



Preliminary interpretation of electromagnetic, heat flow, seismic, and geochemical data for gas hydrate distribution across the Porangahau Ridge, New Zealand

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ABSTRACT

Porangahau Ridge, located offshore the Wairarapa on the Hikurangi Margin, is an active ocean-continent collision region in northeastern New Zealand coastal waters. Bottom simulating reflections (BSRs) in seismic data indicate the potential for significant gas hydrate deposits across this part of the margin. Beneath Porangahau Ridge a prominent high-amplitude reflection band has been observed to extend from a deep BSR towards the seafloor. Review of the seismic data suggest that this high-amplitude band is caused by local shoaling of the base of gas hydrate stability due to advective heat flow and it may constitute the location of elevated gas hydrate concentrations. During R/V *Tangaroa* cruise TAN0607 in 2006 heat flow probing for measurements of vertical fluid migration, sediment coring for methane concentrations, and additional seismic profiles were obtained across the ridge. In a subsequent 2007 expedition, on R/V *Sonne* cruise SO191, a controlled source electromagnetic (CSEM) experiment was conducted along the same seismic, geochemical, and heat flow transect to reveal the electrical resistivity distribution. CSEM data highlight a remarkable coincidence of anomalously high resistivity along the western, landward flank of the ridge which point to locally higher gas hydrate concentration above the high amplitude reflection band. Measured sediment temperature profiles, also along the western flank, consistently show non-linear and concave geothermal gradients typical of advective heat flow. Geochemical data reveal elevated methane concentrations in surface sediments concomitant with a rapid decline in sulfate concentrations indicating elevated methane flux and oxidation of methane in conjunction with sulfate reduction at the landward ridge base. Together, these data sets suggest that the western rim of Porangahau Ridge is a tectonically driven zone of rising fluids that transport methane and cause an upward inflection of the base of gas hydrate stability and the formation of locally enriched gas hydrate above the reflective zone.

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1. Introduction

Understanding the factors that control the formation, accumulation, and release of methane from marine sediments is globally important. Gas hydrates contain highly compressed natural gas, and constitute a potential source of energy in future (Kvenvolden et al., 1993; Milkov and Sassen, 2002; Kvenvolden and Rogers, 2005). Also, melting of gas hydrates contributes to seafloor destabilization, release of methane and global warming. Therefore, there is a need to apply multidisciplinary geophysical, geochemical, and geological tools to

improve the detection and volume estimates of methane hydrates in marine sediments.

Marine methane hydrate exploration was initiated with single and multichannel seismic (MCS) profiling, and the mapping of bottom simulating reflectors (BSRs). These data indicated changes in the acoustic velocity through hydrate stable sediments above the base of the gas hydrate stability zone (BGHSZ) and an unstable free gas region due to elevated temperature below the BGHSZ (Stoll et al., 1971; Paull and Dillon, 1981; Rowe and Gettrust, 1993; Holbrook et al., 1996; Paull and Matsumoto, 2000). While seismic data alone provide valuable signatures for recognizing the presence of free gas beneath the BGHSZ little information can be derived about hydrate formation and distribution throughout the hydrate stability zone. For example, studies have shown that hydrates are present in regions absent of BSRs (Paull et al., 1996). However, recent studies demonstrate the

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importance of combining seismic acquisition together with additional geochemical and geophysical data (e.g. Cooper and Hart, 2003; Coffin et al., 2008).

Shallow sedimentary methane and sulfate concentration data reveal the depth of the sulfate methane transition (SMT) zone where most sedimentary methane is consumed during the process of anaerobic oxidation of methane (AOM). Methane concentration data as well as the depth of the SMT have been used to calculate upward methane diffusive flux rates in many continental margins (Niewoehner et al., 1998; Hensen et al., 2003; Paull et al., 2005; Treude et al., 2005; Coffin et al., 2007a). These flux estimates and ground-truthed measurements of methane concentrations in surficial sediments provide a basis to predict the minimum depth at which gas hydrate accumulations may be present.

Because the occurrence of gas hydrate is controlled by temperature and pressure heat flow data derived from geothermal measurements are valuable to constrain the thickness of the gas hydrate stability zone. Geothermal data also have the potential to indicate areas of focused upward flux of fluids.

Controlled source electromagnetics (CSEM) is a promising, but so far rarely applied technique to evaluate submarine gas hydrate. The electrical resistivity of marine sediments derived from CSEM data depends on the porosity, and the conductivity and connectivity of the pore water. It is typically in the order of 1–2 Ω m within the first hundred of meters below the seafloor (mbsf). Gas hydrates as well as free gas are electrically insulating and reduce the effective sediment porosity, thus causing a higher observed resistivity where hydrate forms in sufficient quantities. Electrical resistivity logging is also one of the standard tools to identify gas hydrates in boreholes. The applicability of the CSEM method for gas hydrate evaluation has been outlined by Edwards (1997). Case studies have been reported from the Cascadia Margin (Yuan and Edwards, 2000; Schwalenberg et al., 2005), Hydrate Ridge (Weitemeyer et al., 2006), the Gulf of Mexico (Ellis et al., 2008), and New Zealand (Schwalenberg et al., 2009, this issue). Marine CSEM, in principle, is apt to sound the entire gas hydrate stability zone (GHSZ). Here, CSEM complements seismic methods and provides bulk physical properties in areas where seismic reflection data may suffer from attenuation or blanking due to the presence of gas, but lacks the detailed stratigraphic images obtained from high-resolution seismic data.

In this paper we present first results from a combined evaluation of geochemical and geophysical data sets to study fluid expulsion, the transport of methane, and the distribution of gas hydrate across the southern extension of the Porangahau Ridge.

2. Regional setting

Potential gas hydrate deposits, outlined by BSRs in seismic data, appear to be widespread on the southern Hikurangi Margin east of New Zealand's North Island (Katz, 1981). Along this margin, the Pacific Plate is being subducted beneath the Australian Plate at a rate of ~4 cm/yr. The southern Hikurangi Margin is accretionary with high sedimentation rates (Barnes and Mercier de Lépinay, 1997; Barnes et al., 2009, this issue) leading to significant fluid expulsion – subduction along this margin is sometimes referred to as “subduction of a sponge” (Townend, 1997). BSRs have been identified in various seismic data sets collected primarily for tectonic studies. These data have also shown focused fluid expulsion related to gas hydrate deposits and fluid flow on this margin (Pecher and Henrys, 2003; Henrys et al., in press). In 2005, GNS Science together with the New Zealand Ministry of Economic and Development acquired an industry-style seismic survey (line 05CM-38, Fig. 1) with the vessel M/V *Pacific Titan* across the southern Hikurangi Margin including Porangahau Ridge (Barker et al., 2009). The Porangahau Ridge is located in water depth between 1900 m and 2150 m. On the landward flank of the ridge seismic data show a high-amplitude band extending from the

regional BSR level to approximately half the distance to the seafloor (Crutchley et al., 2006, and Fig. 5c). This high-amplitude band is interpreted to be caused primarily by free gas beneath a locally up-warped base of the BGHSZ due to advective heat flow (Pecher et al., 2009, this issue). The region was revisited during the R/V *Tangaroa* survey (TAN0607) in 2006 (Pecher et al., 2007). A high-resolution seismic survey has been conducted along nine lines whereby line TAN0607-02 coincides with line 05CM-38 (Fig. 1). Piston coring for geochemical analysis and heat flow probing have been acquired along the same transect (Pecher et al., 2007; Coffin et al., 2007b). As part of the 2007 “New Vents” project (R/V *Sonne* cruise SO191) this transect was again reoccupied to conduct a CSEM survey (Bialas et al., 2007, Fig. 1).

3. Materials and methods

In the following sections geophysical and geochemical methods and materials are described in order of acquisition.

3.1. Seismic

Multichannel seismic (MCS) data were acquired with a 45/105 cu-in Generator/Injector (GI) airgun, and a 500 m long Hydrosience streamer with 32 active channels. The data shown in Fig. 5c are from line TAN0607-02 after shipboard processing (Pecher et al., 2007). They constitute of common-depth point (CDP) sorting at 6.25 m binning, selection of the CDP neartrace, normal moveout correction at a constant velocity of 1500 m/s, and post-stack migration, as well as some trace editing and broad frequency filtering. A more detailed, quantitative analysis of the seismic data jointly with CSEM data is ongoing. Note that in Pecher et al. (2009, this issue) this line is renamed to P6.

3.2. Geochemistry

3.2.1. Sample collection and handling

Sediment cores up to 4.8 m long were collected during TAN0607 using a piston corer (PC) fitted with a 6.5 m long barrel lined with 2.75” I.D. polycarbonate core liners (PC locations are identified in Fig. 1). After recovery cores were cut in 10 cm whole round sub-sections at 10 to 43 cm intervals. Sampling intervals were selected based on the appearance of gas pockets, the observations of dark (black) sediment, and hydrogen sulfide odor which are indicators of sulfide production possibly associated with the SMT. Fewer samples were taken near the sediment-water interface while the resolution was increased toward the SMT depth. On average 15 sediment sections were sampled from each core. Sediment plugs were collected from each section in 3 ml polyethylene syringes with the ends cut off and transferred to 20 ml serum vials to measure methane concentrations. It is noted that since cores were not pressurized during recovery, measured concentrations may represent minimal values. Approximately 5 g of wet sediment was sub-sampled from each section and frozen at –20 °C until laboratory measurements of sediment porosity were made. The remaining sediment from each section was transferred to 400 ml Reeburgh-style squeezers (Reeburgh, 1967), and porewater was extracted as described in Hamdan et al. (2008).

3.2.2. Geochemical analysis

Methane and sulfate concentrations were determined shipboard. Methane concentrations were derived according to the headspace technique (Hoehler et al., 2000) and quantified against certified gas standards (Scott Gas). Concentrations were calculated using sediment porosity and dry weight data obtained at the land-based laboratory. Analysis was performed using a Shimadzu 14-A gas chromatograph (Hamdan et al., 2008).

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