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Geological controls on focused fluid flow through the gas hydrate stability zone on the southern Hikurangi Margin of New Zealand, evidenced from multi-channel seismic data

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ABSTRACT

Highly concentrated gas hydrate deposits are likely to be associated with geological features that promote increased fluid flux through the gas hydrate stability zone (GHSZ). We conduct conventional seismic processing techniques and full-waveform inversion methods on a multi-channel seismic line that was acquired over a 125 km transect of the southern Hikurangi Margin off the eastern coast of New Zealand's North Island. Initial processing, employed with an emphasis on preservation of true amplitude information, was used to identify three sites where structures and stratal fabrics likely encourage focused fluid flow into and through the GHSZ. At two of the sites, Western Porangahau Trough and Eastern Porangahau Ridge, sub-vertical blanking zones occur in regions of intensely deformed sedimentary layering. It is interpreted that increased fluid flow occurs in these regions and that fluids may dissipate upwards and away from the deformed zone along layers that trend towards the seafloor. At Eastern Porangahau Ridge we also observe a coherent bottom simulating reflection (BSR) that increases markedly in intensity with proximity to the centre of the anticlinal ridge. 1D full-waveform inversions conducted at eight points along the BSR reveal much more pronounced low-velocity zones near the centre of the ridge, indicating a local increase in the flux of gas-charged fluids into the anticline. At another anticline, Western Porangahau Ridge, a dipping high-amplitude feature extends from the BSR upwards towards the seafloor within the regional GHSZ. 1D full-waveform inversions at this site reveal that the dipping feature is characterised by a high-velocity zone overlying a low-velocity zone, which we interpret as gas hydrates overlying free gas. These results support a previous interpretation that this high-amplitude feature represents a local "up-warping" of the base of hydrate stability in response to advective heat flow from upward migrating fluids. These three sites provide examples of geological frameworks that encourage prolific localised fluid flow into the hydrate system where it is likely that gas-charged fluids are converting to highly concentrated hydrate deposits.

1. Introduction

Gas hydrates, ice-like species of hydrocarbon gas (usually methane) enclosed in a rigid and stable framework of water molecules, are a common sedimentary constituent of marine continental margin settings (e.g. Buffett, 2000). The marine gas hydrate stability zone (GHSZ) is the sub-seafloor region within which temperature and pressure conditions are suitable for formation of natural gas hydrate. The actual distribution of gas hydrates within the GHSZ is dependent on the availability of methane in excess of its solubility in water (Xu and Ruppel, 1999). High localised methane flux into the GHSZ can result in highly concentrated gas hydrate accumulations, such as those that have been identified on the Nankai Trough offshore of Japan (Nouze et al., 2004) and on the Cascadia Margin at Hydrate Ridge (Tréhu et al., 2004).

The Hikurangi Margin, east of New Zealand's North Island (Fig. 1A and B), is host to a large marine gas hydrate province. The extent of the province is based on the positive identification of bottom simulating reflections (BSRs) within numerous multi-channel seismic data sets

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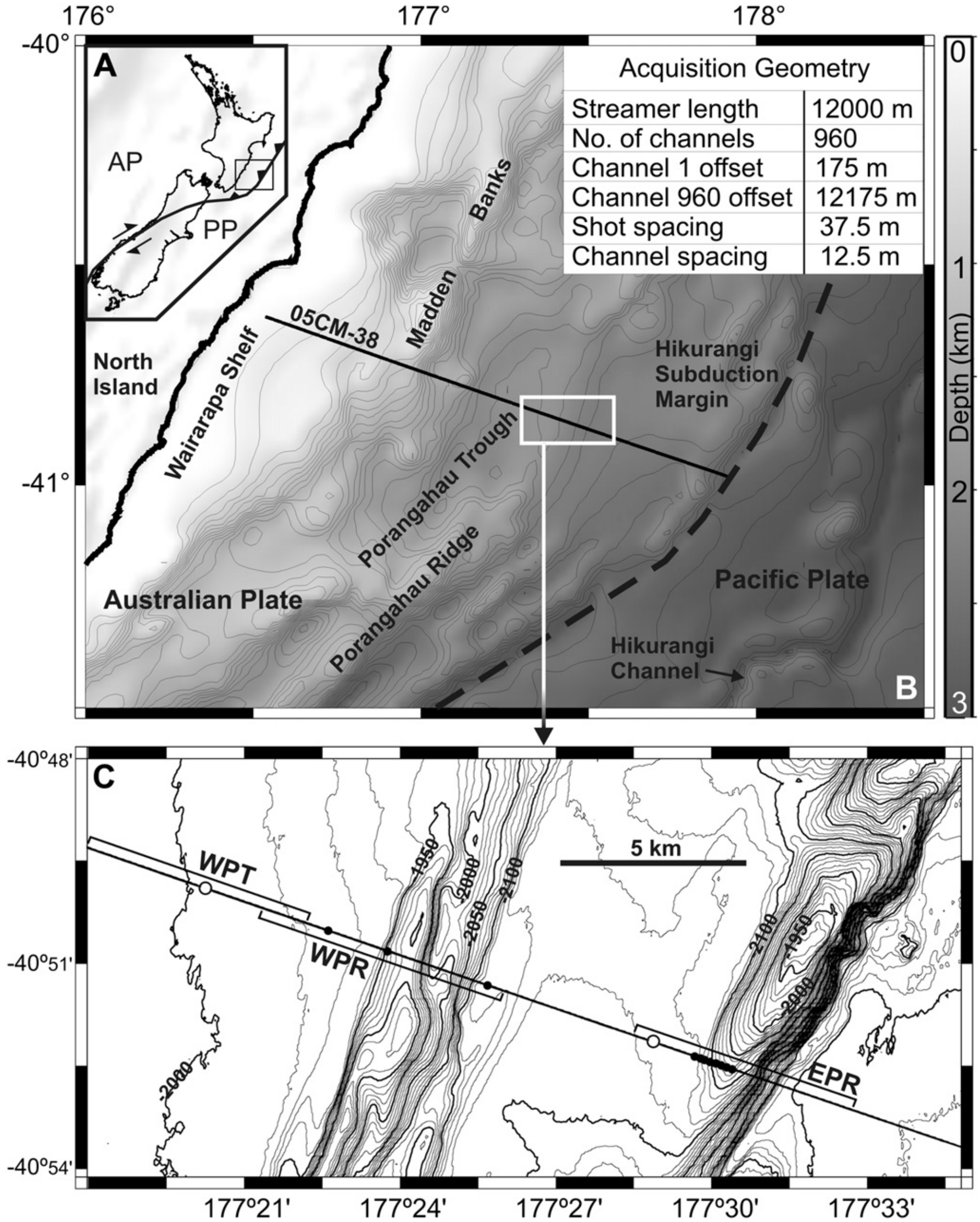

Figure 1. (A) The regional tectonic setting of New Zealand with a box showing the outline of the field of view in (B). AP, Australian Plate; PP, Pacific Plate. (B) Location map of the offshore Wairarapa region showing the location of Seismic Line 05CM-38 (solid line) with respect to the Hikurangi Subduction Margin (dashed line). The acquisition geometry for the line is given in the inset table. The box over part of Line 05CM-38 outlines the region of the field of view given in (C). (C) Enlarged field of view showing contoured high-resolution bathymetry around the three sites. The two prominent northeast trending ridge systems are Western Porangahau Ridge and Eastern Porangahau Ridge. The three sub-sections of Line 05CM-38 presented in this study are marked by square braces and labelled "WPT" (Western Porangahau Trough), "WPR" (Western Porangahau Ridge) and "EPR" (Eastern Porangahau Ridge). The white dots on the line show locations of blanking features highlighted in Figs. 2 and 6. The black dots show locations where 1D full-waveform inversions were carried out.

(Pecher and Henrys, 2003). On the Hikurangi Margin there is a strong correlation between BSR strength and geological features that focus fluid flow, such as faults, dipping strata, and anticlines (Henrys et al., 2009). Relatively permeable damage zones around faults often act as conduits to fluid flow (Caine et al., 1996), and sedimentary layering is also predicted to have a strong influence on flow pathways. In the case of layered sediments, permeability in strata is usually significantly higher along layers (parallel to layer boundaries) compared with across them. Gas chimneys represent another geological system where fluids may be intensely focused (Gay et al., 2007; Liu and Flemings, 2007). A strong link between gas hydrates and fluid flow has been proposed for the Hikurangi Margin, with the highest gas hydrate accumulations inferred to exist in close proximity to these types of structures.

Here, we present results of high-resolution seismic imaging and waveform inversions that were employed to locate and characterise three particular sites where we interpret pronounced fluid flow through the GHSZ and, by inference, the existence of anomalously high gas hydrate concentrations. These three sites are herein referred to as (1) Western Porangahau Trough, (2) Western Porangahau Ridge and (3) Eastern Porangahau Ridge (locations marked on Fig. 1C). The inversion scheme, a 1D full-waveform method, facilitated characterisation of the fine-scale velocity structure of strong reflections. The velocity structure contributes quantitative information to the study that assists in the interpretations of enhanced fluid flux and both gas and gas hydrate distribution. Ultimately, we elaborate on the importance of relationships