Characterisation of focused gas hydrate accumulations from the Pegasus Basin, New Zealand, using high-resolution and conventional seismic data

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SUMMARY

Gas hydrates are reported widely in seismic data from New Zealand's Hikurangi Margin (east coast of the North Island). Over the last decade, conventional petroleum exploration interests in this region have led to the collection of several regional seismic datasets. These data have greatly improved our understanding of hydrate accumulations in the area; however, the resolution of industry multichannel seismic surveys is limited by the bandwidth of the airgun sources used. We present preliminary results from an academic high-resolution generator-injector (GI) airgun seismic survey, undertaken in mid 2015, that targeted focused gas hydrate accumulations lying within thrusted accretionary units in the Pegasus Basin, at the south end of the Hikurangi Margin. Each feature was surveyed with 5 to 10 closely spaced seismic lines that provide an opportunity to examine the three-dimensional structure and stratigraphy with better resolution than the original lines.

Two main processes of natural gas migration and resulting accumulation as hydrate are examined more fully: (1) vertical transport into the shallow seafloor driven by overpressure and (2) inclined transport upward along dipping permeable beds. In both of these cases, our data show significant three-dimensional variability is needed to focus fluid migration from below into hydrate trapping configurations within the hydrate stability field nearer to the seafloor. Due to the absence of well data in this basin, the high-resolution seismic data also help to constrain interpretations of basin stratigraphy which plays a significant role in hosting and trapping hydrate accumulations.

Key words: gas hydrates, seismic reflection data, seismic resolution, generator-injector airgun source, case history

INTRODUCTION

Gas hydrates are complex clathrate solid compounds containing natural gas (mostly methane) molecules caged by a lattice of water molecules. They are widespread around the world on continental margins where the temperatures are cold enough and pressures are high enough for them to be stable in shallow ocean sediments. They are widely studied for their role in the global carbon cycle, their potential as an unconventional energy resource, and the hazards associated with hydrate dissociation within seafloor sediments.

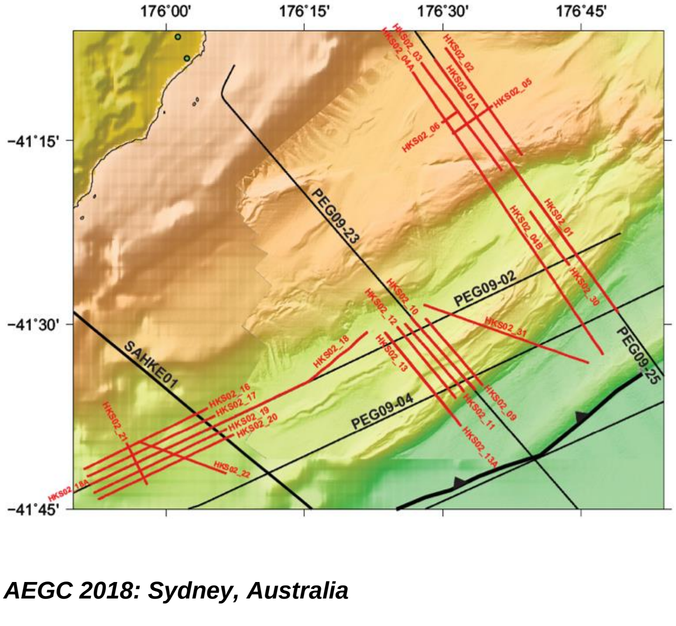

Figure 1: Location of industry (PEG09 survey – coloured black) and high-resolution (HKS02 survey – coloured red) seismic lines collected on the Hikurangi Margin east of New Zealand. The North Island's Wairarapa coastline is at the upper left; the Hikurangi Subduction Zone deformation front is at lower right. Indicative bathymetry is based on multibeam surveying (source of bathymetry: National Institute of Water and Atmospheric Research (NIWA).

Seismic reflection profiling provides a means for characterising gas hydrate accumulations as the negative impedance contrast resulting from the phase change from hydrate filled sediments to gas filled sediments can be readily identified as a bottom simulating reflection (BSR). New Zealand's Hikurangi Margin, an active margin located where the Pacific Plate subducts beneath the North Island east of New Zealand, has been a focus area for the study of hydrate accumulations using seismic methods (e.g., Henrys et al., 2003; Pecher et al., 2005; Crutchley et al., 2015; Fraser et al., 2016). A wealth of data has been collected recently due to exploration interest for conventional hydrocarbons in the East Coast basins. The absence of well data from this margin means that hydrate occurrences have not been confirmed by subsurface sampling or logging.

Data from two contrasting seismic surveys, PEG09 and HKS02, are presented here to highlight the benefits of joint interpretations of conventional petroleum industry seismic data and high-resolution shallow-penetration seismic data. The PEG09 survey was conducted in 2009-2010 by the New Zealand government to stimulate oil and gas exploration in the Pegasus Sub-basin at the south end of the Hikurangi Margin. Acquisition included three Bolt APG 8500s airguns recorded by a 10-km-long 800-channel hydrophone array. The HKS02 survey was an academic experiment conducted in June 2015 aboard the *RV Roger Revelle* during voyage RR1508. The acquisition system included two 45/90 generator-injector (GI) airguns and a 600-m-long 48-channel streamer. The HKS02 seismic lines focus on a number of features that were identified in the earlier PEG09 dataset. Specific features were targeted by a closely spaced set of lines that could provide some three-dimensional control on the structures present (Figure 1).

SEISMIC DATA COMPARISONS AND INTERPRETATION

The gas hydrate features targeted in this study are related to structures that focus accumulations either in the vicinity of vertically oriented chimneys or along inclined sedimentary units. An excellent example of hydrates associated with a chimney has been identified on line PEG09-02 (Fraser et al., 2016). This feature was imaged again along the same transect in line HKS02-18A (Figure 2). Both images show a central chimney structure (centred on CMP 29900 on PEG09-02 and CMP 2700 on HKS02-18A) that pierces a distinct BSR. A zone of hydrate blanking extends laterally away from the central chimney. This zone is about 8 km wide just above the BSR at depths of about 600 m below the seafloor (using 2000 m/s as an average velocity of the near seafloor sediments) thinning to region about 3 km wide at a subseafloor depth of 300 m. Below the BSR, strata adjacent to the chimney exhibit relative high reflectivity which is inferred to correspond to sediments charged with free gas. A flat spot is observed at the base of the free gas.

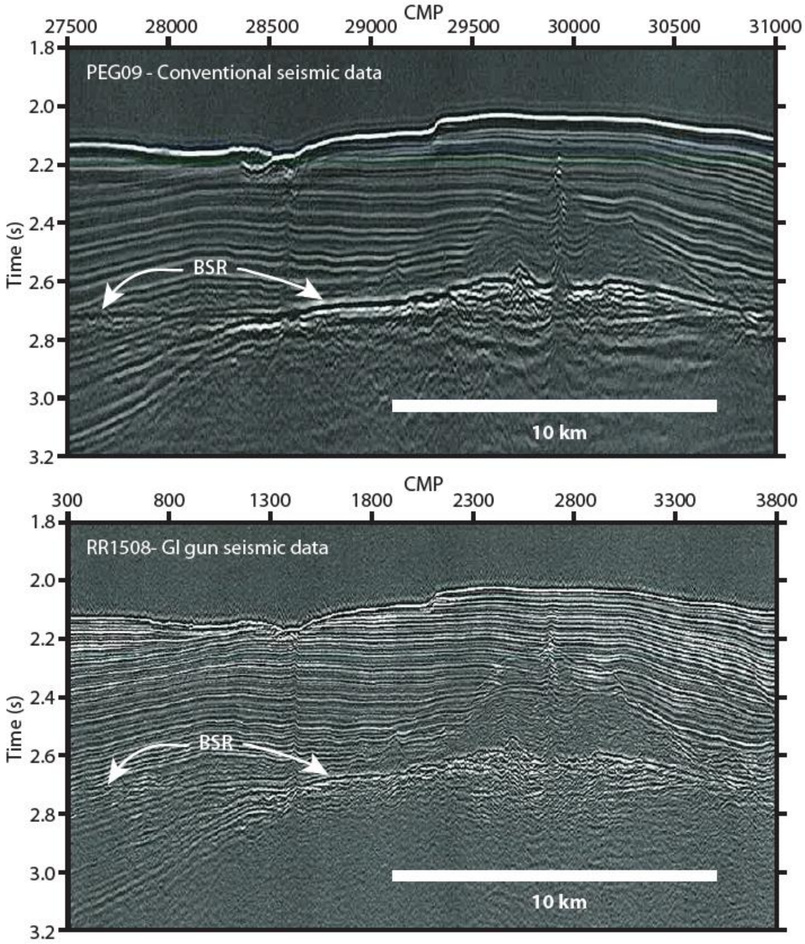

Figure 2: Comparison of conventional (upper section – line PEG09-02) with high-resolution (lower image – line HKS02-18A) GI airgun seismic data across a gas hydrate blanking feature on the continental slope east of New Zealand (Pegasus Basin). (See Figure 1 for locations).

In general, the lower frequency PEG02 data clearly show the major features present in the focused gas hydrate systems on the Hikurangi Margin. However, the higher frequencies present in the HKS02 data enable a more detailed interpretation of the strata and structures that host the associated hydrate and gas. Frequency content in the HKS02 and PEG09 datasets was determined by extracting frequency spectra from CMP gathers and testing bandpass filters with a range of frequencies. These frequency-domain filters were used to attenuate low- and high-frequency noise in the data. Trapezoidal bandpass filters with corner frequencies of 12-35-160-210 Hz (HKS02) and 5-10-50-60 Hz (PEG09) were applied. The dominant frequency of 30 Hz in the PEG09 data corresponds to a vertical resolution (corresponding to a quarter-wavelength) of about 17 m, whereas the dominant frequency of 80 Hz in the HKS02 data corresponds to a vertical resolution of about 6 m. This difference means that the higher-resolution data are more likely to be able to investigate individual stratigraphic units, whereas the lower-resolution data are limited to general observations of averaged properties.

Concentrated gas hydrate accumulations are also possible where fluid flow is focused along dipping permeable stratigraphic units that transect the base of hydrate stability (Crutchley et al., 2011b). An excellent example of such a feature was identified on line PEG09-25 and investigated further in high-resolution on line HKS02-01 (Figures 1 and 3). In this case a polarity reversal occurs along a reflection where it crosses the base of hydrate stability. This is inferred to correspond to a change from free-gas-bearing strata below to hydrate-bearing strata above; the bulk impedance of the hydrate-bearing strata is assumed to be higher than the background impedance, whereas the bulk impedance of the gas-bearing strata is assumed to be lower than the background, hence the polarity of the resulting reflection is reversed. In this case, the resolution of the data is high enough that a classic BSR is not seen. Instead, the polarity of individual reflectors can be used to identify the position of the top of gas and base of hydrate. The mechanism for transport of methane into the hydrate stability field and formation of concentrated hydrate is an area of active research.

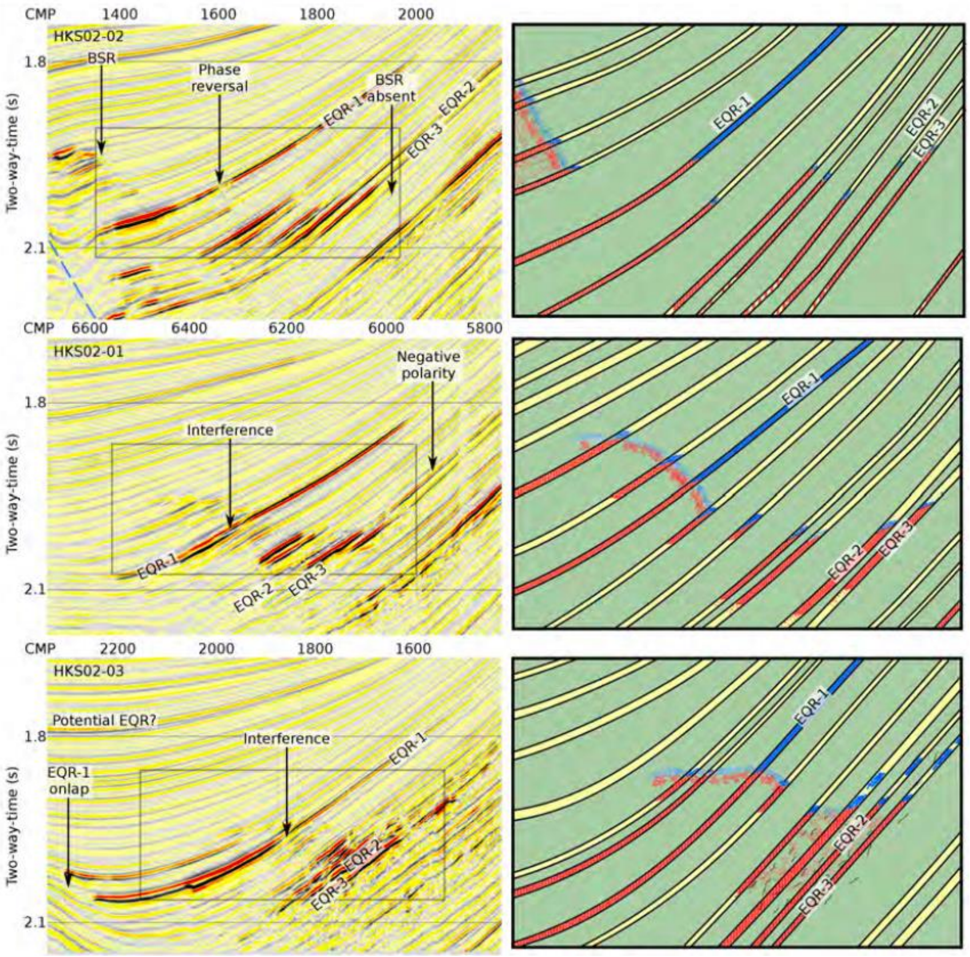

Figure 3: Comparison of three adjacent high-resolution GI airgun seismic lines across a gas hydrate injection feature on the continental slope east of New Zealand (Pegasus Basin). (See Figure 1 for locations). Note the polarity of the reflections reverses at the position where the pore filling material changes from gas (below) to hydrate (above). In the models on the right, red represents interpreted gas accumulations, blue represents interpreted has hydrate accumulations within thin porous sandstone units; the shade represents the degree of hydrate saturation (darker shades represent higher saturations).

The HKS02 survey was also able to examine the lateral variability of some of the features first imaged in the PEG09 data. For example, the bright reflection attributed to concentrated hydrate on line HKS02-10 was imaged by a series of parallel lines with a spacing of about 1 km (Figure 1). Distinct differences in this feature and associated features is seen in the neighbouring lines (Figure 3).

CONCLUSIONS

The data presented show the value of focused – and relatively inexpensive – high-resolution seismic data in refining our understanding of near seafloor accumulations of gas hydrate. As we move from bulk observations of hydrate on a margin to focused investigations of specific features, it becomes more important to understand the three-dimensional dynamic system that the hydrates are found in. The next step in this work will be to invert the data for lithological/stratigraphic controls; in the absence of well information, it is critical to better constrain what types of sediments are present in these systems (e.g., Kroeger et al., 2015). It is also anticipated that examination of these features using industry 3D seismic data would also be complemented by high-resolution 3D seismic methods which have proven useful for hydrate studies elsewhere (e.g., Crutchley et al., 2011a).

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