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How cold is a forearc basin? Geothermal gradient indications from gas hydrate thickness offshore Peru

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Keywords

Forearc Basin, BSR, Gas Hydrate, Geothermal Gradient

Abstract

Forearc basins are mostly considered to be associated with low geothermal gradients and therefore with a high risk in source rock maturity. This is the main reason why Peru offshore southern basins remain largely unexplored, with only a handful of wells drilled. Two main questions can be asked. Is a low geothermal gradient a fair assumption? With no deep-water wells, what evidence is there that the geothermal gradient is low? Bottom Simulating Reflectors (BSRs) are a main source of information which can be used to calculate the geothermal gradient. Previous studies have shown that the BSR often seen in seismic data at the base of the gas hydrate stability zone (GHSZ), can be used as a proxy for geothermal gradient. This predictive method can be a useful tool for use in frontier regions where well calibration of geothermal gradients is limited. The results are used to inform basin modelling studies for deeper thermogenic sources and help to de-risk prospects in frontier margins.

Using an enhanced regional seismic dataset, a BSR- derived geothermal gradient was obtained throughout the southern offshore basins yielding surprisingly high values of nearly 50°C/km which agree with the value of 47°C/km observed at the ODP 688 site, where methane hydrate was also recovered. These high values might be related to the young age of the oceanic crust which is being subducted in this area. But whatever the reason, the implications are very positive for future exploration as the Upper Cretaceous inferred source rock, is modelled to be in the hydrocarbon generation window, providing confidence of a working hydrocarbon system. Additionally, there are strong indications of hydrocarbon accumulations associated with the base of the methane hydrate zone itself. A pseudo depth seismic section reveals that there are multiple separate anomalies under several 4-way dip closures, suggesting free gas trapped below the BSR.

Introduction

Methane hydrate is an ice-like substance consisting of methane and water, that is stable at low temperature and under high pressure. In deep ocean sediments gas hydrate commonly occurs where bottom-water temperatures approach 0°C and the water depth exceeds about 300 m (Sloan, 1990; Kvenvolden, 1988) and where there is enough methane being generated in the system either by thermogenic or bacterial processes. In other words, gas hydrates exist where methane is trapped under sufficient pressure and low temperature conditions to maintain stability as a solid frozen phase. However, below the seabed the temperature of the sedimentary column increases with burial depth, until the gas hydrate crystal is no longer stable, and methane remains as free gas.

In offshore settings, based on natural gas hydrate stability conditions, water bottom temperature and thermal conductivity, the thickness of the methane hydrate stability zone can be used to estimate shallow geothermal gradients and associated surface heat flow (Vohat et al., 2003).

Identification on seismic data

A significant decrease in acoustic impedance is observed on seismic data at the base of the methane hydrate stability zone, where the phase changes to methane gas. This also normally results in a high amplitude event running parallel to the seabed, known as a Bottom Simulating Reflector (BSR) (Figure 1). The BSR has opposite polarity to the seabed and often cross-cuts stratigraphy. It is also characterised by a free gas zone below, which may be associated with high amplitude anomalies as the gas is trapped within reservoirs at this level. The base of the hydrate stability zone can act as a sealing lithology for deeper hydrocarbon accumulations.

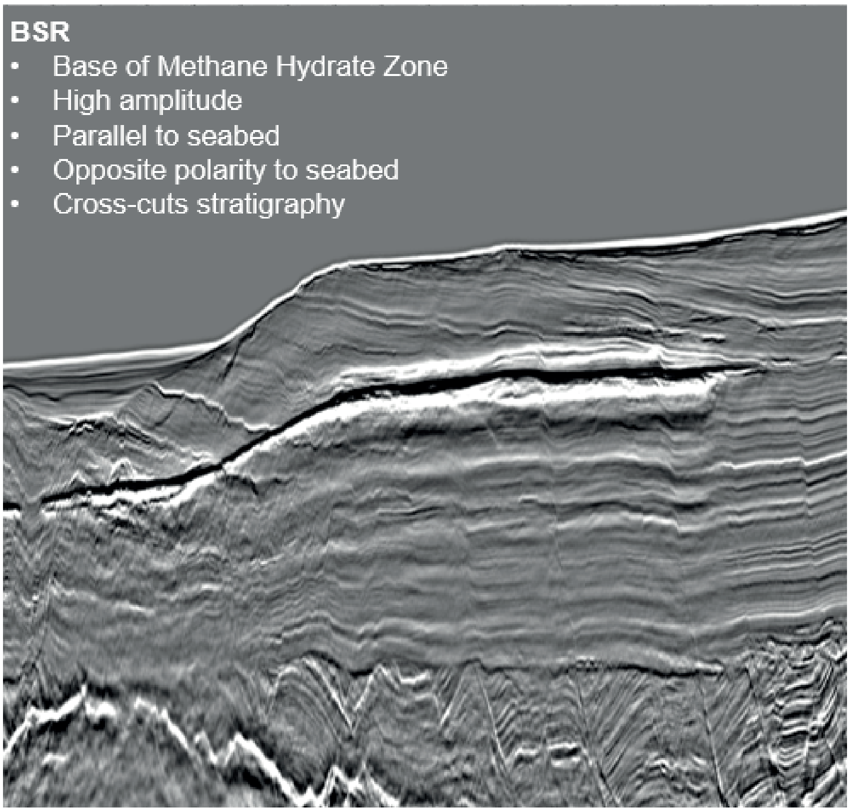

Figure 1: BSR seismic example from offshore Peru (Searcher 2019 Reprocessed PSTM)

Using an extensive enhanced seismic database and these diagnostic characteristics, a series of BSRs potentially associated with methane hydrate deposits have been identified offshore Peru.

How cold is the forearc basin offshore Peru?

With forearc basins mostly considered to be associated with low geothermal gradients and therefore with a high risk in source rock maturity, Peru offshore southern basins remain largely unexplored with only a handful of wells drilled. In order to address this risk, there are three main sources of information which can be used to calculate the geothermal gradient:

1. Exploration well data – There is no better method to confidently evaluate heat-flow and geothermal gradient than bottom hole temperatures taken from well log data. However, in a frontier basin, the extrapolation and/or basin modelling methods used have large associated uncertainty and result in continued exploration risk.
2. Ocean Drilling Program (ODP) well data – Where available, these wells normally provide temperature information which can be used to calibrate geothermal gradients estimated from BSRs.
3. Bottom Simulating Reflector (BSR) – Previous studies have shown that the bottom simulating reflector (BSR)

often seen at the base of the gas hydrate stability zone (GHSZ) can be used as a proxy for geothermal gradient. This predictive method can be a useful tool for use in frontier regions where well calibration of geothermal gradients is limited. The thickness of the GSHZ is directly related to seafloor temperature, hydrostatic pressure and geothermal gradient; where other variables are known, geothermal gradient can therefore be estimated. The results are used to inform basin modelling studies for deeper thermogenic sources and help to de-risk prospects in frontier margins.

Despite some source evidence from wells and studies carried out in the Trujillo, Salaverry, Lima and Pisco Basins, the strongest evidence of a working hydrocarbon system in these basins, is observed in a large post-stack reprocessed seismic dataset covering all the offshore basins, in the form of Bottom Simulating Reflectors (BSRs) interpreted as the base of the gas hydrate stability zone. A BSR- derived geothermal gradient was calculated throughout the basin yielding surprisingly high values of nearly 50°C/km which agree with the value of 47°C/km observed at the ODP 688 site, where methane hydrate was also recovered.

These high values might be related to the young age of the oceanic crust which is being subducted in this area. Whatever the reason, the implications are very positive for future exploration as the Upper Cretaceous, Redondo Formation, (Sternbach et al.,) is buried under a relatively thin 2 km sedimentary cover. This has been considered one of the highest risks as, with the expected low gradient usually associated with this type of basin, the source rock would be immature. However, the high gradient places the source rock in the hydrocarbon generation window and provides confidence of a working

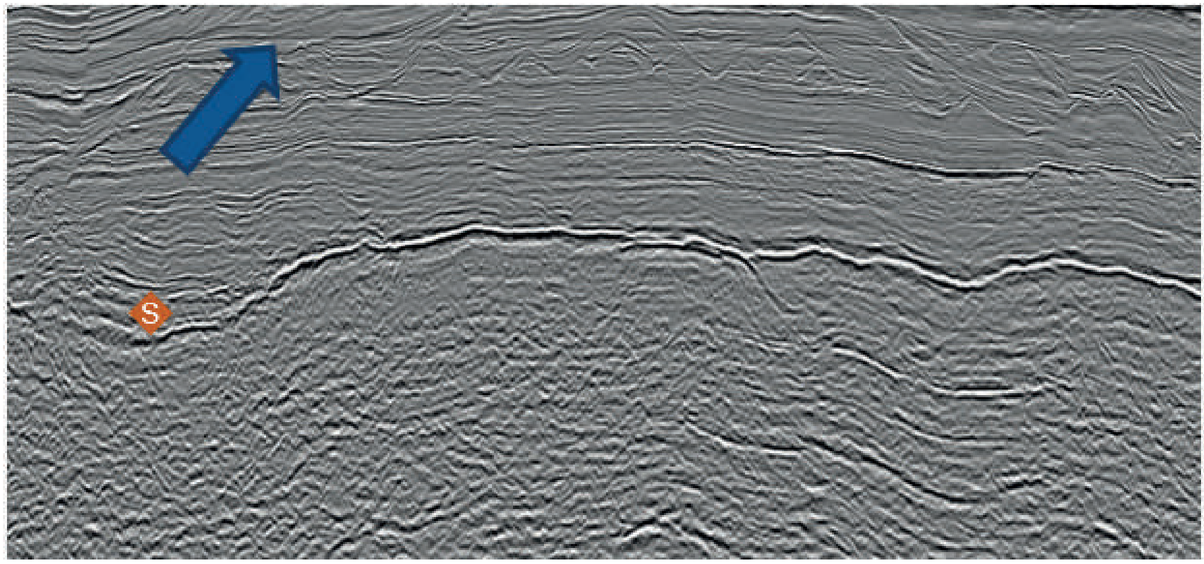

Figure 2: Seismic Line offshore Peru. The blue arrow points at a BSR. The possible source rock interval is indicated by the “S”. Being buried under at least 2 km of sediment and with a gradient of around 50°C/km, it should be in the oil window. Notice the shallower channel system which has been interpreted as a mixed turbidite/contourite system, a prolific play type (Rodriguez et al., 2021), associated with significant discoveries, including the Sergipe Barra Complex, offshore Brazil, with > 3 BBOE.

hydrocarbon system (Figure 2).

The identification of BSRs offshore Peru has enabled a better understanding of source rock presence, maturity, distribution and possible migration pathways. Additionally, there are strong indications of hydrocarbon accumulations associated with the base of the methane hydrate zone itself. A pseudo depth seismic section reveals that there are multiple separate anomalies under several 4-way dip closures, suggesting the bright anomaly is free gas trapped below a BSR on the section (Figure 3)

Conclusions

The presence of BSRs offshore Peru has enabled

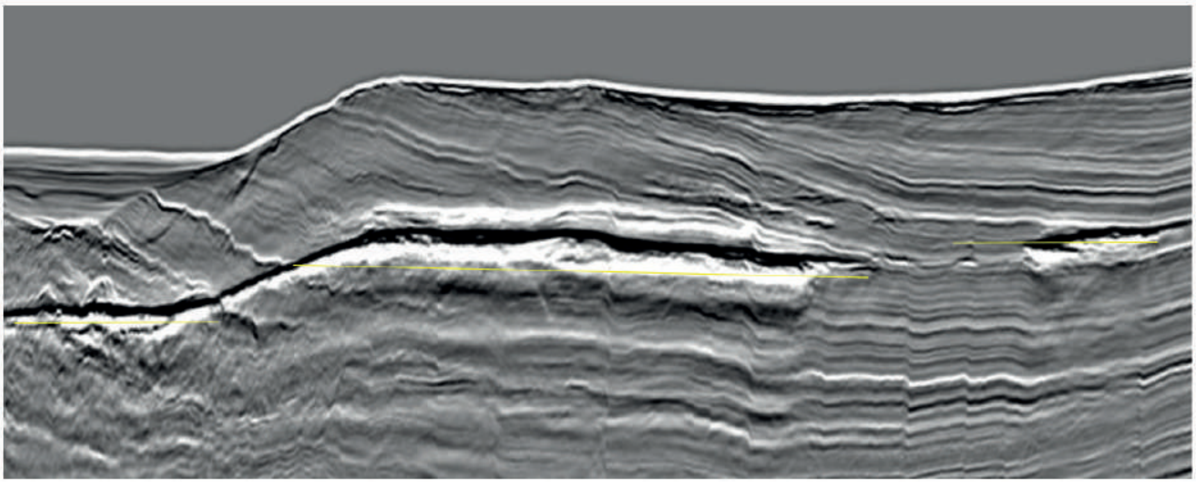

Figure 3: Seismic pseudo depth section showing several potential hydrocarbon accumulations at the base of the methane hydrate zone.

a better understanding of source rock presence, maturity, distribution and possible migration pathways. Offshore Peru has proven hydrocarbon systems and ample evidence of significant untapped hydrocarbon potential. The enhanced seismic dataset provides a consistent regional dataset that hands a gift in understanding to the explorer beginning to unlock this potential.

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