Ultra-deepwater 4C offshore Brazil

Bill Cafarelli, Santi Randazzo, and Steve Campbell, PGS, Jorge Fiori Fernandes Sobreira, Marcos A. Gallotti Guimaraes, Carlos Rodriguez, Paulo Johann and Carlos Theodoro, PETROBRAS S.A.*

Summary

This paper is the case history of an ultra-deepwater 4C seismic program, just acquired in the Campos and Santos Basins, offshore Brazil. All aspects of the program will be discussed, from the feasibility study which first indicated the potential value of multicomponent technology to this region, to the survey objectives, to the illumination analysis used in designing the survey, to the field operations. Acquisition completed April 19, 2005 and data processing is expected to be finished by September. We plan to present and discuss the fully processed results when delivering this paper.

Introduction

From December 2004 to April 2005, PGS acquired a 4C Test Program under PETROBRAS Research Project PRAVAP 19 (Seismic IOR Program) in 4 areas in the prolific Santos and Campos Basins, offshore Brazil. These surveys employed 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

See Figure 1 for the survey locations. This program was the first wide scale application of multicomponent technology to offshore Brazilian oilfields. It was also quite notable for another important reason. Recording the Roncador 3D survey shattered the existing deep water record for seafloor seismic 3D work. Water depths reached 1,860 m--triple those seen earlier during the Viola 3D in the Campos Basin, the deepest prior 3D (see the Roncador bathymetry in Figure 2). By comparison, seafloor seismic activity in the North Sea has been limited to water depths less than 400 m. Surveys elsewhere have usually been in water depths less than 150 m. To be fair, it is true that a handful of 2D surveys and a few 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 until now there has been no sustained 3D operation using seafloor seismic equipment (cables or nodes) in water depths greater than those in Viola (620 m). Looking ahead, we know that at least one other deepwater 4C 3D survey is planned to be acquired in the coming months.

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 whether 4C data would help in the location of hydrocarbon-bearing sands. Well log data with dipole sonics together with P-wave streamer data indicated that C-waves would provide a better tool than P-wave AVO analysis in identifying Class II sands, and in detecting false AVO anomalies. See Figures 3 & 4 from the Feasibility Study.

Objectives

Survey objectives varied depending upon the particular area. The Violao lead in the Santos Basin is an exploratory prospect in 750 m water depth. The targets are deep reservoirs (3,400 to 4,300 m) where oil and gas are expected. Several amplitude anomalies are associated with medium-sized structures. However, 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 addition, there is a seismically “blind” zone which may be related to gas and semi-transparent (P-wave) reservoirs, which PS data could help clarify.

Cachalote & Jubarte are oil and disseminated gas fields recently discovered in the northern Campos Basin. The water depth is about 1,350 m; reservoir rocks lie at a depth of 1,250 m below the seafloor. In these fields, shallow gas may be obscuring P-wave imaging at times. There is also a need to validate P-wave flat-spot anomalies, and to obtain a better image of the relatively transparent Oligocene reservoirs. S-wave sonic logs suggest a higher PS than PP impedance contrast for the top reservoir.

Albacora is a giant oil field located in the central Campos Basin in water depths of 300 to 1,000 m. There are multiple reservoirs at depths of 2,600 to 2,900 m. In Albacora there are semi-transparent P-wave reservoirs, false AVO anomalies, complex dipping water-bottom multiples, and image distortion due to gas. Log analysis indicates these semi-transparent reservoirs may be visible on PS data. Also, the troublesome water bottom multiples which exist can be suppressed better on P-wave OBC data through powerful dual sensor summation techniques.

Roncador is another giant oil (and secondarily gas) field in the Campos Basin in water depths ranging from 1,100 to 2,200 m. The targets are relatively deep sands (3,000 to 3,700 m). 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. The validation of several oil-water contacts is also sought.

Illumination Analysis

The survey design chosen for the Roncador 3D was based upon an illumination analysis of a key reservoir sand. A 3D velocity model with horizon data from previous seismic were input to a robust 3D ray-tracing package (see Figure 5). 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 evaluating 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.

Survey Geometry

The key acquisition parameters on the Roncador 3D were:
2 or 4 cable swath
300 m cable separation
25 m group interval
6 km continuous maximum offset
Dual source (75 m port/stbd separation)
10 or 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).

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 the 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.

In the 2D areas, the key acquisition parameters were:
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

Operations

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. Over the past 4 years, the crew has worked continuously in the North Sea, the Gulf of Mexico, the Middle East, Asia, West Africa and Brazil. They can operate in water depths ranging from 7 to 2,000 m. Presently, this is the only cabled seafloor seismic system proven to work in these water depths. Furnished with 36 km of in-water equipment, it's an efficient operation. Excellent coupling and vector fidelity is achieved using a 4C 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 deepwater cable-handling system was installed on the Bergen Surveyor.

In Violao, there were no surface or subsurface obstructions to consider. However, water depths varied from 200 to 1,300 m. These rapid seafloor topography changes required modifying the cable deployment method to allow extra "slack", which ensured good coupling. See figure 6.
In Cachalote/Jubarte, water depths varied from 1,200 to 1,500 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 1,250 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. Besides creating some mild noise due to flowing liquids, they can locally affect sensor coupling. 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.

Acquisition of the Roncador 3D just finished. It was the first sustained deepwater operation ever undertaken with a seafloor seismic system in anything approaching 1,860 m water depths. Although there were many pipelines in the survey area, they did not present a problem because the cables were simply draped over them. There were two to three rigs operating in the survey area, and we coordinated 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 was occasionally interrupted by oilfield activity.

Conclusions

The acquisition of 4C 3D seafloor seismic with cabled systems is possible in water depths of 1,860 m. Deepwater oil and gas fields throughout the world can now share in the benefits of multicomponent technology. Data acquisition was completed on April 19, 2005. Data processing is currently in the very early stages, but expected to be finished by September. We plan to present and discuss the fully processed results when delivering this paper.

References

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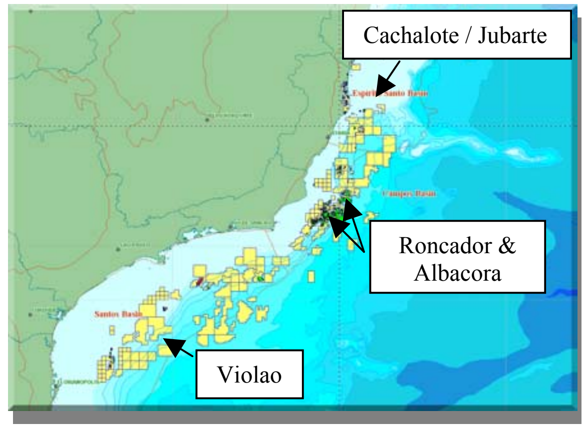

Figure 1 - Location of the 4 surveys.

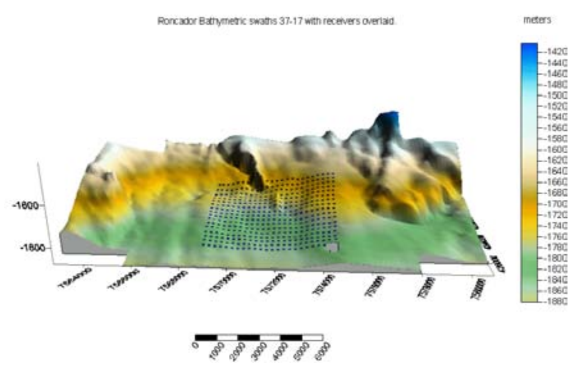

Figure 2 – Bathymetry for a large portion of the Roncador 4C 3D survey. Note the green area where water depths exceed 1,800 m.

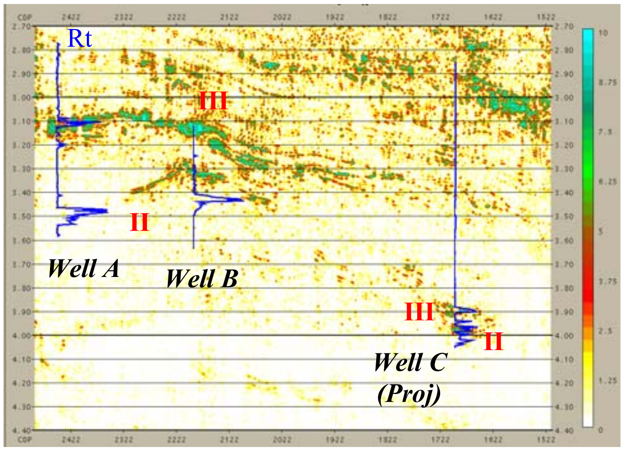

Figure 3 - Wells A, B and C in Roncador encountered Class II sands over 100 meters thick (as indicated by the lower portion of the overplotted resistivity logs). By definition these sands were not visible on P-wave stack sections, and were weak on AVO analysis sections.

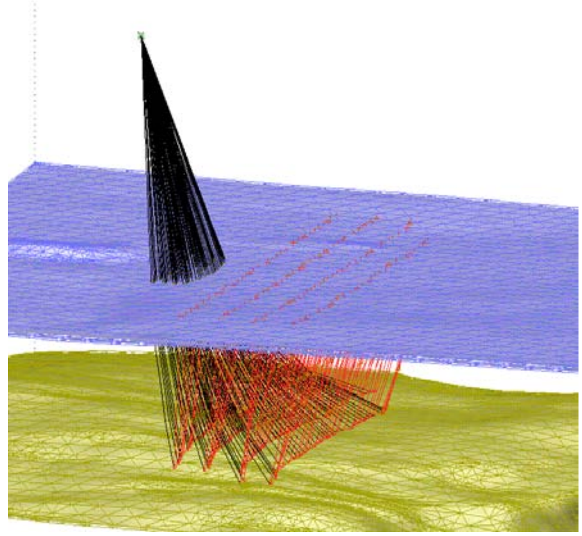

Figure 5 – Raypaths from one shot traveling through the velocity model, mode-converting at a reservoir horizon, and emerging to be detected by 4 cables on the seafloor.

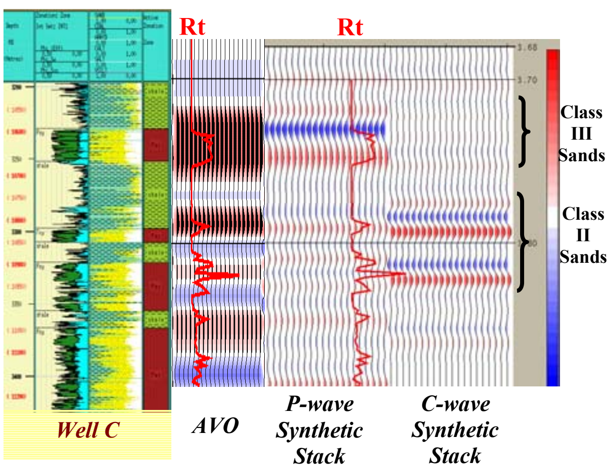

Figure 4 - For the Class III sands, a strong P-wave response and dim converted-wave response is evident.
For the Class II sands, a dim P-wave response and strong converted-wave response is evident.

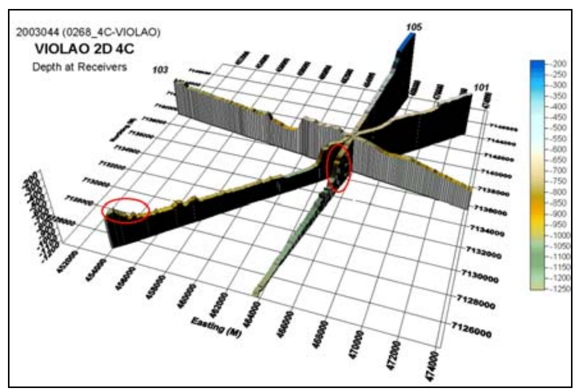

Figure 6 – The 3 lines acquired in Violao. Note the two areas with rapid seafloor topography changes, indicated by the red ellipses.