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The structures beneath submarine methane seeps: Seismic evidence from Opouawe Bank, Hikurangi Margin, New Zealand

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ABSTRACT

The role of methane in the global bio-geo-system is one of the most important issues of present-day research. Cold seeps, where methane leaves the seafloor and enters the water column, provide valuable evidence of subsurface methane paths. Within the *New Vents* project we investigate cold seeps and seep structures at the Hikurangi Margin, east of New Zealand. In the area of Opouawe Bank, offshore the southern tip of the North Island, numerous extremely active seeps have been discovered. High-resolution seismic sections show a variety of seep structures. We see seismic chimneys either characterised by high-amplitude reflections or by acoustic turbidity and faults presumably acting as fluid pathways. The bathymetric expression of the seeps also varies: There are seeps exhibiting a flat seafloor as well as a seep located in a depression and small mounds.

The images of the 3.5 kHz Parasound system reveal the near-surface structure of the vent sites. While high-amplitude spots within the uppermost 50 m below the seafloor (bsf) are observed at the majority of the seep structures, indicating gas hydrate and/or authigenic carbonate formations with an accumulation of free gas underneath, a few seep structures are characterised by the complete absence of reflections, indicating a high gas content without the formation of a gas trap by hydrates or carbonates. The factors controlling seep formation have been analysed with respect to seep location, seep structure, water depth, seafloor morphology, faults and gas hydrate distribution. The results indicate that the prevailing structural control for seep formation at Opouawe Bank is the presence of numerous minor faults piercing the base of the gas hydrate stability zone.

1. Introduction

Focused fluid flow in marine sediments is a worldwide phenomenon. Although it has been the subject of numerous recent studies all over the world, it is not yet really understood (e.g. Eichhubl et al., 2000; Berndt, 2005; Dupré et al., 2007). In particular, the impact of methane release at the seafloor on the global carbon cycle is still under debate (Judd et al., 2002; Etiope and Klusman, 2002; Etiope et al., 2007). Seabed methane escape occurs at coasts (estuaries, bays, drowned valleys, deltas, etc.), continental shelves (faults, breached antiforms, salt diapirs), continental slopes and rises, deep oceans and convergent plate boundaries (Judd, 2003). Topographic expressions of fluid expulsion at the seafloor range from build-ups (mud volcanoes, carbonate mounds) to depressions (pockmarks) (Mazurenko and Soloviev, 2003; Berndt, 2005). In general, the distribution of fluid seeps is controlled by buried underlying features such as major faults, polygonal faults, salt diapirs, erosional surfaces and palaeo-channels (Gay et al., 2007). Fluid expulsion has been inferred as a factor in slope instability (Collot et al., 2001; Lewis et al., 1998; Cochonat et al., 2002). Furthermore, a link between methane seepage and gas hydrate reservoirs has been discussed by several authors (e.g. Mazurenko and Soloviev, 2003; Gay et al., 2007).

In this study, we focus on seep structures at the Hikurangi Margin, offshore New Zealand. Within the New Vents project, a number of active seeps have been discovered at Opouawe Bank (Greinert et al., 2010-this issue; Klaucke et al., 2010-this issue; Schwalenberg et al., 2010-this issue; Krabbenhoeft et al., 2010-this issue). The main objectives in investigating these seeps are the relation between seep locations and gas hydrate deposits, indicated by a bottom simulating reflection (BSR), and to understand their structural control on the observed seep structures, their seafloor topography, their location and the subsurface fluid pathways. In order to distinguish between the

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seeps as a seafloor phenomenon and their subsurface signature as observed in the seismic sections, the subsurface phenomenon will be called 'seep structure'. It will be indicated where a seeps structure can be unequivocally linked to a seep observed at the seafloor.

2. Geological setting

The authors refer to Barnes et al. (2010-this issue) for a detailed description of the geological background and a tectonic map as well as Greinert et al. (2010-this issue) for an overview of the multidisciplinary cruises undertaken in 2006 and 2007 to Opouawe Bank. The following comprises only a brief introduction to the area. The research area is located at the Hikurangi Margin, on the continental slope (Fig. 1). The Hikurangi Margin, off North Island and the southern tip of South Island, New Zealand, is the southernmost expression of the Tonga–Kermadec subduction zone of the SW Pacific. In this part, the subduction started at about 21 Ma (Field et al., 1997). Because of the movement of the rotation pole of the Pacific Plate the subduction is highly oblique (e.g. Robinson, 1986; Walcott, 1987; Collot et al., 1996). Plate convergence decreases southwards along the margin until at ~42°S strike-slip motion dominates and subduction occurs no more (e.g. Reading et al., 2001).

Barnes and Mercier de Lépinay (1997) identified and dated 8 sedimentary horizons in deep water in the area around the south-eastern tip of the North Island. They derived an accumulation rate of compacted sediment of 0.65 mm/a for the Quaternary trench fill in front of the wedge. A sedimentation rate of 0.42 mm/a is assumed for the time between 0.8 Ma and 2 Ma and a rate of 0.3 mm/a between 2 Ma and 5 Ma.

Gas hydrate occurrences at the Hikurangi Margin have been investigated by several authors (e.g. Katz, 1981, 1982; Pecher et al., 2004, Pecher et al., 2005). An extensive BSR has been observed along the entire margin (Townend 1997). Lewis and Marshall (1996) were the first to collate evidence of seep faunas, bubble plumes, and seabed carbonate chimneys and mats from around New Zealand and to relate them to tectonic setting. Pecher et al. (2004) have investigated the coexistence of gas hydrates and gas conduits for seeps within the gas hydrate stability zone (GHSZ) at the Hikurangi Margin and postulated ample methane supply at these venting systems. Faure et al. (2006) analysed seeps and BSR occurrence in Rock Garden offshore Hawke's Bay and found that gas hydrates are probably a controlling factor for seepage and seafloor stability along the Hikurangi Margin. Kvenvolden and Pettinga (1989) analysed two onshore seeps near Hawke's Bay. They demonstrated that gas compositions of both seeps are different from geothermal gases, proving that they are not influenced by volcanic-related geothermal processes and thus do not originate from great depths. By calculating thermal gradients from the BSR depths at Rock Garden using different gas compositions, Faure et al.

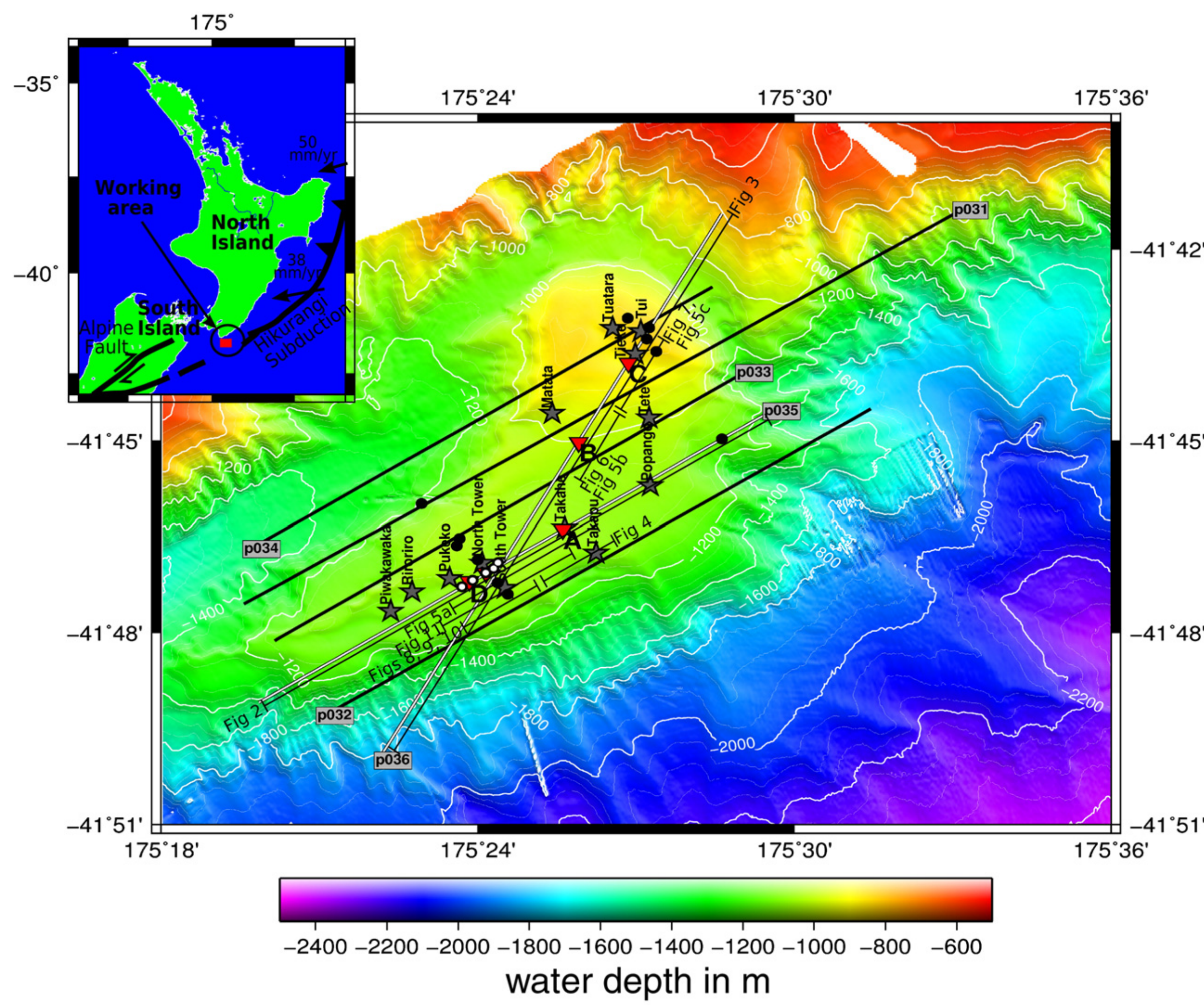

Fig. 1. Map of study area. The location is shown in the inset. Annotated arrows indicate the direction and amount of plate motion, half arrows indicate transform/strike-slip faults (after Barnes and Mercier de Lépinay, 1997). Black lines indicate multichannel seismic profiles. Black circles mark OBS locations, the five OBS stations used for migration (compare Fig. 10) are indicated by white circles. Profile numbers and OBS numbers are annotated. Bathymetry was acquired from Simrad system during cruise SO190. Previously known seeps are marked in the map by grey stars. Seep Structures discussed in this paper are indicated by white triangles.