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# DISTINCT EXPRESSIONS OF THE BSR USING VARIOUS FREQUENCIES OFFSHORE URUGUAY AND ITS CORRESPONDENCE WITH THE GAS HYDRATE STABILITY ZONE

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## ABSTRACT

At the Uruguayan continental margin, seismic evidence for the occurrence of gas hydrate has been identified based on the presence of BSRs in densely spaced 2D reflection seismic sections from different surveys. Mapping of BSRs based on 2D seismic data acquired in 2007 and 2008 suggested the presence of gas hydrates in areas that were not previously identified; hence hydrate occurrence offshore Uruguay is more widespread than previously thought. Recently ANCAP has digitized offshore seismic data acquired between 1970 and 1982. Being able to work on this data using interpretation software, and integrating results with the latest interpretations performed on the seismic collected in 2007 and 2008, the BSR extends over an area of approximately 25.000 km$^2$. It is present in water depths greater than 500 m and has high continuity in Pelotas Basin but is more discontinuous at Punta del Este Basin and southern part of Oriental del Plata Basin.

In offshore basins around the world the base of GHSZ can have different seismic expressions such as continuous, segmented, and high-relief BSRs depending on the stratigraphic, fluid and geothermal setting. Here, we present examples of the influence of the acquisition parameters on the acoustic expression of the BSR, comparing commercial seismic sections acquired for hydrocarbon exploration and high resolution seismic sections acquired during the R/V Meteor Cruise M49/2 in 2001 and R/V Meteor Cruise M78/3a (May - June 2009) using different sources and streamer system. For the different data sets the BSR presents differences regarding its continuity and amplitude strength. In high resolution seismic, enhanced amplitudes and phase reversals are observed for several reflectors while deep penetration seismic shows only one single continuous reflector.

This comparison may help to visualize the complexity of the free gas, gas hydrate and stratigraphic system behind the BSR, which is usually masked on low-frequency deep penetration seismic data.

*Keywords*: gas hydrates, offshore Uruguay, seismic imaging

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## INTRODUCTION

Natural gas hydrates are crystalline solids formed by natural gas (mainly methane) and water that are stable under thermobaric conditions of high pressure and low temperature [1].

Methane hydrate occurs in sediments within and below thick permafrost in Arctic regions and in the subsurface of most continental margins where water depths are greater than 500 meters [2].

Gas hydrate accumulations may represent an enormous source of methane. Based on global estimations of methane concentrations in natural appearing gas hydrates, the methane content is about 2 to 10 times greater than those of technically recoverable conventional natural gas resources [2]. The existence of such a large methane hydrate resource has provided a strong global research incentive and international interest, which has severely grown in the last years.

### *Hydrate identification from reflection seismic*

The first acoustic indication of gas hydrate occurrence is given by presence of the BSR (Bottom Simulating Reflector) in seismic sections due to a significant change in acoustic impedance between sediment containing hydrates and sediments containing free gas [3] [4]. The seismic appearance corresponds to a reflector parallel to seafloor including a polarity reverse with respect to the seafloor reflector.

The BSR is usually a good indication of gas trapped bellow the base of the gas hydrate stability zone (GHSZ) implying that gas hydrates are present [1]. On the other hand, gas hydrate can exist without creating a well defined BSR, especially when gas fluxes are directed though faults or comparable permeable fluid pathways [1].

In offshore basins around the world the base of the GHSZ can have different seismic expressions such as continuous, segmented, and high-relief BSRs depending on the stratigraphic, fluid and geothermal setting [5].

Another seismic response associated to the presence of gas hydrates in marine sediment is the blanking. It can be used to identify sediment formations, in which hydrates have been formed. However, blanking is not a good indicator of the base of GHSZ, because there are several possibilities leading to signal attenuation like the original or diagenitic character of strata as well as artefacts produced during seismic processing [1].

### *Offshore Uruguay - Geological framework*

The continental margin of Uruguay was formed during seafloor rifting, which included strong volcanic activity [6]. Two offshore basins were created during this process: Punta del Este and Pelotas (Fig. 1) [7], which both have a total extent, regarding the 200 nautical miles limit, of near 120.000 km$^2$, and a maximum volcano-sedimentary fill of 8.000 m based on seismic data [8].

These basins are genetically related to the Western Gondwana breakup (~130 Ma ago), and the subsequent development of the Atlantic Ocean and thus, are part of a important series of depocenters which include offshore hydrocarbon productive basins such as Santos and Campos basins (Brazil), and also the conjugate Orange Basin (South Africa and Namibia)[8].

Figure 1. Sedimentary basins of Uruguay

The Punta del Este Basin is a NW-SE trending aborted rift, perpendicular to the general trend of the continental margin [7]. In contrast, the NE-SW trending Pelotas Basin, belongs to the flexural border of a precursor rift structure, and continues in the Brazilian margin up to the Florianópolis Platform [8].

The Punta del Este and Pelotas basins are separated in shallow waters by the Polonio High. The distal part of both basins, where the Polonio High is not present and comprises a thick Cenozoic package, is called by some authors the Oriental del Plata Basin (Fig. 1) [9] [10].

### *Oceanographic framework*

Different water masses and currents coexisting in the area play a fundamental role in the occurrence of gas hydrates considering temperature, salinity and pressure conditions as well as sediment erosion and deposition.

Today, the continental margin of Uruguay is characterized by strong contour currents and the important input of huge amounts of sediments from the Río de la Plata [11].

The area comprises a very complex and dynamic oceanographyc regime. At surface level, dense and cold antarctic water masses from the Malvinas/Falkland Current flowing northward converge with the warm and saline Brazil Current flowing towards the South, resulting in the Brazil-Malvinas Confluence (BMC, Fig. 2) [12].

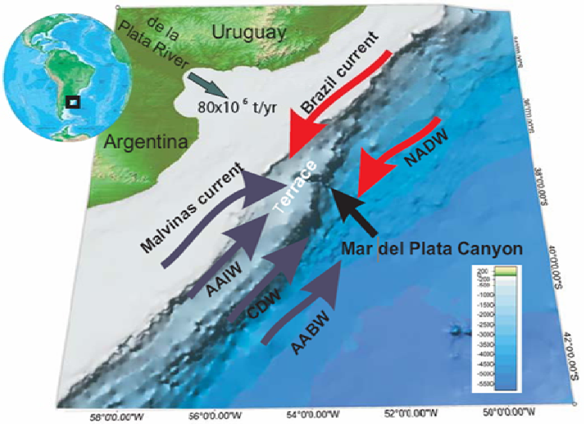

Figure 2. Oceanographic setting at the study area. AAIW: Antarctic Intermediate Water, AABW: Antarctic Bottom Water, NADW: North Atlantic Deep Water. Modified from Krastel et al (2011) [26].

However, the confluence is not confined to surficial currents and as well the interaction of intermediate water masses results in a complicated flow pattern. While Antarctic Intermediate Water (AAIW) and Circumpolar Deep Water (CDW) are flowing northward, the southward flowing Nor-Atlantic Deep Water (NADW) separates the CDW into Upper-CDW and Lower-CDW. The deep basins are under the influence of the Antarctic Bottom Water (AABW) [13].

Interaction between these currents strongly affects sedimentary processes as well as margin morphology. The existence of strong contour currents leads to the generation of a large Contouritic Depositional Complex, which at least extends from southern Argentine margin to the margin of Uruguay, including various kinds of erosive and depositional sedimentary features [14]. In addition, these along slope processes interact with down slope sedimentary gravitational processes, which as well have a large impact in the study area. In this way, mainly in the southern region (Punta del Este Basin), a series of submarine channels are developed.

The existence of these channels have a negative effect on BSR identification mainly because of the complex non-parallel sedimentary pattern.

### *Gas hydrate offshore Uruguay*

First work regarding gas hydrates offshore Uruguay was performed by De Santa Ana et al (2004) [15], where the presence of a BSR was recognized the first time. Gas hydrate distribution and thickness were afterwards estimated based on the available seismic grid allowing first approximations on resource potential. Initial determination of mineralized area was 5.000 km$^2$ resulting in 86 trillion cubic feet (TCF) of natural gas under normal conditions [15], based on seismic information available at that time in non-digital format.

In 2005, the presence of gas hydrates was reported by Neben et al from the German institute BGR after a 2D seismic survey in the area [16]. In this work, the BSR area was mapped from seismic sections acquired at that survey, resulting in a minimum of approximately 7.000 km$^2$.

Even if the BSR represents the most reliable indication of the existence of gas hydrates within the study area, high methane concentrations and AOM (Anaerobic Oxidation of Methane) within the upper few meters of the sediments indicates the existence of methane hydrate in the study area [17].

Hydrocarbon generation and migration offshore Uruguay has been confirmed through fluid inclusion analysis [18], which were recognized in syn-rift and post-rift sequences from two wells drilled in the area [19].

In 2008, oil seeps were identified by satellite images [20] [21] and post-stack processing for gas chimney identification [22] was performed on 2D seismic sections, which showed vertical disturbances of the seismic signal. These signal anomalies, reaching into larger depth, were interpreted as hydrocarbon migration pathways and suggest a thermogenic origin of the gases that reach gas hydrate reservoirs [23].

Nowadays ANCAP posses a digital database of 2D reflection seismic data, which were acquired during different surveys for hydrocarbon exploration offshore Uruguay between 1970 and 2008 and allow high resolution mapping of the BSR area.

Interpretation of the base of GHSZ from seismic data in the area, shows a widespread distribution of the occurrence of gas hydrate bearing sediments.

Continuous and segmented BSR were observed while so-called ’high relief’ BSRs were not identified (Fig. 3, Fig. 4).

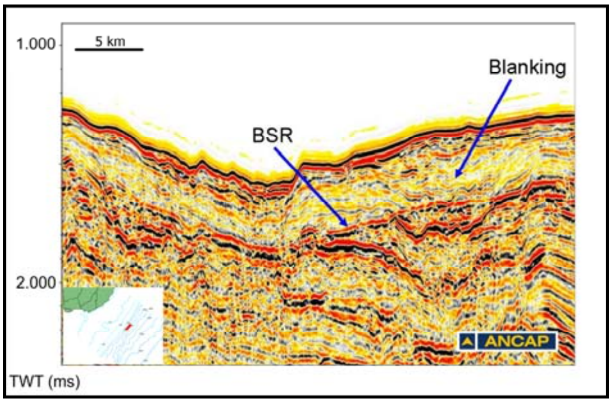

Figure 3. Section UR82_004 from Pelotas Basin. BSR present at 1982 survey showing blanking at the hydrate zone.

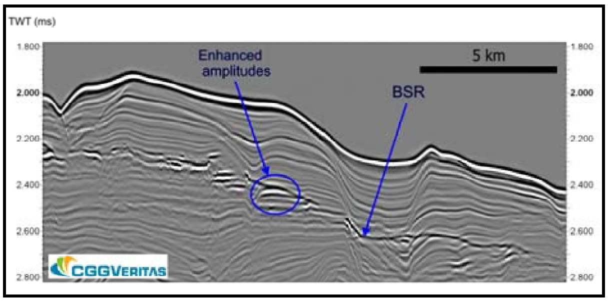

Figure 4. Seismic line from Punta del Este Basin showing a BSR at 0.330 sec TWT from the seafloor and enhanced amplitudes bellow the BGHSZ. Modified from [23]. Courtesy of CGG Veritas.

BSR extends over an area of approximately 25.000 km$^2$. It is present in water depths greater than 500 m and has high continuity in Pelotas Basin but is more discontinuous at Punta del Este Basin and southern part of Oriental del Plata Basin. The total area of the gas hydrate zone, including areas without clear BSR but within the stability zone, represents 32.500 km$^2$ and is shown in Fig. 5.

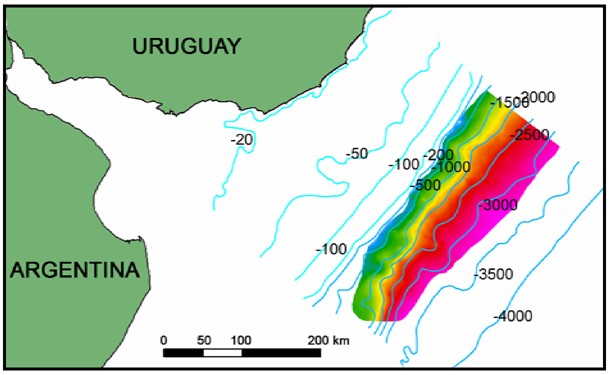

Figure 5. Total hydrate area considering the envelope of BSR interpretations.

Here, we present examples of the influence of the acquisition parameters on the acoustic expression of the BSR, comparing conventional seismic sections acquired for hydrocarbon exploration and high resolution seismic sections acquired during the R/V Meteor Cruise M49-2 in 2001 and R/V Meteor Cruise M78-3a (May - June 2009) using different seismic sources and streamer system.

## MATERIALS AND METHODS

During the R/V Meteor Cruise M49/2 (2001) and R/V Meteor Cruise M78/3 (2009) high resolution seismic was acquired using different high resolution multi-channel seismic streamer systems. While data recorded in 2001 was acquired using a 600 m streamer system with 6.25 m channel spacing, data acquired in 2009 was collected with a 200 m streamer with a hydrophone group interval of 1.56 m. In addition different seismic sources were used: a Mini-GI airgun with reduced chamber volume (0.25 L; 100–600 Hz) in 2009 and a GI airgun with normal chamber volume (1.7 L; 30–400 Hz) in 2001. Guns with larger chamber volume are of greater penetration into the sea floor, revealing the larger scale structural framework, whereas guns with smaller chamber volume are of higher resolution, revealing finer details of the upper 200-400 m of the sediment [24].

In 2007, the M/V Bergen Surveyor acquired 7.125 km of 2D seismic sections for hydrocarbon exploration offshore Uruguay. In this opportunity, data was acquired using a 8.000 m streamer system with 12.5 m group interval. A 72,1 L Bolt Long-Life Airgun (6 – 100 Hz) towed at 6 m water depth was used as source, the shot interval was 25 m or 37.5 m. Sample rate was 2ms [25].

## RESULTS

Figure 6 shows an arbitrary line trough seismic sections of the three mentioned surveys (M49-2, M78-3 and UR07) showing different acoustic expressions of BSR. While conventional low frequency seismic shows a strong continuous appearance of the BSR with the typical phase reversal, the high resolution data set shows a more complex acoustic expression of the BSR. The BSR is represented by several reflections, which are not continuous and vary strongly in amplitude.

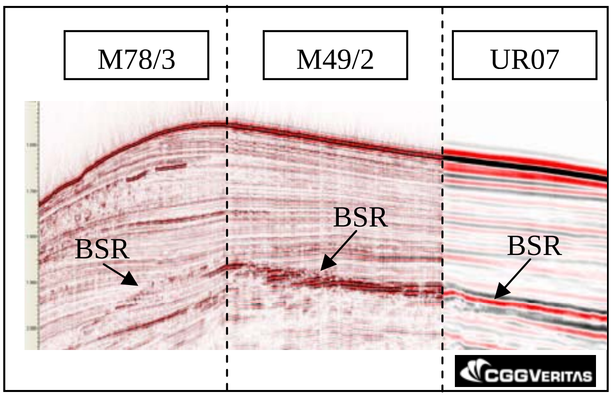

Figure 6. Arbitrary line trough three seismic sections showing different acoustic expressions of BSR. Location of line is shown on Fig. 7.

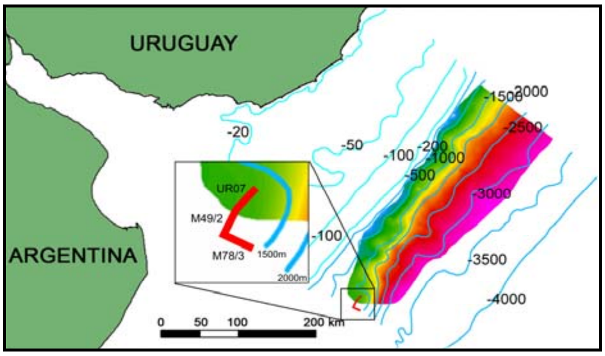

Figure 7. Location of studied arbitrary line.

Both low and high frequency seismic sections present bright spots (indicators of free gas accumulations). These bright spots are inferred to correlate with sand-rich units and the intervening sections being more clay-rich [5].

## DISCUSSION

In the high resolution seismic data, enhanced amplitudes and phase reversals are observed for several reflectors while deep penetration seismic shows only one single continuous reflector.

The reflection from the BSR, well defined in conventional low-frequency seismic is much more weaker at the high frequency data. As observed by Gettrust et al, the BSR reflection coefficient decrease with increasing frequency, such as to be only intermittently observed [27]. According to Vanneste et al [28], higher frequencies are preferentially attenuated. This effect gains substantially even more importance when the sediment is partially gas-saturated.

In high resolution seismic, the base of the GHSZ presents a discontinuous reflection pattern comparable to segmented BSR observed at some conventional seismic sections.

According to Chapman et al [29] the negative reflection coefficient at the BSR is the result of local decrease in seismic velocity and therefore, in acoustic impedance as well. Low frequency signals with a wavelength larger than the velocity gradient are not capable of resolving the continuous change in velocity. The fine structures of the BSR can neither horizontally nor vertically be resolved using low frequencies. Hence the BSR is imaged as one strong reflector with clearly reversed polarity. In contrast, high frequency signals are capable to resolve the velocity gradient resulting in multiple weaker reflections.

Therefore the base of the hydrate occurrence and the top of the free gas zone may not be at the same depth and can involve a transition zone with gradually changing properties [28], [29]. The thickness of this transition zone depends on the upward methane flux rate, ranging from tens to few meters [29] when the methane flux below the GHSZ exceeds a critical value.

## CONCLUSIONS

The presence of a distinct BSR in high resolution seismic sections gives strong evidence for the presence of gas hydrate in the area and support previous BSR interpretations made on deep penetration low resolution seismic sections. However, this comparison may help to visualize the complexity of the interference pattern resulting from free gas, gas hydrate and stratigraphic system behind the BSR, which is usually masked on low-frequency deep penetration seismic data.

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