The first 4C surveys acquired on the Eastern Brazilian Margin

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Abstract

In this paper, we discuss the first 4C surveys acquired on the Eastern Brazilian Margin. All aspects will be reviewed, from the feasibility study which first indicated the potential value of multicomponent technology in this region, to the objectives, through the illumination analysis used in the survey design process, to the seismic crew which acquired the data, and finally through the field operation itself. Acquisition will be completed in April, and data processing is expected to be finished by September. We plan to present and discuss the fully processed results when delivering this paper at the congress in September.

Introduction

In 2004/2005, PGS acquired a 4C Test Program for PETROBRAS over several important fields in the Campos and Santos Basins, offshore Brazil. These surveys utilized multicomponent technology to address specific geophysical problems in areas where conventional P-wave seismic solutions were considered insufficient. The 4C Test Program was composed of:

- 48 km of 2D in Violao (3 lines)
- 96 km of 2D in Cachalote / Jubarte (4 lines)
- 96 km of 2D in Albacora (5 lines)
- 45 receiver sq km of 3D in Roncador

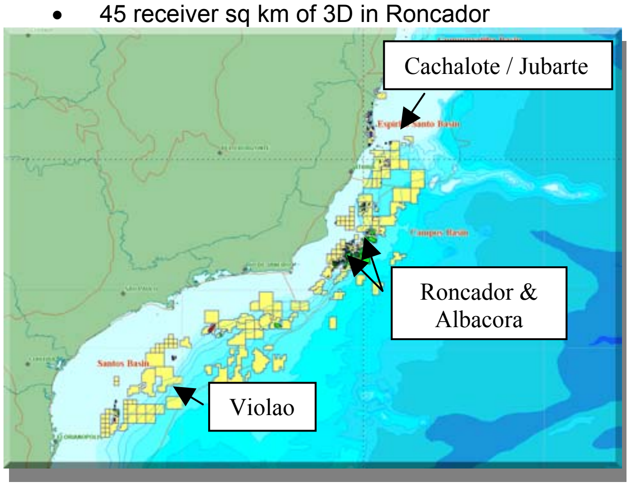

Figure 1 - Location of the 4 surveys.

Prior to this, there had been some limited 4C activity in Brazil. A small experimental multicomponent survey was acquired, and seafloor seismic surveys in Viola and Enchova recorded 4C data, but the latter two were essentially P-wave OBC infill surveys. This 4C Test Program was the first wide scale application of multicomponent technology to offshore Brazilian oilfields. It is also quite notable for another reason. Recording the Roncador 3D survey shattered the existing deep water record for seafloor seismic 3D work. Water depths reached 1860 m, triple those seen earlier during the Viola 3D. Prior 3D seafloor seismic activity in the North Sea has been limited to water depths less than 300 m. Surveys elsewhere have been even shallower. To be fair, it is true that some 2D surveys and small-scale tests have been performed using this and related seafloor seismic systems in water depths approaching those encountered in Roncador. However, to our knowledge there has been no sustained 3D operation using seafloor seismic equipment (cables or nodes) in water depths greater than those in Viola (620 m).

Objective

Survey objectives varied depending upon the particular area. In Violao, basalts produce false anomalies which are difficult to distinguish from hydrocarbons. 4C data may be critical in discerning the difference between the two situations. In Cachalote & Jubarte, shallow gas may be obscuring P-wave imaging. There are now many examples of successful imaging through shallow gas with mode-converted "C-waves", so this is a fairly routine application of multi-component data. In Albacora, there are semi-transparent P-wave reservoirs and false AVO anomalies, as well as complex dipping water-bottom multiples. Log analysis indicates these semi-transparent reservoirs may be visible on C-wave data. Also, the troublesome water bottom multiples which exist can be suppressed better on P-wave OBC data through powerful dual sensor summation techniques. In Roncador, there are transparent P-wave reservoirs which are difficult to map using conventional (stacked) data, AVO techniques based on P-wave data, or elastic inversion. As in neighboring Albacora, log analysis indicates these reservoirs may be visible using converted waves.

Acquisition Crew

The data was acquired by the FOURcE crew. This is a three boat operation, comprised of a source vessel--the Falcon Explorer, a recorder--the Ocean Explorer, and a cable-handling vessel--the Bergen Surveyor. The crew has a wealth of experience; for the past 3 years, it has worked continuously in the North Sea, the Gulf of Mexico, Asia, West Africa and Brazil. They can operate in water depths ranging from 7 to 2000 m. Presently, this is the only cabled seafloor seismic system proven to work in these deep waters. Furnished with 36 km of in-water equipment, it's an efficient operation. Excellent coupling and vector fidelity is achieved using a 4-C sensor which resulted from years of testing and evaluation, both in the laboratory and on the seafloor. During deployment, cables are "steered" with precision into pre-planned positions using a real-time acoustic navigation system. This ability to repeat receiver positions is an important consideration when time-lapse seismic is used to optimize reservoir management. Prior to commencing this project, the majority of the cables in the inventory, many of them 3 years old, were replaced with new ones. Also, a specially designed deep water cable-handling system was installed on the Bergen.

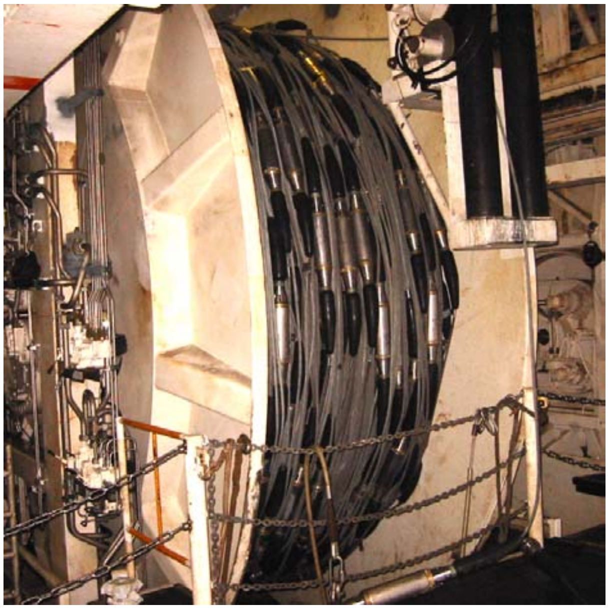

Figure 2 – A 6 km reel of FOURcE cable. The 4C modules are visible.

Survey Geometry

The key acquisition parameters were:

In the 2D areas

- 25 m group interval
- 6 km continuous maximum offset (split-spread)
- 31.25 m shotpoint interval
- 190 fold in 12.5 m bins
- 10s records

On the Roncador 3D

- 2-4 cable swath
- 300 m cable separation
- 25 m group interval
- 6 km continuous maximum offset
- Dual source (75 m port/stbd separation)
- 6 sail lines/swath
- 62.5 m shotpoint interval (31.25 m flip-flop)
- 190 fold in 12.5 x 37.5 m bins
- 10s records

This is a moderately wide-azimuth design. The source was a 3090 cu. in. tuned airgun array. Recording was done by the 24-bit Geophysical Acquisition System (gAS).

2D Survey Design

In the 2D areas, the survey design process to a large degree was reduced to determining the maximum offset and record length needed for good C-wave imaging at reservoir level. The shotpoint interval essentially became the distance the shooting vessel could transit at optimal speed while maintaining the chosen record length. To aid in locating the groups on the seabed, positioning lines were shot on both sides of the receiver lines at an offset approximately equal to the water depth. Since the water depth varied, these were not parallel lines. The first arrival data collected during these runs was used in an integrated solution which included USBL high frequency acoustic data from all 3 vessels, recorded by transponders spaced at 300 m increments along the cable.

3D Illumination Analysis & Survey Design

For the Roncador 3D, the survey design was chosen based upon an illumination analysis of a key reservoir sand. 3D velocity model and horizon data from previous seismic were input to a robust 3D ray-tracing package. It performed full offset shot domain ray-tracing using the wavefront construction method, in which the whole wavefield was propagated instead of individual rays. After testing numerous shooting schemes, we arrived at an operationally efficient design which illuminated the target reservoir sands with both P-waves and C-waves. It's worth noting that for seafloor seismic acquisition in deep water, the midpoint concept is not even valid for P-waves.

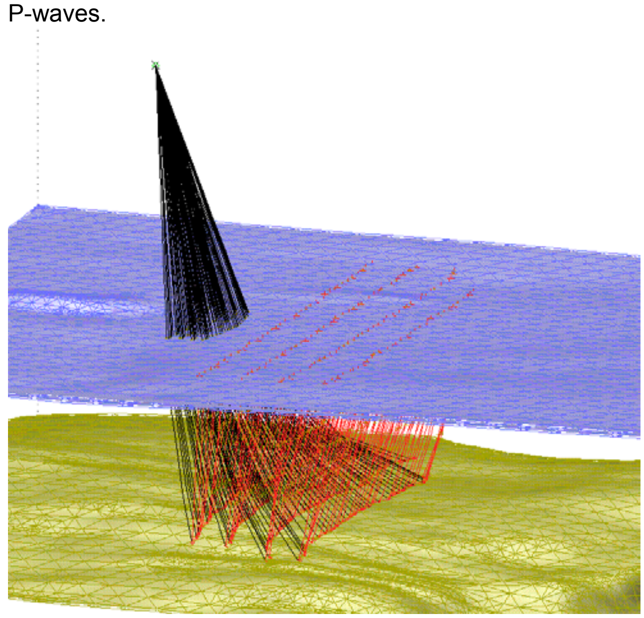

Figure 3 – Converted wave raypaths from a shot outside 4 receiver cables.

Feasibility Study

Long before the 4C Test Program was conceived, a 4C Feasibility Study was conducted for the Roncador and Albacora fields, among others. The goal was to determine if 4C data would help in the location of hydrocarbon-bearing sands. Well log data with dipole sonics together with P-wave streamer data showed that C-waves would be a better tool than P-wave AVO analysis in identifying Class II sands, and in detecting false AVO anomalies.

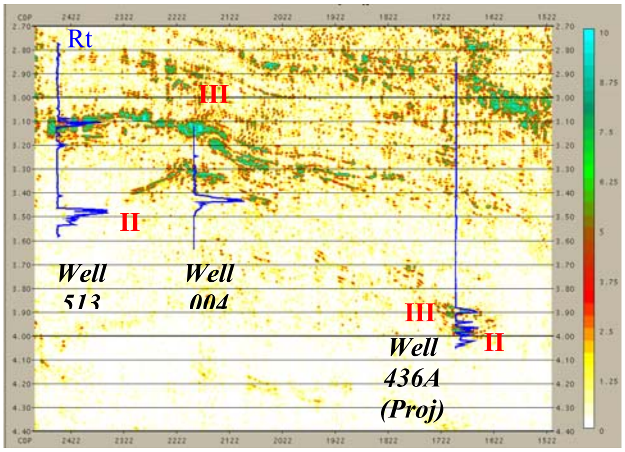

Figure 4 - Wells 513, 004 and 436A encountered Class II sands over 100 meters thick (as indicated by the lower portion of the overplotted resistivity logs).
By definition these sands were not visible on P-wave stack sections, and were weak on AVO analysis sections.

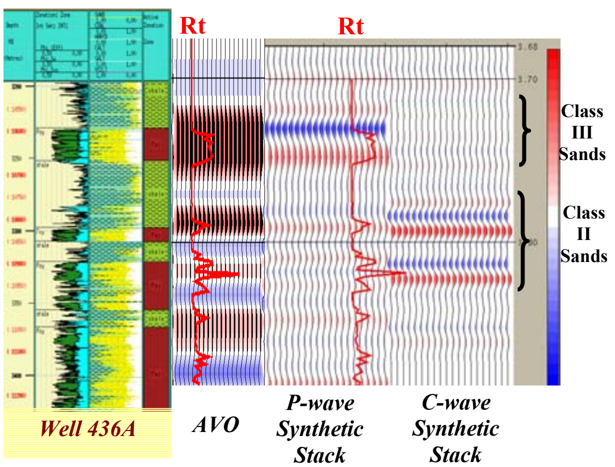

Figure 5 - For the Class III sands, a strong P-wave response and dim converted-wave response is evident.
For the Class II sands, a dim P-wave response and strong converted-wave response is evident.

Operations

In Violao, there were no surface or subsurface obstructions to consider. However, water depths varied from 200 to 1300 m. These rapid seafloor topography changes required modifying the cable deployment method to allow extra "slack", which ensured good coupling.

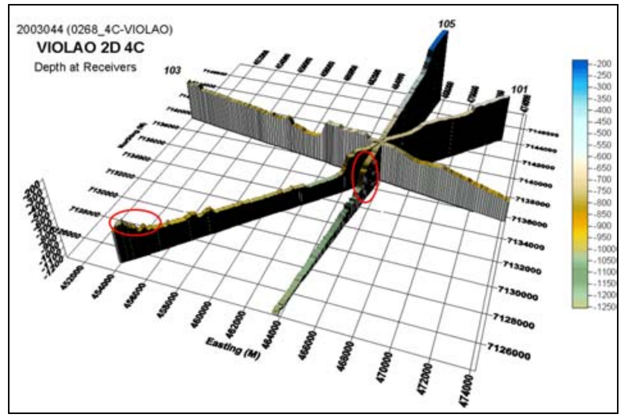

Figure 6 – The 3 lines acquired in Violao. Note the two areas with rapid seafloor topography changes, indicated by the red ellipses.

In Cachalote/Jubarte, water depths varied from 1200 to 1500 m. There was nothing of consequence to complicate acquisition other than some mild seismic interference and a few surface obstructions just outside the survey area. Albacora, on the other hand, was a different story. Water depths ranged from 250 to 1250 m. Some of the lines were obstructed by shuttle tanker operations around an FPSO, or by the anchor pattern extending from a rig. Pipelines crisscrossed the survey area, creating some mild noise. There was also seismic interference from a neighboring crew, as well as noise from nearby vessels, including tanker traffic. Regardless of all that, Albacora was still completed on schedule.
The Roncador 3D is currently being acquired. It is the first sustained deepwater operation ever undertaken with a seafloor seismic system in anything close to 1860 m water depths. There are many pipelines in the survey area, but they do not present a problem. The cables are simply draped over the pipelines. There are also two rigs in the survey area, and we are coordinating our close approaches with the rigs. When operating in these busy oilfields, careful planning and co-ordination is essential for safe, efficient operations. As might be expected, shooting has been occasionally interrupted by oilfield activity.

Conclusions

The acquisition of 4C 3D seafloor seismic with cabled systems is possible in water depths of 1860 m. As of this writing (end of March, 2005), the 2D areas have all been acquired. The Roncador 3D is 24% complete, and is expected to be finished in April. Data processing is currently in the very early stages. We plan to present fully processed results from all areas of the 4C Test Program at the congress in September.

Acknowledgements

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References

Sobreira, J.F.F. et al., 2005, A four component (4C) seismic experimental survey offshore Eastern Brazil, submitted to the 9th Int. SBGf Congress.