, elevated gas concentration leading to strong BSRs, is therefore expected at locations where fluid migration is focussed, very unlike conventional gas reservoirs that require trapping of gas. Our hunt for gas hydrate “sweet spots” with elevated gas hydrate concentrations that may be of commercial interest in the future, therefore focuses on identifying locations where strong BSRs coincide with structures that favour fluid flow focussing. We here present first results from a multi-channel seismic line recently acquired offshore of the Wairarapa. We related amplitude anomalies within the gas hydrate stability zone at locations of suspected hydrate “sweet spots” to possible occurrences of gas hydrates at higher concentration.

Introduction

Gas hydrates, a frozen form of energy, are molecules that consist of gas (usually methane) enclosed in a rigid framework of water molecules. While the amount of carbon stored in gas hydrates has been estimated to be in the same order as that in all conventional hydrocarbon reservoirs, much of this gas hydrate is at a concentration of only several percent of the pore space. For a possible commercial production of gas from gas hydrates, we need to detect locations of high concentration (“sweet spots“) where roughly >30% of the pore space is saturated. Such “sweet spots” have been detected on-shore in permafrost hydrates (Dallimore & Collett 2005) and offshore of Japan in the Nankai Trough (Nouze et al. 2004).

Gas hydrate stability requires moderate pressure and low temperature – conditions that prevail in deep-water marine environments. BSRs are often present at the base of gas hydrate stability (BGHS) in marine sediments. Strong BSRs are the seismic expression of a pronounced velocity decrease at the BGHS caused by the existence of free gas, and its resulting low velocity (Domenico 1977), beneath gas hydrates and their resulting comparatively high velocity. Weak BSRs on the other hand, are sometimes thought to be caused by a velocity decrease attributable to only a small amount of free gas, if any (Minshull et al. 1994; Pecher et al. 1996). The gas hydrate stability zone (GHSZ) is the maximum zone over which gas hydrate can exist in the sediments – it extends from the BSR upward to the seafloor.

A breakthrough in our understanding of gas hydrate / free gas systems was achieved in the late 1990s when it was found that rather than being static deposits, they are (quasi-) steady-state systems that are supplied with gas for hydrate formation from below while constantly losing gas into the upper sediment layers (where methane is oxidised) and ocean (Xu & Ruppel 1999; Zatsepina & Buffett 1997). Shutting down the gas supply would lead to a disappearance of gas hydrates, even within the appropriate pressure / temperature conditions, mainly because gas molecules would still diffuse out of the molecular hydrate cavities (leading to hydrate dissociation). Hence, in order to maintain deposits with highly concentrated hydrates, gas supply needs to be high and gas hydrate "sweet spots" are likely to form in areas of focussed fluid flow. As a "side effect", gas concentration at the BGHS is predicted to be high at such locations, causing strong BSRs. For identifying possible hydrate "sweet spots", we are therefore looking for locations with (1) strong BSRs and (2) structures that focus fluid flow such as anticlines, layer outcrops, and fault systems (Pecher & Henrys 2003). Note that this concept is fundamentally different from conventional gas traps that require seals ideally leading to zero fluid flow.

Data

Data were acquired offshore of the Wairarapa (specific location shown in Figure 1) in March of 2005 by an industry vessel with a 12 km long streamer and 960 channels. Acquisition geometry is outlined in Table 1. The data were recorded to 10 seconds two-way-time (TWT) at a sampling rate of 2 milliseconds. The dominant frequency present in the data set is ~50 Hz.

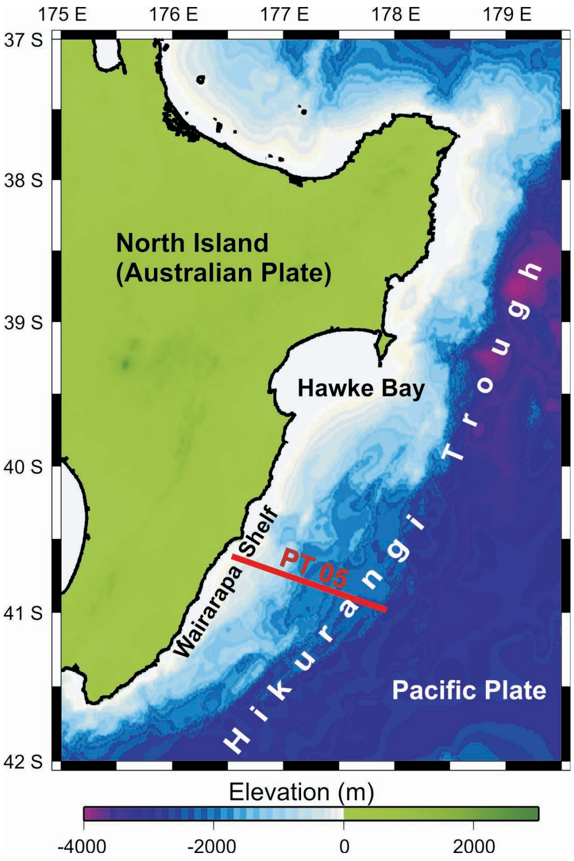

Figure 1: Location map – annotated red line labelled "PT 05" is the seismic line acquired in March of 2005.

Table 1. Acquisition geometry.

Source spacing	*37.5 m*
Receiver spacing	*12.5 m*
No. of groups	*960*
Near offset	*175 m*
Far offset	*12175 m*

A near-trace stack was desired to provide the closest representation of true normal-incidence amplitudes and to ensure that amplitude-versus-offset (AVO) effects were minimised. To process the data into a near-trace stack, all but the first six traces of each shot record were removed and the resulting records were sorted to CDPs. The acquisition geometry (Table 1) dictated the number of traces per ensemble that resulted from the CDP sorting – (two traces per CDP). A normal move-out correction was applied with an 'rms' velocity field that had been previously defined on the full-offset data set. The data were then stacked and migrated with a finite-difference algorithm – requiring a smoothed interval velocity model that was created from the 'rms' field. The amplitudes of the resulting seismic section were then scaled to correct for spherical divergence and absorption. Absorption effects were corrected for by assuming no absorption in the water column and a constant attenuation factor (Q) in the sediments below.

Instantaneous amplitude (a complex seismic trace attribute) plots were created from the stacked data by applying a Hilbert transform. The plots provide a useful way to view the absolute amplitudes of seismic features.

First results

Figure 2 is a near-trace, post-stack-migrated section (variable-area plot) that extends from a water depth of ~650 m on the landward end to ~2700 m on the seaward end. Two separate anticlines, labelled as 'Anticline A' and 'Anticline B', have been identified as hosting possible gas hydrate "sweet spots". Enlarged variable-area plots of these two anticlines are displayed in Figure 3 (Anticline B) and Figure 4 (Anticline A).

The strikingly high amplitude zone within Anticline B (refer to Figure 5 - an instantaneous amplitude plot of the data within Anticline B) is likely to be due mainly to the presence of free gas. The high amplitude zone extends from the BSR to a level about half-way between the BSR and the seafloor, and the fact that the BSR and the high amplitude zone truncate each other is strong evidence for gas migration from below the BSR into some form of fluid-flow conduit – forming a gas chimney. Gas hydrate precipitation in response to conductive cooling of the chimney makes this feature a good "sweet spot" candidate. Inversion techniques are needed to provide information about layer properties and thicknesses responsible for the observed reflectivity.

Relatively subtle amplitude anomalies within the GHSZ of Anticline A are best highlighted in the instantaneous amplitude plot (Figure 6). The annotated red ellipses show areas of anomalous reflectivity that have been targeted as "sweet spots". The features occur within the same stratigraphic package that can be traced, in the landward direction, to a level that is below the BSR. It is likely that fluid (gas) flow from below the BSR into the anticline would occur preferentially along these layer boundaries. Once inside the regional GHSZ, the free gas can contribute to forming concentrated hydrate deposits.

Conclusions

We have identified at least two locations where gas hydrate concentrations are potentially high enough to be considered “sweet spots”. Anomalous amplitudes within Anticline A are quite subtle in comparison with the conspicuously high amplitudes of the dipping feature in Anticline B. Both features seem to have formed in response to enhanced localised fluid flow from beneath the BGHS. In the case of Anticline A, the flow path appears to be focussed along layers with higher permeability. Layer boundaries are not as evident within Anticline B, and the selected flow path could be due to other phenomena, such as a permeable fault zone.

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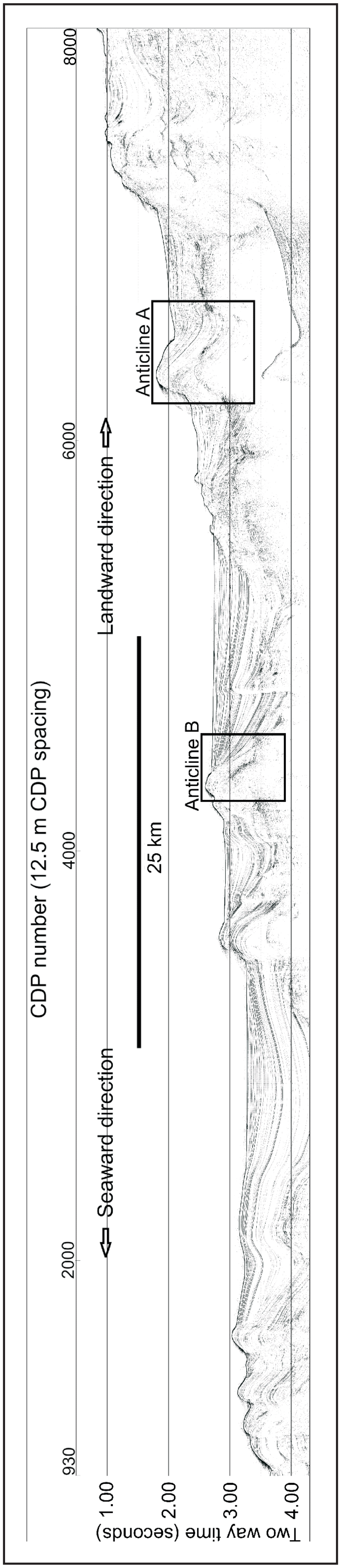

Figure 2: Near-trace, post-stack-migrated section extending from CDP 930 to CDP 8000. Zoomed in plots of the data within Anticline B and Anticline A are displayed in Figures 3 and 4, respectively.

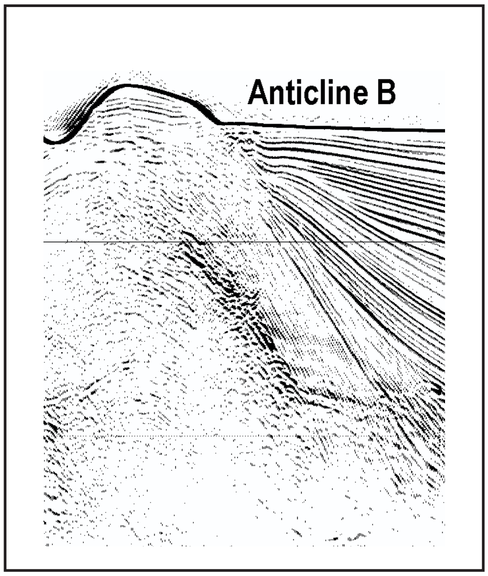

Figure 3: Zoomed-in variable-area plot (from Fig. 2) of the data within Anticline B.

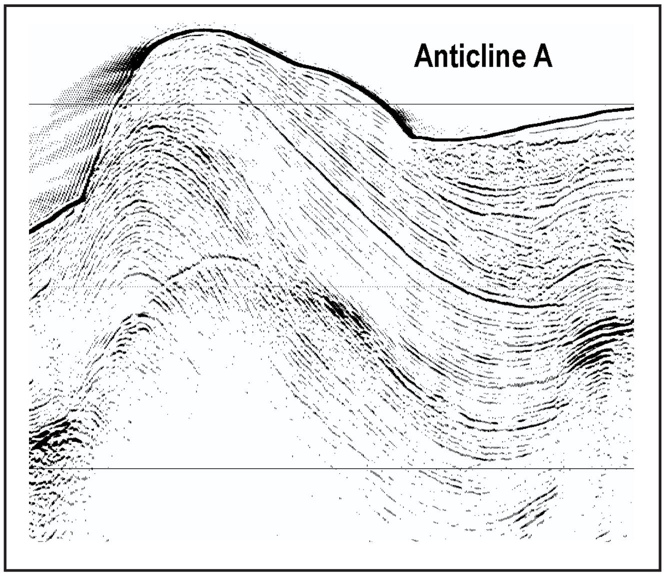

Figure 4: Zoomed-in variable-area plot (from Fig. 2) of the data within Anticline A.

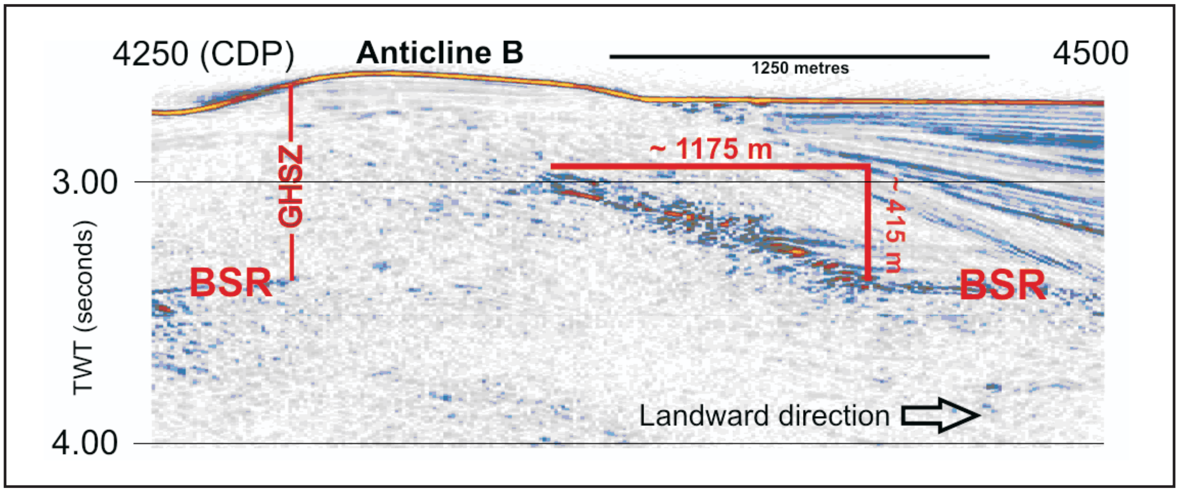

Figure 5: Instantaneous amplitude plot of the data making up Anticline B (note - less vertical exaggeration than plots in Fig. 2 - 4). White corresponds to zero amplitude, with the colour scale working its way up through blue, to red and finally yellow (corresponding to the highest amplitudes). The landward-dipping high amplitude zone extends from the BSR to approximately halfway to the seafloor.

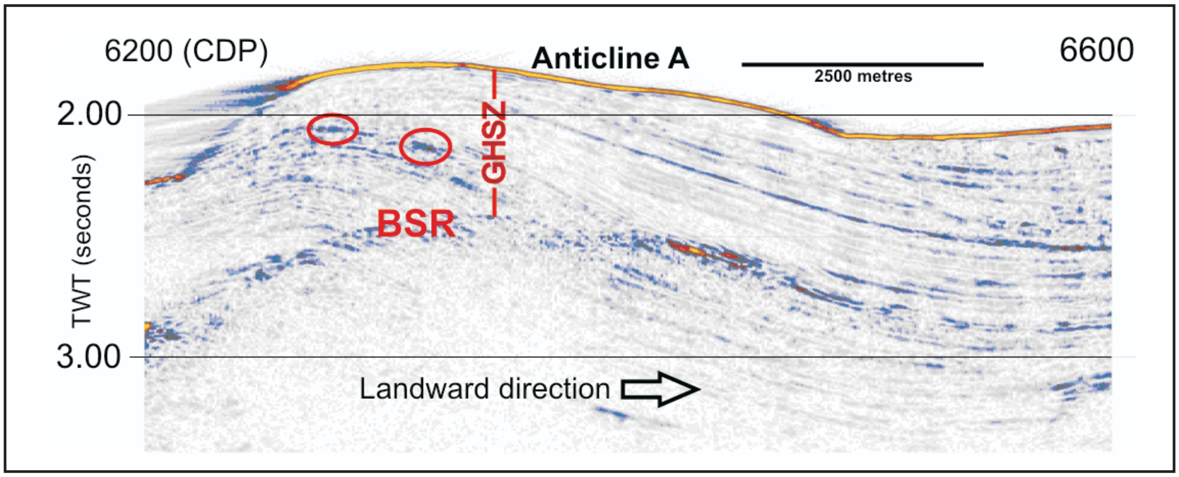

Figure 6: Instantaneous amplitude plot of the data making up Anticline A (note – less vertical exaggeration than plots in Fig. 2 - 4). The colour scale is the same as in Figure 5. Red ellipses outline high amplitudes within the gas hydrate stability zone (GHSZ).

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