# Seismic identification and applications of methane hydrate as a future energy source

Karyna Rodriguez[1*], Neil Hodgson[1] and Hannah Kearns[1] discuss the various applications of seismic BSRs (Bottom Simulating Reflectors) associated with methane hydrate zones, from which methane can be extracted to provide a future source of energy.

## Introduction

Methane hydrate, or clathrate, is an ice-like substance consisting of methane and water that is stable at low temperature and under high pressure. It has a pentagonal dodecahedron molecular structure comprising one molecule of methane surrounded by molecules of water. It is usually found in areas with low temperatures, such as in the Arctic, in the form of methane hydrate deposits above and below the lower limit of permafrost. Hydrates are also common in deep water where the water column above 300 to 500 m water depth provides the high-pressure conditions required for their formation.

Pilot experiments in recent years using methane hydrates found under land ice have shown that methane can be extracted from these deposits. As efforts to extract natural gas from methane hydrate increase, it is set to become a critical energy source, particularly for resource-poor countries such as Japan. Other countries including Canada, the US and China have also been looking into ways of exploiting methane hydrate deposits (BBC News Business, 2013). Offshore deposits present a potentially enormous source of methane which can be identified at a global scale from a large 2D and 3D seismic database. In 2012, a joint project between the United States and Japan produced a steady flow of methane by injecting carbon dioxide into the methane hydrate accumulation. The carbon dioxide replaced the methane in the hydrate structure and liberated the methane to flow to the surface (Hobart M. King). Japanese engineers have also successfully developed a depressurisation method that turns methane hydrate into methane gas (*The Japan Times,* 2013), setting the scene for the exploitation of this future source of energy.

## Formation process

Methane hydrate is deposited under the right temperature and pressure conditions where there is enough methane being generated in the system. Methane can be generated by thermogenic processes where the source rock is buried to sufficient depth for thermal cracking of the kerogen and/or previously generated liquid hydrocarbons to take place. Alternatively, methane can have a bacterial origin, generated biogenically at low temperatures, early in a basin's history. In permafrost regions, biogenic methane is generated by bacterial action in shallow sediments and is deposited below the lower limit of permafrost. In contrast, slow seepage of thermogenic methane to the surface can be observed in deep water settings, where methane hydrate will be deposited most commonly below the seafloor or can travel up faults to accumulate as hydrate mounds on the seafloor (Figure 1).

The phase diagram in Figure 2 shows the range of temperatures and pressures at which methane hydrate is stable. With an increasing geotherm under a relatively constant pressure within the methane hydrate stability zone (red line in Figure 2), methane hydrate will change phase to methane gas as the temperature increases. This happens in deep water settings as the temperature of the sedimentary column increases with burial depth. Depending on the geothermal gradient, methane hydrate will change phase to methane gas (also known as free gas) at different depths.

In deep water offshore settings, the methane hydrate zone thickness depends on seafloor temperature, hydrostatic pressure related to the water column and therefore water depth, and geothermal gradient and therefore heat flow properties of the sedimentary column. 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

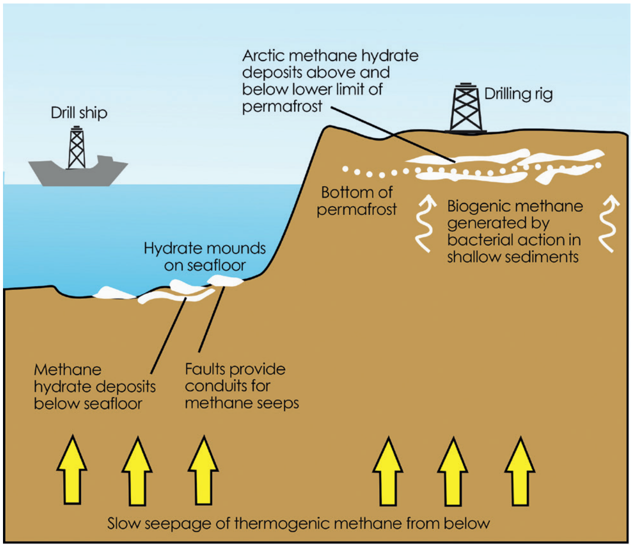


**Figure 1** Methane hydrate depositional model (modified from King, no date).

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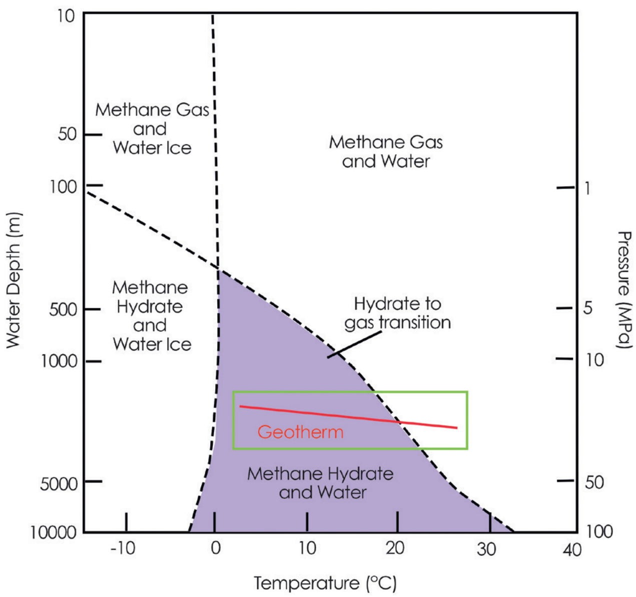


**Figure 2** Phase Diagram with methane hydrate stability zone associated with a range of pressure-temperature conditions coloured in grey (King, no date).

heat flow (Vohat et al., 2003). Geothermal gradient estimates derived from this thickness correspond to the temperature difference between the seabed and estimated temperature at the base of the stability zone.

## Identification on seismic data

The base of the methane hydrate stability zone, at which the phase changes to methane gas, is associated with a significant decrease in acoustic impedance on seismic data, which usually results in a high amplitude event running parallel to the seabed, known as a Bottom Simulating Reflector (BSR) (Figure 3). The BSR has opposite polarity to the seabed and often cross-cuts stratigraphy. It is also characterized 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.

Seismic velocity within the methane hydrate zone can be altered where the methane hydrate is deposited in a pore space > 40%. The BSR is often easier to identify when the seabed is flattened.

Using these diagnostic characteristics, a series of BSRs potentially associated with methane hydrate deposits have been identified at a global scale using an extensive 2D and 3D seismic database (Figure 4). The USGS published a map of known and inferred locations of gas hydrate occurrence. Using the extensive modern 2D seismic database available for this study, several locations with recovered gas hydrate samples had associated BSRs on seismic data and furthermore, some points where gas hydrate was only inferred also had clear BSRs.

## Methane hydrate implications and application examples

Methane hydrate is considered a drilling hazard. When oil wells are drilled through hydrate-bearing sediments, the warm temperature of the oil moving up through the frozen hydrate zone can cause melting which can result in well failure (King, no date). There are recent cases of deep-water exploration wells being relocated in order to avoid drilling through the methane hydrate zone. However, several ODP wells have either targeted or drilled through the methane hydrate zone without any major incidents.

Methane hydrates can also cause dissociation-induced instability in slope settings resulting in slumping, landslides and/or subsidence. At the same time that this can be a hazard, it might provide a way to identify palaeo-BSRs and could explain a trigger in stability failure in gravity collapse systems.

The relationship of the base of the hydrate zone with the temperature at which methane hydrate changes phase to methane gas, enables the use of the thickness of the methane hydrate zone as a geothermal gradient proxy in frontier basins where there is usually limited well control. The BSR depth is converted to pressure which in turn is converted to temperature by a series of well-established relationships. This methodology has been applied in numerous examples around the globe and has provided invaluable information to help derisk the petroleum system in frontier basins.

In the Pelotas Basin offshore Brazil, a very clear and extensive BSR extending over 100,000 km², has been identified and mapped. A BSR-derived geothermal gradient was used in a basin modelling exercise in which the main potential source rock was modelled to be in the oil window in the deeper part of the basin, where the overburden is thinner. A series of sea surface oil slicks identified from satellite imagery line up with the updip limit of the BSR. Methane hydrate is expected to be an efficient

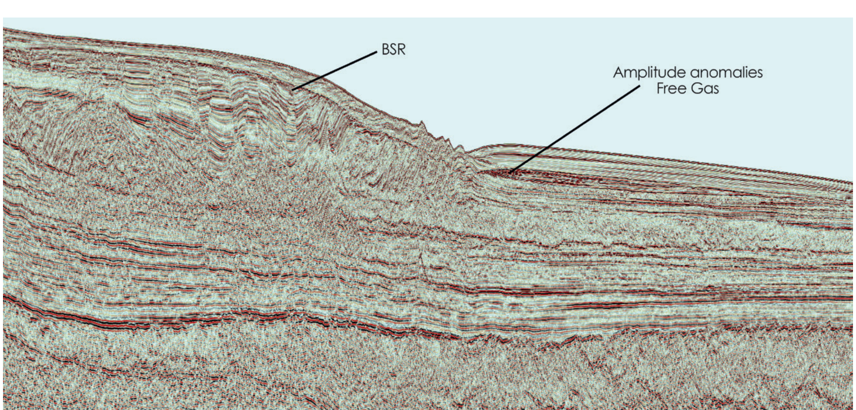


**Figure 3** BSR in the Pelotas Basin in Brazil. Note the clear bright amplitude event parallel to the seabed, cross-cutting stratigraphy and with a zone of high amplitude anomalies where methane is found in the methane gas phase.

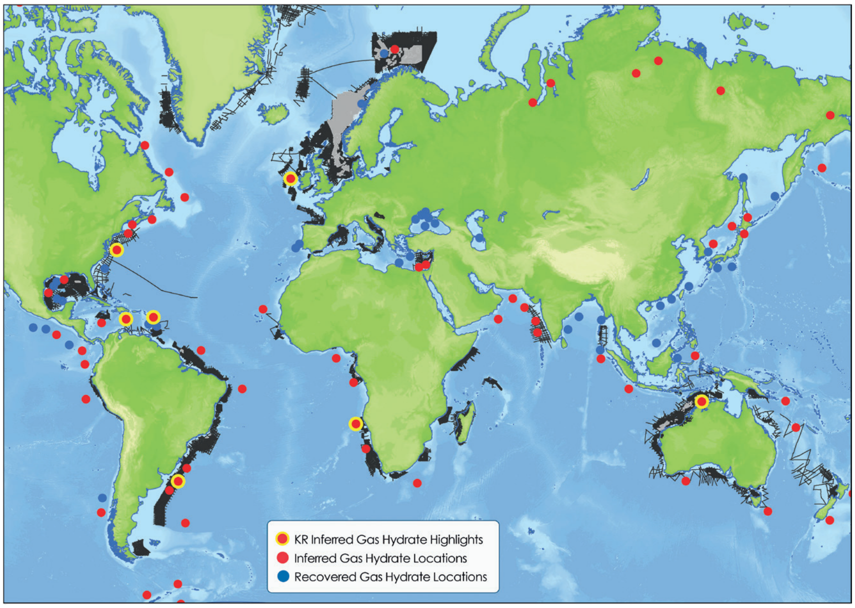


**Figure 4** Gas hydrate occurrence from recovered and inferred locations also showing the extensive seismic database available and the location of the study areas.

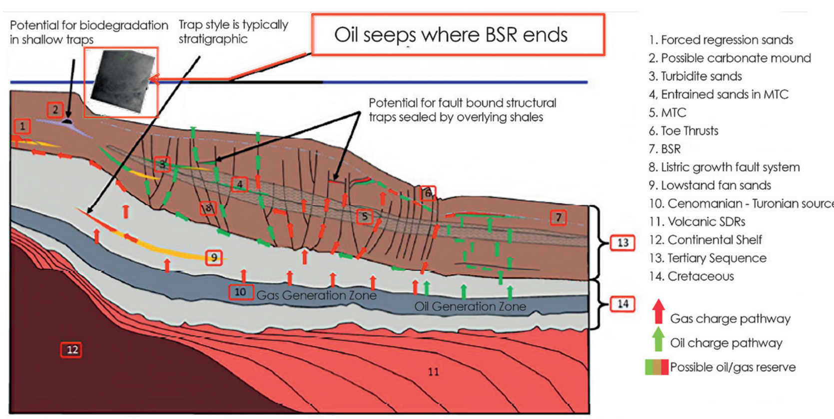


**Figure 5** BSR-derived geothermal gradient predicts oil generation in Pelotas Basin Brazil, supported by oil slicks located at the updip limit of the BSR (methane hydrate zone).

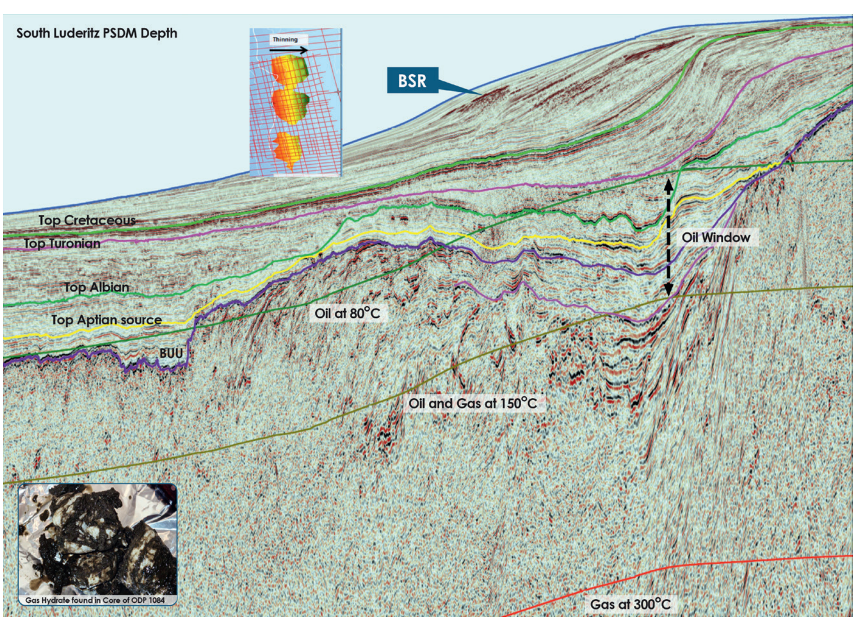


**Figure 6** Inset: Gas Hydarte recovered from core in ODP 1084 well. BSR-derived geothermal gradient in the Lüderitz Basin, Namibia, displaying calculated isotherms which indicate Aptian source rock oil kitchens beneath the present-day shelf and basin.

sealing lithology. The concentrated location of the oil slicks here indicates that there is a working oil-generating petroleum system beneath the methane hydrate zone (Figure 5).

The conjugate Lüderitz Basin in Namibia also has a BSR which is less extensive and, owing to the steep gradient of the slope and fast-changing pressure profile, is not actually parallel to

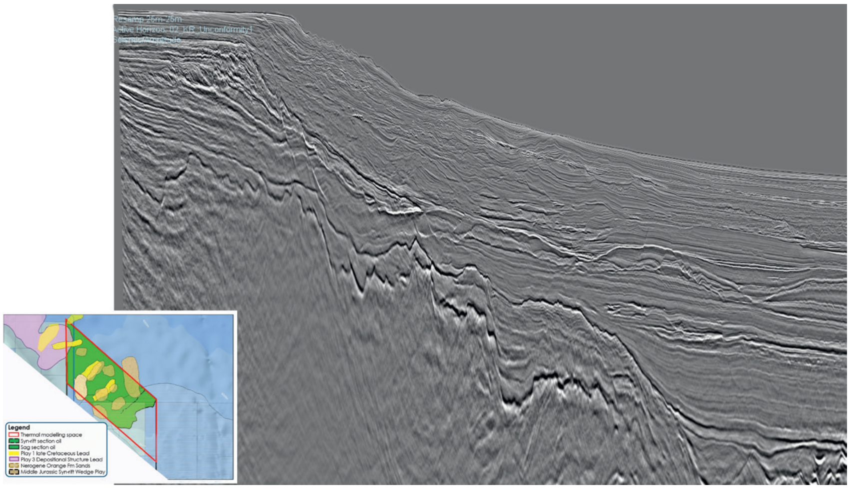

**Figure 7** Left: Thermal maturity model showing oil kitchen combined with mapped leads, using BSR-derived geothermal gradient integrated with all available well data in Foz do Amazonas Brazil. Right: BSR observed on 3D seismic data confirming extension of oil window to NW.

the seabed (Figure 6). The presence of a BSR related to methane hydrate was confirmed by flattening on the seabed reflector, and seeing the cross-cutting stratigraphy relationship as well as the intersecting ODP 1084 well which recovered methane hydrate (Figure 6). The BSR-derived geothermal gradient was in agreement with the ODP 1084 bottom hole temperature measurements as well as values obtained from present-day hydrocarbon maturity warm and cool heat flow models, adding confidence to the BSR-derived geothermal gradient methodology.

A clear BSR was also identified and mapped in the Foz do Amazonas Basin offshore Brazil. The BSR-derived geothermal gradient was integrated with ODP and exploration well bottom hole temperature data. This allowed the definition of cool case and warm case scenarios. The modelled thermal maturity was compared to well results with the warm case model selected as the most likely scenario. The oil kitchen from this model was overlain on a series of identified leads (Figure 7) and interestingly can also be inferred to extend to the NW where a 3D dataset shows a clear BSR giving a geothermal gradient in line with the 2D models (Figure 7).

## Methane hydrate BSR applications summary

Positive identification of a BSR using associated seismic characteristics, is a strong indication that a methane hydrate zone is present. A BSR is therefore a DHI (Direct Hydrocarbon Indicator). It is not possible to tell from the BSR whether the methane is biogenically- or thermogenically-derived, or from combined sources, but it does indicate that a significant amount of methane has been generated.

As seen from the Pelotas example, when integrated with satellite-based sea surface slick observations, deriving geothermal gradients using this method can help to derisk the petroleum system and can contribute towards understanding the potential source of oil, its migration and distribution. Additionally, Blake Ridge (Offshore Florida) was used as an analogy to estimate resources over the 100,000 $km^2$ methane hydrate zone in Pelotas, (porosity 57-58%, saturation 0-20%). This yields huge methane resources in Pelotas, ranging from 93.8e+012 $m^3$ to 203e+012 $m^3$.

Basin heat flow modelling and integration with well data have confirmed that BSRs can be used to calculate a reasonable proxy for geothermal gradient estimation in frontier basins. Isotherms from the BSR-derived geothermal gradient have allowed the determination of oil windows with respect to potential source rocks. This has provided a great tool for source rock maturity derisking.

There is additional hydrocarbon potential in the free gas zone as indicated by the numerous amplitude anomalies observed in examples such as the Pelotas Basin in Brazil.

Finally, methane hydrate may provide a future source of energy. Extensive areas containing methane hydrate have been identified and quantified using regional 2D seismic data. Once engineers find a safe and commercial method for extracting methane from the vast methane hydrate deposits, the potential of this future source of energy can be exploited to provide clean energy at a time when the energy transition revolves around a greener future.

## References

King, H.M. [no date]. *Methane Hydrate: The world's largest natural gas resource is trapped beneath permafrost and ocean sediments.* https://geology.com/articles/methane-hydrates/.

Vohat, P., Sain, K. and Thakur, N.K. [2003]. Heat flow and geothermal gradient from a bottom simulating reflector: A case study. *National Geophysical Research Institute*, **85**, (9), 1263-1264.