Marine and Petroleum Geology 38 (2012) 19–34

Contents lists available at SciVerse ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Analysing sand-dominated channel systems for potential gas-hydrate-reservoirs using an AVO seismic inversion technique on the Southern Hikurangi Margin, New Zealand

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ARTICLE INFO

Article history:
Received 1 May 2012
Received in revised form
17 July 2012
Accepted 7 August 2012
Available online 31 August 2012

Keywords:
Gas hydrate
New Zealand
Sands
Channel systems
Bottom-simulating-reflection (BSR)
Amplitude-versus-offset (AVO)

ABSTRACT

Gas hydrates have recently been recognised as a class of unconventional petroleum resource and the economic viability of gas production from hydrates is now being viewed as a realistic possibility within the next decade. Therefore, potential offshore hydrate accumulations in the world-class endowed gas hydrate province, the Hikurangi Margin, New Zealand, represent a significant medium- to long-term opportunity to meet the country's future energy requirements.

In this paper we delineate a potential gas hydrate reservoir in the East Coast Basin, New Zealand and quantitatively estimate its gas hydrate concentrations from 2D seismic data with no well information available.

The target is interesting for exploration since it shows evidence for gas-hydrate bearing sands, in particular, buried channel systems. We use a combined analysis of high-resolution velocity analysis, amplitude-versus-offset (AVO) attribute and AVO inversion to investigate whether we can identify regions that are likely to contain highly concentrated gas hydrates and whether they are likely to be sand-dominated. To estimate hydrate concentrations we apply a rock physics model.

Our results indicate the presence of several – up to 200 m thick – zones that are likely to host gas hydrates, with one location predicted to consist of high-permeable channel sands and an inferred gas hydrate saturation of ~25%. These findings suggest significant amounts of gas hydrates may be present in high-quality reservoirs on this part of the margin.

1. Introduction

1.1. Gas hydrates

Gas hydrates are naturally occurring ice-like substances composed of gas molecules (mainly methane) and water (Sloan, 1990). Hydrate accumulations worldwide are most commonly estimated to contain ~700,000 trillion cubic feet (tcf) of natural gas (Boswell, 2009; Kvenvolden, 1988), however, approximations on how much hydrate is really present diverge over several orders of magnitude (e.g., Boswell and Collett, 2011; Buffett and Archer, 2004; Klauda and Sandler, 2005; Milkov, 2004). Despite these uncertainties, gas hydrates have the potential to become an economically viable source of energy within a decade, a reason why numerous countries initiated national gas hydrate programmes over the last ten years (e.g., Collett, 2002; Koh et al., 2012; Makogon et al., 2007).

Gas hydrates occur in a very variable geological environment (e.g., Kvenvolden and Lorenson, 2001) but the growing consensus is that potential gas hydrate reservoirs suitable for exploitation should be ideally hosted in high-quality, high-permeable sands (e.g., Moridis et al., 2009), just as it is the case for conventional hydrocarbon fields. The major challenge today still lies in understanding the entire gas hydrate system, including gas source, migration pathways, reservoir emplacement, and seal (Collett et al., 2009), while recognizing key attributes associated with gas hydrates in pore-filling and fracture-filling media.

In this paper we attempt to delineate a potential gas hydrate reservoir located within the East Coast Basin, New Zealand and estimate its gas hydrate concentrations based on 2D seismic data with no well information available. This study is carried out to

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0264-8172/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpetgeo.2012.08.001

improve our local understanding of reservoir host lithology for a potential gas hydrate development site.

1.2. *Detecting gas hydrates – methodology*

Hydrate concentrations within sediments have previously been approximated by relating seismic velocities to hydrate saturations, e.g. directly from seismic velocities (e.g., Korenaga et al., 1997; Wood et al., 1994) by relating acoustic velocities to porosity and saturation using the time-average equation (Wyllie et al., 1958) or by using a weighted-equation model (Lee et al., 1996), which relates hydrate velocities to a weighted sum of Wyllie's and Wood's equation (Wood, 1941; Wyllie et al., 1958). The downside of these models is that they are based on empirical relationships which fail to predict accurate concentrations in high-porosity, unconsolidated sediments (Dvorkin and Nur, 1998), sediments that we expect to be present at our study site. Yet, the study of variations of amplitude-versus-offset (AVO) in pre-stack seismic gathers (e.g., Ostrander, 1984; Rutherford and Williams, 1989) and resulting attributes and AVO inversion have been successfully used in conventional hydrocarbon exploration to derive lithology and reservoir characteristics (e.g., Castagna et al., 1998). Combined with various rock-physics models, these techniques have been applied to estimate gas and gas hydrate saturations from BSRs (e.g., Andreassen et al., 1995; Ecker et al., 1998, 2000; Hyndman and Spence, 1992). Especially the analysis of 3D data improved the assessment of gas hydrates, e.g. in the permafrost region (e.g.,Inks et al., 2009; Lee et al., 2009) and integrated workflows of 3D pre-stack seismic inversion, rock physics modelling and stratigraphic interpretation have proven to quantify significant hydrate concentrations, e.g. in the Gulf of Mexico (e.g., Shelander et al., 2010, 2012).

A combined analysis of high-resolution velocity analysis, amplitude-versus-offset (AVO) attribute and AVO inversion were undertaken to investigate whether we can identify regions that are likely to contain highly concentrated gas hydrates and whether they are likely to be sand-dominated. We use interval velocities as a proxy for elevated hydrate concentrations and apply a deterministic rock-physics model based on the Hertz–Mindlin theory (Mindlin, 1949), which has been successfully applied to study gas hydrate bearing sediments (e.g., Helgerud et al., 1999) to constrain hydrate saturations. A similar approach for identifying gas hydrate deposits, using a seismic rock physics inversion method, has been successfully adapted in the Gulf of Mexico (Dutta and Dai, 2009).

1.3. *East Coast Basin, New Zealand*

The East Coast Basin, located at the Hikurangi Margin east of the North Island, is currently considered the economically most promising gas hydrate province in New Zealand (Fig. 1A). To date, gas hydrate research has focussed on a regional analysis of seismic data to assess the distribution of gas hydrates along the East Coast and to document the initial work on geochemistry and associated ecosystems (e.g., Beggs et al., 2008; Pecher et al., 2010b).

Widespread bottom-simulating reflections (BSRs) related to the base of gas hydrate stability zone have been observed along the margin (e.g., Henrys et al., 2003; Katz, 1982; Lewis and Marshall, 1996; Pecher and Henrys, 2003), which indicate the likely presence of gas hydrate and possibly free gas below (e.g., Crutchley et al., 2010; Henrys et al., 2008; Pecher et al., 2010c). Even though it has been demonstrated that BSRs can be caused by an impedance contrast between hydrate filled sediments overlying gas-free sediments (Hyndman and Spence, 1992), seismic indicators and AVO signature often point to the presence of free gas below BSRs in the basin (e.g., this study; Crutchley et al., 2010; Pecher et al., 2010c).

The East Coast Basin is a fore-arc basin characterised by accretionary tectonics and a classical imbricated frontal wedge (refer to Study Area and Geology), where BSRs are proposed to form by upward fluid expulsion (Hyndman and Davis, 1992) due to tectonic thickening and loading in initially under-consolidated sediments, a mechanism that has also been proposed for the Hikurangi Margin (Crutchley et al., 2010; Pecher et al., 2010c).

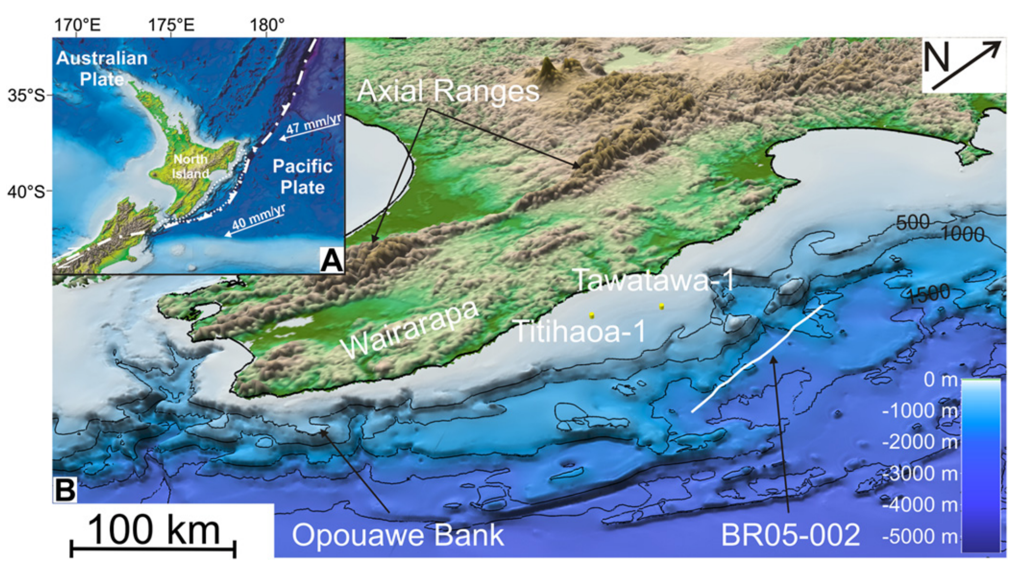

Figure 1. A: Overview of the Pacific-Australia plate boundary in the vicinity of the North Island of New Zealand. The white dashed line is the approximate location of the deformation front of the present plate boundary of the Hikurangi subduction zone and arrows indicate the subduction vector of the Pacific Plate relative to the Australian Plate (De Mets et al., 1994). The white dotted polygon represents the approximate extent of the Hikurangi Margin gas hydrate province within the East Coast Basin (Pecher and Henrys, 2003). The eastern limit of the gas hydrate province is assumed to roughly coincide with the Hikurangi trench. Its southern limit is unknown due to a lack of data (Pecher and Henrys, 2003). B: Bathymetry of the study area displaying a contour interval of 500 m and a vertical exaggeration of 10. The bathymetry of the study area reveals several canyons and channel systems feeding towards the subduction front, while thrust ridges dominate the morphology. Seismic line BR05-002 (solid white line) and offshore wells are annotated (yellow dots).Well logs could not be used in this study (e.g. for deriving background trends) since logging started only at 700 m MD, which is below the zone of interest in this study. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)