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Evaluation of gas hydrate deposits in an active seep area using marine controlled source electromagnetics: Results from Opouawe Bank, Hikurangi Margin, New Zealand

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ABSTRACT

Several known gas seep sites along the Hikurangi Margin off the east coast of New Zealand were surveyed by marine controlled source electromagnetic (CSEM) experiments. A bottom-towed electric dipole–dipole system was used to reveal the occurrence of gas hydrate and methane related to the seeps. The experiments were part of the international multidisciplinary research program "New Vents" carried out on German *R/V Sonne* in 2007 (cruise SO191) to study key parameters controlling the release and transformation of methane from marine cold vents and shallow gas hydrate deposits. Two CSEM lines have been surveyed over known seep sites on Opouawe Bank in the Wairarapa region off the SE corner of the North Island. The data have been inverted to sub-seafloor apparent resistivity profiles and one-dimensional layered models. Clearly anomalous resistivities are coincident with the location of two gas seep sites, North Tower and South Tower on Opouawe Bank. A layer of concentrated gas hydrate within the uppermost 100 m below the seafloor is likely to cause the anomalous resistivities, but free gas and thick carbonate crusts may also play a role. Seismic data show evidence of fault related venting which may also indicate the distribution of gas hydrates and/or authigenic carbonate. Geochemical profiles indicate an increase of methane flux and the formation of gas hydrate in the shallow sediment section around the seep sites. Takahe is another seep site in the area where active venting, higher heat flow, shallow gas hydrate recovered from cores, and seismic fault planes, but only moderately elevated resistivities have been observed. The reasons could be a) the gas hydrate concentration is too low, even though methane venting is evident, b) strong temporal or spatial variation of the seep activity, and c) the thermal anomaly indicates rather temperature driven fluid expulsion that hampers the formation of gas hydrate beneath the vent.

1. Introduction

Methane seepage from the seafloor in New Zealand has been first reported by Lewis and Marshall (1996). More seep sites have been found by New Zealand scientists during several cruises on *R/V Tangaroa*, and are described in e.g. Pecher et al. (2004) and Faure et al. (2006). However, the most extensive and complete investigations to date took place during *R/V Sonne* cruise SO191 in January–March 2007 within the "New Vents" project (Bialas et al., 2007, and this issue). The project "New Vents" focused on studying key parameters that control the release and transformation of methane from marine gas seep sites and shallow gas hydrate deposits on the Hikurangi Margin, an accretional convergent margin setting along the NE coast of New Zealand. The aim of the controlled source electromagnetic (CSEM) experiment was to map the electrical nature of gas and gas hydrate filled sediments that are associated with the seeps. Both gas hydrate and gas are electrically insulating and enhance the electrical bulk resistivity in areas where they form in sufficient quantities. Methane, released from the seafloor through the dissociation of gas hydrate, or transported through the gas hydrate stability zone (GHSZ) along faults and fissures or in solution with the pore water, is believed to play a significant role in the global methane cycle. Gas seeps are known as areas of focused methane supply, and are often indicated by bubbles and flares ascending through the water column above the seep. Seep structures are often controlled by faults which can be imaged by seismic reflection data. Heat flow data identify areas of fluid advection characteristic of vent structures and fluid seepage. Geochemical profiles reveal methane flux through the shallow sediment section. Even though all these features have been observed in a variety of submarine settings worldwide, the process of fluid venting is not completely understood. In particular, what triggers gas venting, controls its volume, and sets the temporal variability?

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Another open question is the amount and distribution of gas hydrate which has accumulated beneath these seeps. These hydrate accumulations may also be an important sink for the methane supply released from the seafloor. Within the “New Vents” project these objectives have been addressed with various geophysical, geochemical, and observational exploration methods. CSEM data, in this context, are sensitive to the presence and amount of gas hydrate. In principle, they cover the depth range of the entire gas hydrate stability zone while most other observations are confined to the seafloor or the shallow sediment section. Seismic data which cover the same depth range can be scattered or blanked by the presence of gas or hydrate. Thus CSEM data provide an important complement to the pool of sub-seafloor imaging tools.

Edwards (1997) showed that CSEM could be used for submarine gas hydrate investigation. The first prominent case study is known from the Northern Cascadia Margin offshore Vancouver Island. Yuan and Edwards (2000) reported on early marine CSEM field trials over known bottom simulating reflectors (BSRs). Riedel et al. (2002) analyzed seismic data from a nearby target area and revealed a series of seismic blank zones interpreted as cold vents. They suggested that blanking is the effect of intense hydrate formation inside the blank zone. Piston coring also gave evidence of shallow gas hydrate within the largest of the blank zones known as Bullseye. Schwalenberg et al. (2005) collected CSEM data along a profile over the vents and intersecting Bullseye. The resistivities derived from the CSEM data are clearly anomalous over the vents pointing at volumes of massive gas hydrate. The Bullseye vent was later on drilled during the Integrated Ocean Drilling Program, IODP Leg 311 (Riedel et al., 2006). A 40 m thick massive gas hydrate cap as well as anomalously high resistivities in wire line and logging-while-drilling logs have been observed in the same depth range (Riedel et al., 2006) which also explains the CSEM results.

More case studies are available from Weitemeyer et al. (2006) who reported on a CSEM survey over gas hydrate deposits on Hydrate Ridge, offshore Oregon, and Ellis et al. (2008) who conducted a CSEM survey to study a mud volcano and gas hydrate in the Gulf of Mexico.

Within the “New Vents” project marine CSEM was employed for the first time off the coastlines of New Zealand. CSEM data have been collected along four profiles in three target areas. Two of these areas, Opouawe Bank off the Wairarapa and LM9 (see insert in Fig. 1), are characterized by gas seepage and active seafloor venting. Analysis of a CSEM transect across Porangahau Ridge is subject of Schwalenberg et al. (2010). In this paper we present results from two CSEM lines surveyed on Opouawe Bank in the Wairarapa region (Fig. 1). Our models show highly elevated resistivities beneath the gas seeps. The most plausible explanation is that large amounts of gas hydrate have accumulated below the seep sites. We apply Archie's Law (Archie, 1942) to estimate the gas hydrate concentration associated with the anomalous resistivity at one seep site. In the discussion we also include results from seismic, heat flow, and geochemical observations from the same target area.

2. Study area

The Wairarapa region is part of the Southern Central Hikurangi Margin off the east coast of New Zealand's North Island, an active convergent margin system formed by the westward oblique subduction of the Pacific plate beneath the Australian plate. In its central part the Hikurangi Plateau, an elevated 10–15 km thick oceanic crust (Davy and Wood, 1994), is subducted beneath the Australian plate at slow rates (about 40–50 mm/yr) and low angle (about 3°) (Barnes et al., 2010). The central margin off the Wairarapa is dominated by accretionary tectonics and a classical imbricated frontal wedge which is poorly drained and over-pressured. According to Townend

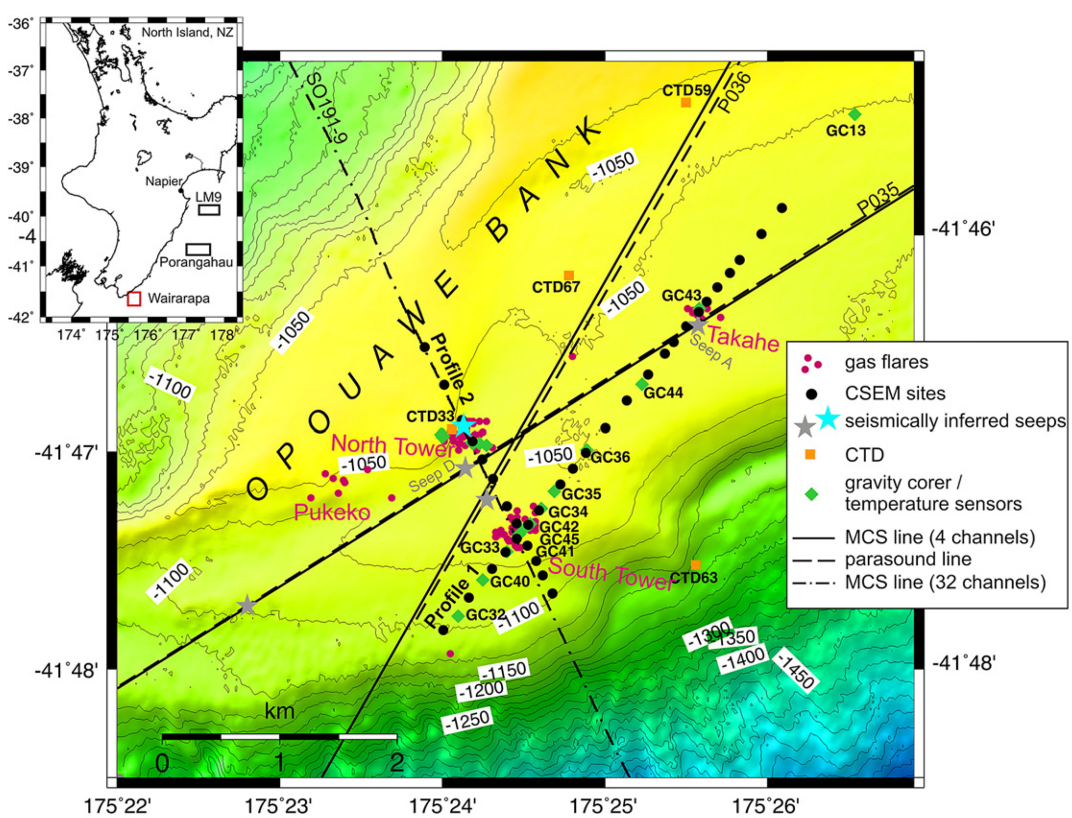

Fig. 1. Bathymetric map of Opouawe Bank in the Wairarapa target area showing seep sites and geophysical observation sites as indicated in the legend. The insert map also shows two other target areas where CSEM data were collected. Grey stars mark seismically inferred seep sites by Netzeband et al. (2009-this issue), the blue star refers to a seep site described in Barnes et al. (2009—this issue).