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Research paper

Potential for gas hydrate formation at the northwest New Zealand shelf margin - New insights from seismic reflection data and petroleum systems modelling

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A B S T R A C T

In this study we provide evidence for methane hydrates in the Taranaki Basin, occurring a considerable distance from New Zealand's convergent margins, where they are well documented. We describe and reconstruct a unique example of gas migration and leakage at the edge of the continental shelf, linking shallow gas hydrate occurrence to a deeper petroleum system. The Taranaki Basin is a well investigated petroleum province with numerous fields producing oil and gas. Industry standard seismic reflection data show amplitude anomalies that are here interpreted as discontinuous BSRs, locally mimicking the channelized sea-floor and pinching out up-slope. Strong reverse polarity anomalies indicate the presence of gas pockets and gas-charged sediments. PetroMod™ petroleum systems modelling predicts that the gas is sourced from elevated microbial gas generation in the thick slope sediment succession with additional migration of thermogenic gas from buried Cretaceous petroleum source rocks. Cretaceous–Paleogene extensional faults underneath the present-day slope are interpreted to provide pathways for focussed gas migration and leakage, which may explain two dry petroleum wells drilled at the Taranaki shelf margin. PetroMod™ modelling predicts concentrated gas hydrate formation on the Taranaki continental slope consistent with the anomalies observed in the seismic data. We propose that a semi-continuous hydrate layer is present in the down-dip wall of incised canyons. Canyon incision is interpreted to cause the base of gas hydrate stability to bulge downward and thereby trap gas migrating up-slope in permeable beds due to the permeability decrease caused by hydrate formation in the pore space. Elsewhere, hydrate occurrence is likely patchy and may be controlled by focussed leakage of thermogenic gas. The proposed presence of hydrates in slope sediments in Taranaki Basin likely affects the stability of the Taranaki shelf margin. While hydrate presence can be a drilling hazard for oil and gas exploration, the proposed presence of gas hydrates opens up a new frontier for exploration of hydrates as an energy source.

1. Introduction

Gas hydrates at the shelf edge of continental margins are of particular interest due to their possible impact on shelf stability (Kayen and Lee, 1991; Kvenvolden, 1993; Mienert et al., 1998; Mountjoy et al., 2014), the potential release of the greenhouse gas methane where the hydrate layer pinches out at the limit of its stability (Westbrook et al., 2009; Kroeger et al., 2011; Berndt et al., 2014; Skarke et al., 2014) as well as their resource potential (Kvenvolden, 1988; Collett, 2002; Frye, 2008; Boswell et al., 2012). Identification of hydrate bearing sediments is commonly based on indirect evidence such as bottom simulating reflections (BSRs) in seismic reflection data. BSRs are caused by high reflectivity of sediments containing free gas that has accumulated under a layer of sediment where pore space is at least partially filled by ice-like hydrate crystals (water ice cages that enclose guest molecules, most commonly methane) at the base of gas hydrate stability (BGHS; Kvenvolden, 1993; Holbrook et al., 1996). The stability of gas hydrate in the subsurface increases with pressure and decreases with temperature. On continental slopes, BSRs therefore may crosscut strata where the HSZ becomes progressively thinner up-

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slope due to increasing temperature and, more importantly, decreasing pressure of the overlying water column. However, in many cases BSRs have been shown to be weak, discontinuous or absent even where hydrates are present (Shedd et al., 2012; Bai et al., 2016; Paganoni et al., 2016). Discontinuous BSRs are particularly common where hydrate formation is related to focussed fluid flow (Bünz et al., 2003; Hustoft et al., 2007; Chand et al., 2012; Boswell et al., 2012).

Abundant evidence for gas hydrates has been documented from New Zealand's Hikurangi and Fiordland subduction margins (Katz, 1981; Townend, 1997; Henrys et al., 2003; Pecher et al., 2004; Faure et al., 2006; Crutchley et al., 2007, 2011; Fohrmann et al., 2009; Plaza-Faverola et al., 2012; Koch et al., 2016, Fig. 1), whereas seismic anomalies attributed to gas hydrates in the Northland and northern Taranaki Basins in northwestern New Zealand away from active subduction are more ambiguous (Ogebule and Pecher, 2010). Here we present evidence for active fluid flow, shallow gas and the likelihood of gas hydrate bearing sediments occurring west of the Taranaki shelf break (Fig. 1). Reconstruction of the thermal regime at the Taranaki shelf and gas migration and hydrate formation modelling is used to predict hydrate deposits and corroborates the interpretation of geophysical data.

Extensive industry standard 2D seismic reflection data are available that cover the shelf, slope and deep water region of Taranaki Basin. In addition several petroleum exploration wells were drilled close to the shelf edge. In this study, we focus in particular on the area around the Hoki-1 (AWE, 2007) and Tane-1 (Shell BP & Todd Oil Services Ltd, 1976) wells 100 km away from the shoreline of New Zealand's North Island (Fig. 1).

2. Geological setting

At present day the Taranaki shelf to deep water transition is characterised by a deepening of sea-floor depth from less than 180 m to more than 1500 m below sea level (Figs. 1 and 2). The formation of the present-day regressive continental shelf-slope margin of the Taranaki Basin began in the Miocene, when evolution of the convergent plate boundary led to progressive hinterland uplift and an increase in sediment supply (King and Thrasher, 1992, 1996). However, most of the progadation of the shelf into the deep water Taranaki Basin as evidenced by prominent kilometre thick foresets (Fig. 2) has occurred since the Late Miocene. In the Pliocene, a steepening of the shelf is observed, giving rise to the characteristic informally named Giant Foreset Formation with well-established sigmoidal foresets (Pilaar and Wakefield, 1978; Beggs, 1990; Hansen and Kamp, 2004; Salazar et al., 2015, Fig. 2). The steepening itself is due to an increasingly mud rich depositional system, possibly related to a wider shelf or increasing sediment bypass (Hansen and Kamp, 2006; Salazar et al., 2015). A mud-rich system also led to a high tendency of slumping and mass wasting as shown by disrupted reflectivity and folded or faulted packages of sediment. A particularly large mass transport deposit (MTD) of Pliocene to Pleistocene age is intersected by seismic line dtb01-23 (TGS-NOPEC, 2001) northwest of the Tane-1 and Hoki-1

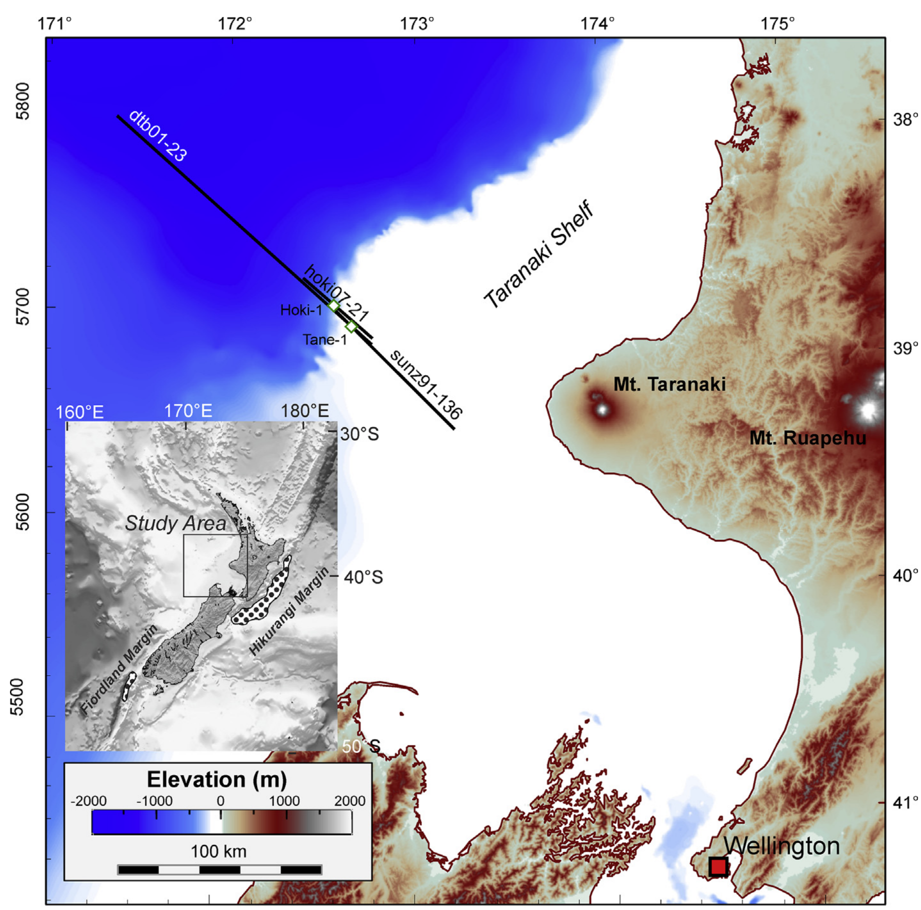

Fig. 1. Map of the study area showing the western North Island and northern tip of the South Island of New Zealand, the Taranaki Basin shelf and slope, and the location and names of seismic lines used in this study. Coordinates are given as geographic (degrees) and as New Zealand Transverse Mercator projection (km). Inset shows the location of the study area relative to New Zealand and the distribution of hydrates along the Hikurangi and Fiordland subduction margins (dotted polygons).