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BSR Distribution From Newly Acquired 2D Seismic and the Potential Link to Thermogenic Petroleum Systems, Offshore Newfoundland and Labrador, Canada

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Summary

Newly acquired 2D broadband seismic data has led to new data coverage over the slope and deep water regions of the margin. In other petroleum exploration regions there are several examples of attempts to link active thermogenic petroleum systems to the occurrence of bottom simulating reflectors. Given the recent increase in seismic data coverage and ongoing seabed sampling programs, are there new observations derived from this dataset that can lend support to the previous efforts undertaken along the Eastern Canadian margin? Four cases of mapped BSR's are highlighted in this study, with emphasis on relating the newly acquired seismic data to observations from previous studies. Some BSR's exist near mapped AVO anomalies with associated faults, potentially feeding the gas hydrates from depth. At the Mizzen oil discovery, the BSR in that region may be related to migration of hydrocarbon from a proven thermogenic petroleum system. Conclusions of previous studies assessed some thermogenic hydrocarbon input to the hydrate and implied charge from depth. Heat flow measurements associated with the seabed coring program also support higher gradients in the slope to deepwater areas. This would support the addition of thermogenically derived C2+ gases in order to explain the hydrate stability depth observed.

Introduction

Beginning in 2011, an initiative to acquire large regional 2D broadband seismic data offshore Newfoundland and Labrador has now led to over 150,000 line km's of new data over slope and deep water regions of the margin. Areas with little to no previous seismic coverage are now yielding information such as extents of syn-rift depocentres, exploration target identification in the subsurface, and gas hydrate distribution through mapping of bottom simulating reflectors (BSR's). Previous studies have reviewed natural gas hydrates in the region through analysis of existing well data in the Eastern Canadian offshore area (Majorowicz and Osadetz, 2003) and through seismic mapping (Mosher, 2008). These efforts were largely focused on assessing the hydrate distribution with respect to potential resource assessment of those deposits.

In other petroleum exploration regions there are several examples of attempts to link active thermogenic petroleum systems to the occurrence of BSR's (Brooks et al., 1986 & 1999; Saunders and Bowman, 2014). In these examples, regionally mappable BSR's were linked to subsurface hydrocarbon migration pathways below, and in some cases surficial geochemistry above these features. Given the recent increase in seismic data coverage and ongoing seabed sampling programs, are there new observations derived from this dataset that can lend support to the previous efforts undertaken along the Eastern Canadian margin? Four cases of mapped BSR's are highlighted in this study (Figure 1) that occur in water depths between 1000 and 3600 metres, with emphasis on relating the newly acquired seismic data to observations from previous studies.

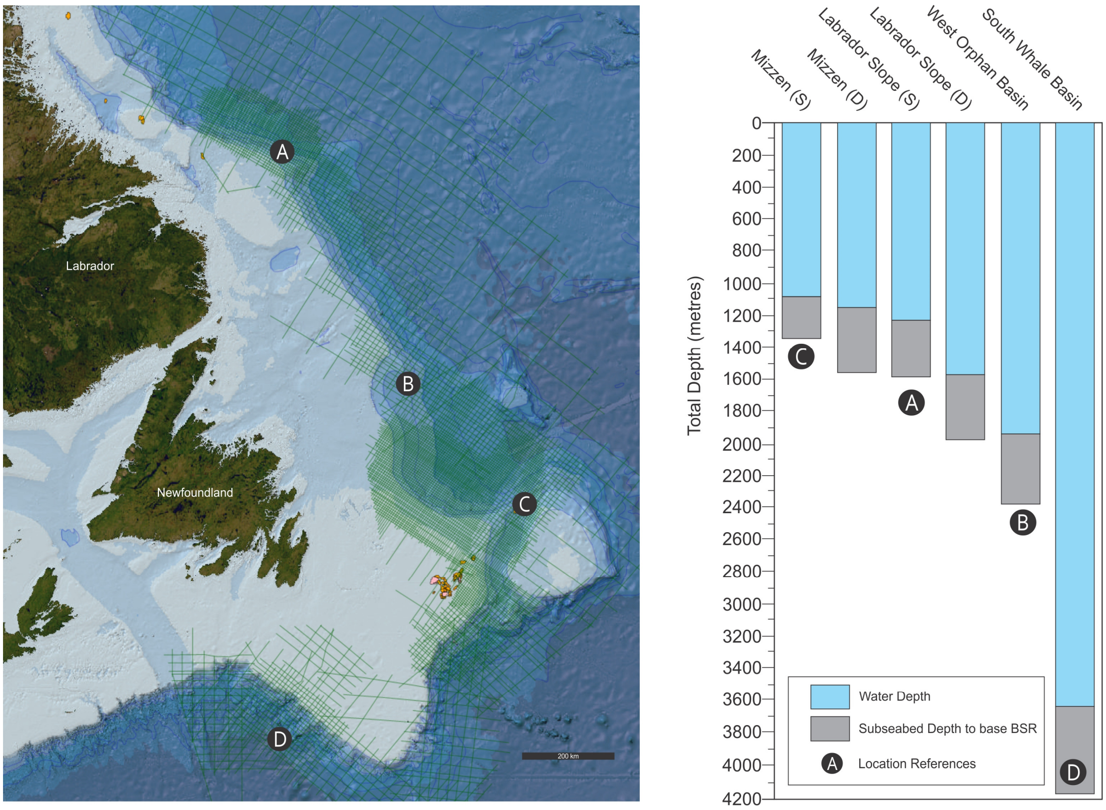

Figure 1: *Right - Study area location with regional 2D seismic grid (green) and Production/Discovery licenses (pink and orange polygons respectively). Left - Base hydrate stability (from BSR's) versus water depth illustrating the distribution from slope to deep water in the Newfoundland offshore. Locations (A through D – S-shallowest marker and D-deepest marker in trend) of the mapped BSR's as shown in figure 2.*

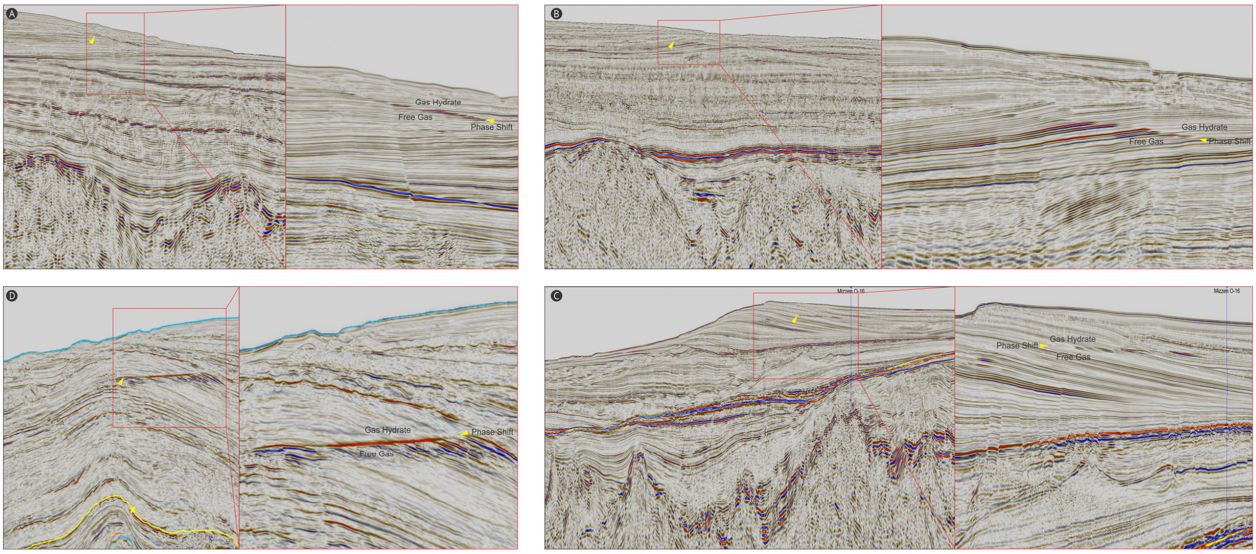

Figure 2: *Bottom simulating reflectors offshore Eastern Canada. A: Labrador, Chidley Basin. B: Cape Freels Prospect, Orphan Basin. C: Mizzen Discovery, Sackville Spur - Flemish Pass Basin. D: Southern Newfoundland, South Whale Basin.*

Discussion

Observations based on interpretation of 2D seismic data illustrate the inferred presence of gas hydrates (from BSR's) along the Atlantic margin of Newfoundland and Labrador. The distribution is relatively localised given that the predicted stability window for hydrate preservation spans the entire margin in water depths ranging from 350 to 3500 metres (Majorowicz and Osadetz; 2003). The seismic reflector at the base hydrate stability marker is taken to represent the lower velocity free gas zone that underlies the hydrate and associated sediments producing the velocity inversion with phase reversal (Shipley et al., 1979). These base hydrate stability zone features are commonly associated with deep seated faults to near surface that may act as migration pathways for thermogenically derived hydrocarbon (Figure 2) and commonly occur adjacent to AVO supported leads.

Labrador

The BSR imaged offshore Labrador lies overtop Cretaceous-aged syn-rift sediments with an adjacent fault to near surface potentially acting as a migration pathway moving hydrocarbon to the shallower section (Figure 2A). This frontier region has no exploration wells and thus no direct confirmation of an active petroleum system, although several gas discoveries have been made on the shelf adjacent to the area. From the new seismic (5km grid spacing) preliminary mapping shows three distinct BSR footprints covering approximately 1300 km^2, occurring in water depths of 500-1600m. Previous studies have not identified BSR's in the region due to lack of seismic coverage. Surficial geochemistry studies done in 2015 have shown evidence of thermogenic hydrocarbon in seabed cores (DeCoster, 2016).

West Orphan

In the West Orphan Basin the identified BSR is situated near the Cape Freels Prospect (Wright et al., 2016; Montevecchi et al., 2016) where AVO supported leads have been mapped. The image in Figure 2B depicts a strong BSR event, again with near surface faults that sole out at depth. As with the previous example, there has been no exploration drilling to date near this feature although several exploration licenses over these features were awarded in 2016.

Mizzen Region
The observed BSR's presented here is in an equivalent region to that of Mosher (2008 –Sackville Spur). In this case, the identified BSR's directly overly the oil discovery at the Mizzen O-16 well (Figure 2C) which was drilled after the Mosher (2008) study. This also corresponds to recent 2D seismic data showing a strong AVO response at the depth of the hydrocarbon filled reservoir, and illustrates faults adjacent to the main structure that project through the rock column to shallower depths. Along the entire margin there are numerous leads identified that share these characteristics.

South Coast
The BSR imaged in the South Whale Basin on the south coast of Newfoundland depicts a strong reflector relating to the interpreted free gas zone, again with faults extending from deeper rift section at depth (Figure 2D). A salt core has created an anticlinal structure with the BSR transecting the stratigraphy producing a clear marker. Water depths in the region of this marker reach in access of 3600m. This is outside of the predicted range of hydrate occurrence of Majorowicz and Osadetz (2003) and down slope from the Haddock Channel BSR of Mosher (2008). This region is also undrilled to date.

Implications for Petroleum Systems
Mapped BSR's in the offshore have a clear range of occurrence extending from Labrador Sea to the South Coast of Newfoundland. Qualitative observations allow for correlation of subsurface exploration leads with BSR distribution, including association with known hydrocarbon discoveries. The key issue with associating thermogenically derived hydrocarbons and BSR's lies in the difficulty in ruling out the classification of hydrates that are biogenically sourced, which is an essential task if attempting to de-risk thermogenic petroleum system presence in frontier exploration regions. Pure methane hydrates are commonly of biogenic origin (Type I), although the same composition can also be thermogenically derived if sourced from a petroleum system prone to dry gas generation. Type II hydrates contain methane as well as other C_2+ hydrocarbon gases and are associated with a thermogenic systems. As shown by Majorowicz and Osadetz (2003), the stability zone for Type II hydrates extends over higher temperatures due to the presence of these additional hydrocarbon components. Each of these have an associated hydrate stability zone that can be calculated using the geothermal gradient and overlying pressure of seawater.

Drilled exploration wells in the study area have known geothermal gradients in the range of 25 to 60 ^{o}C/km (Reiter and Jessop, 1985; GSC Basins Database). Knowing the geothermal gradient is critical in distinguishing Type I from Type II hydrates, as a low gradient with pure methane gas can have the same stability depth as a higher gradient with a mixed gas composition. With limited drilling over the BSR's in the slope and deepwater, establishing the geothermal gradient can be problematic. Where deepwater wells have been drilled, geothermal gradients tend to approach 40^{o}C/km and in some cases have been interpreted to approach 60^{o}C/km. Recent heat flow measurements associated with the seabed coring program also support higher gradients in the slope to deepwater areas. This would support the addition of thermogenically derived C_2+ gases in order to explain the hydrate stability depth observed. This observation aligns with the conclusions of Majorowicz and Osadetz (2003) that detected gas hydrates are unlikely to be Type I as they occur well below the pure methane stability zone where only Type II hydrates are stable.

Conclusions

Recent mapping of newly acquired 2D broadband seismic data has revealed the presence and extent of BSR's over the slope and deep water of Newfoundland and Labrador's offshore. Notably, some BSR's exist near to mapped AVO anomalies with associated fault systems potentially feeding the gas hydrates from depth. In the case of the Mizzen oil discovery, the BSR in that region may be related to migration of hydrocarbon from a proven thermogenic petroleum system. Conclusions of previous studies along the margin generally focused on identifying methane hydrates as a resource or drilling hazard, although Majorowicz and Osadetz (2003) did model for thermogenic input and assessed some

Type II hydrate influence. Mosher (2008) also implied thermogenic charge from depth but did not discern whether the BSR derived hydrates were of Type I or II.

Further work to support the identification of thermogenically influenced hydrate deposits include surficial geochemical studies via seabed sampling and detailed comparison of the hydrate stability window in a modelled versus observed sense. While further heat flow data is required in some of these frontier regions, where recent data has been acquired (exploration wells and heat flow at the seabed) the higher geothermal gradients support some thermogenic hydrocarbon input to the observed BSR occurrences.

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