# Experimental 4C seismic survey offshore Eastern Brazil

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## Abstract

This paper aims to present and discuss geophysical targets, survey planning and acquisition issues for a 4C experimental seismic survey designed for technology evaluation offshore Eastern Brazilian Margin, on Campos and Santos Basins, two of the most prolific oil basins in Brazil. The 4C job, which included both 2D and 3D surveys, was conducted from December 2004 to April 2005. The water depths encountered ranged from 300 m to 1,850 m over the Brazilian Continental Margin, establishing the world's deepest 3D-4C survey ever acquired. The areas selected for this campaign were chosen based on technical criteria that took into account the potential of the 4C Seismic Technology to deal with specific exploratory and reservoir characterization problems, thus enabling a technology's proof of concept, while providing further useful geophysical information from both PP and PS-wave modes. Processing workflow and preliminary results shall also be briefly discussed herein.

## Introduction

Offshore ocean bottom seismic technology for geophysical applications arose decades ago, but has only been widely used during the last two decades with the introduction of two component (2C) seismic recording in the late 80's, and four component (4C) seismic recording in the last few years. While ocean bottom seismic data has been acquired throughout the world, some regions like the North Sea and the Gulf of Mexico have been home to most of the surveys so far recorded. Ocean bottom cables (OBC) or point units (named "nodes") might be employed as receiver systems in such a seismic survey modality.

4C Technology has been used worldwide with both geophysical and operational motivations, here included acquiring seismic data in congested (obstructed with installations) areas, otherwise hardly covered with "conventional" surface (streamer) surveys. In such situation, the acquisition cost may be similar between OBC and streamer surveys.

Although 4C Seismic Technology is useful in dealing with a range of different geological and geophysical problems, cost issues of acquiring 4C data still impose a drawback for full acceptance of the Technology, thus requiring a previous careful technical (and economical) analysis.

In Brazil, PETROBRAS decided to acquire the first "large-scale" 4C campaign during the period from December 2004 to April 2005. It covered four different areas spread over Campos and Santos Basins, including production fields (Roncador and Albacora fields, Campos Basin), an appraisal area (Cachalote-Jubarte fields, on northern Campos Basin) and an exploratory prospect (named Violão lead) on Santos Basin. Every one of these four areas along with their respective geophysical motivations for acquiring multi-component seismic data and acquisition/ design issues shall be presented and discussed hereafter.

## Method

Several factors have been considered for the choice of the selected areas for the 4C seismic experimental survey, which are:

a) operational characteristics, mainly the water depth (since there are known limits for the present-day OBC operation);

b) geophysical characteristics of the targets and the potential of multi-component seismic technology applications to properly deal with the related problems;

c) availability of dipole, P and S-velocity, sonic logs and/or multi-component VSP data, since these provide means to previously evaluate the response expected for 4C seismic (PP and PS) data, besides providing an initial, reliable correlation, between PP and PS volumes;

d) proximity with Campos Basin, where most of the Brazilian hydrocarbon production and reserves lie, thus adding some extra value to the results.

**Geophysical motivations and acquisition parameters**

PGS acquired the experimental 4C seismic survey with its system, which included multiple ocean bottom cables and a three vessels seismic crew, in the areas listed below.

***Cachalote/ Jubarte fields***

Cachalote and Jubarte are oil (and disseminated gas) fields recently discovered in northern Campos Basin. In the proposed area, the water depth is about 1,350 m, and the reservoir rocks, from Oligocene age, lie at a depth of circa 2,150 m (in fact, reservoir rocks may be as old as Upper Cretaceous age).

Four 2D-4C seismic lines (two southward Cachalote and two southward Jubarte) were acquired for several purposes, including the need for imaging through features whose P-wave image is obscured, validating P-wave flat spot anomalies (figure 1) and obtaining a better image for the P-wave relatively transparent Oligocene reservoirs, all with the help of the converted, PS-wave. S-wave sonic logs suggest a higher PS than PP impedance contrast for the top reservoir. Some of the acquisition parameters are: 25 m group interval, 31.25 m shot interval, 6,000 m (6,000 X 6,000 m slit-spread) maximum offset, 2 ms sampling interval and 10 s record length.

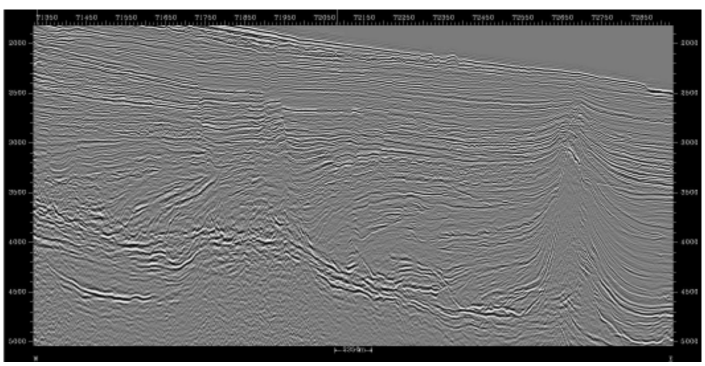

Figure 1 – Hydrophone P-wave section (from 2 to 5 s two-way time) on the Jubarte field area, showing flat-spot and obscured image features; left is west and right is east, and seismic section is about 30 km long

***Violão exploratory lead***

"Violão" is an exploratory lead located in the BM-S-3 block, Santos Basin, at 750 m water depth. The targets are deep (3,400 to 4,300 m depth) Campanian and Santonian reservoirs. Oil and gas are expected. Several seismic amplitude anomalies are associated with medium-size structures (figure 2), which make the prospect especially attractive. These amplitude anomalies (some of which exhibit corresponding AVO anomalies) need however to be validated, to avoid false indications from lithological effects, such as possible igneous rocks occurring in between the targets. There is also a seismically "blind zone" which might be related to gas and semitransparent (P-wave) reservoirs, which PS data could help clarify.

Three 2D-4C seismic lines were acquired, intersecting over one exploratory well. Some of the acquisition parameters are: 25 m group interval, 31.25 m shot interval, 6,000 m (6,000 X 6,000 m split-spread) maximum offset, 2 ms sampling interval and 10 s record length.

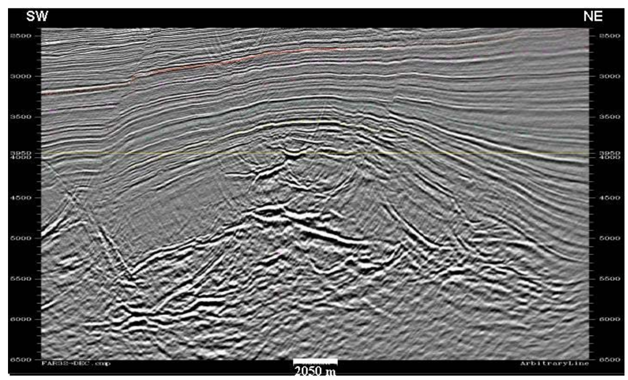


Figure 2 – Hydrophone P-wave section on the Violão exploratory lead area, showing bright-spots and features interpreted as igneous rocks; vertical scale is from 2.5 to 6.5 s two-way transit time; left is southwest and right is northeast; and section length is about 25 km

***Albacora field***

Albacora is a giant oil field, located in central Campos Basin, in water depths ranging from 300 m to 1,000 m. There are multiple reservoirs, named Namorado (the oldest, from Albian), Enchova (from Eocene, about 2,900 m depth), Caratinga (from Eo-Oligocene), Marlim (from Oligocene, about 2,600 m depth) and Albacora (the youngest, from Miocene). Typical problems of the field area that are thought to be potentially handled with multi-component seismic data include the need for validating amplitude anomalies (some of which have resulted in dry wells), image distortion due to likely gas occurrence, low P-wave impedance contrast (Enchova reservoir) and interference with sea-bottom dipping multiple reflections, whose complete removal is hard to be achieved (figure 3). It's thought that PS-wave data can provide an independent and different image from P-wave, which can enable the interpreter to get rid of most of the above problems. Besides, dual sensor summation (from hydrophone and vertical geophone) can provide superior P-wave data than hydrophone, and potentially help solving the multiple reflections problem. Furthermore, seismic resolution needs to be improved in order to characterize pinch-outs and thin reservoirs. In this area, both bottom and surface obstructions are a common obstacle for seismic acquisition.

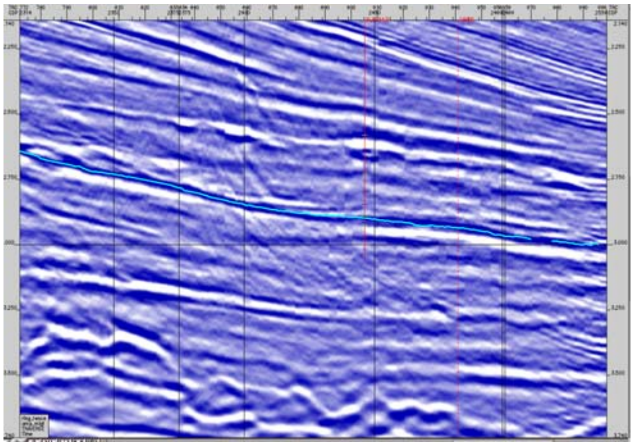

Figure 3 – Hydrophone P-wave section (2.1 to 3.7 s two-way transit time) on the Albacora field area, showing interference of dipping multiple reflections within its central portion; section length is about 5,6 km long; left is southwest and right is northeast

Four 2D-4C seismic lines were designed, intersecting some of the key wells where the above features are observable and where dipole sonic logs are available, covering part of the field and its vicinity, totaling circa 59 km length. A fifth seismic line was proposed with a specific purpose of testing the extraction of geotechnical attributes in the very shallow section (sub-sea bottom), where superior seismic resolution is expected for both PP and PS data, and calibrating them with the direct information derived from some geotechnical holes intersected by the same line. Some of the acquisition parameters are: 25 m group interval, 31.25 m shot interval, 6,000 m (6,000 X 6,000 m split-spread) maximum offset, 2 ms sampling interval and 10 s record length.

***Roncador field***

Roncador is a giant oil field located in Campos Basin, in water depths ranging from 1,100 m to 2,200 m. The targets are 3,000 m to 3,700 m deep maestrichtian sands. Main geophysical problem motivating a 4C seismic acquisition relates to the low P-wave seismic impedance contrast associated with some reservoirs. These, however, show good PS-wave seismic response, as elastically modeled from P and S-wave sonic logs available from some wells (figure 4). Further motivation includes validation of some oil-water contacts suggested on conventional seismic data. Also, a comparison between OBC and streamer imaging is pursued.

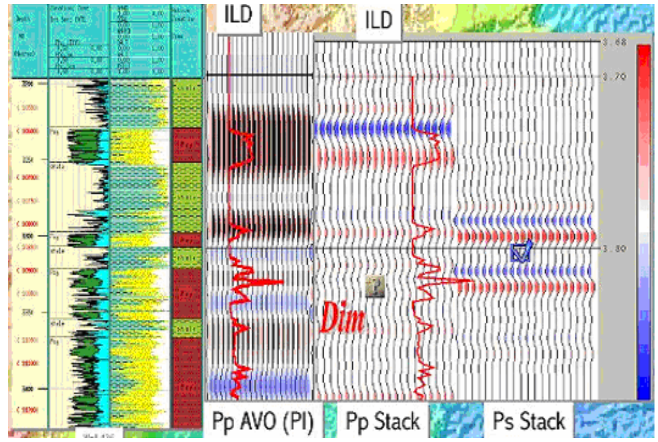


Figure 4 – Synthetic seismic response for PP and PS-wave modes derived from dipole sonic logs from Roncador field. Please note that, while some sandy bodies do exhibit amplitude anomalies on PP-wave alone, others only exhibit amplitude anomalies on PS-wave mode

A 21 sq. km (full fold) 3D area, in water depths ranging from 1,650 m to 1,850 m was chosen, covering part of the field, thus leading to the deepest 3D-4C survey ever shot in the world. That full-fold area corresponds to a 45 sq. km total receiver area (figure 5). The survey design was chosen based upon a P and PS-wave illumination analysis of a key reservoir. Two ocean bottom cables, 6 km long and 300 m apart, were used per unit template. The group interval was 25 m, sampling interval 2 ms and record length 10 s. Shot and receiver lines were parallel in the N-S direction (figure 5) in this inline swath geometry which produced moderately wide azimuths. A 62.5 X 75 m source grid was acquired with a dual-source flip-flop, with two shot lines for each sail line. The maximum continuous offset was 6,000 m, although longer offsets were actually recorded. Obstructions, especially bottom pipelines, are present in the proposed area.

**Processing flow and preliminary results**

A seismic processing workflow was defined separately for PP and PS-data. However, a common pre-processing phase will include data resampling to 4 ms, instrument phase response shaping and system and source time delays removal, besides several intermediate steps, for QC purposes, both in this pre-processing and in the main processing phases.

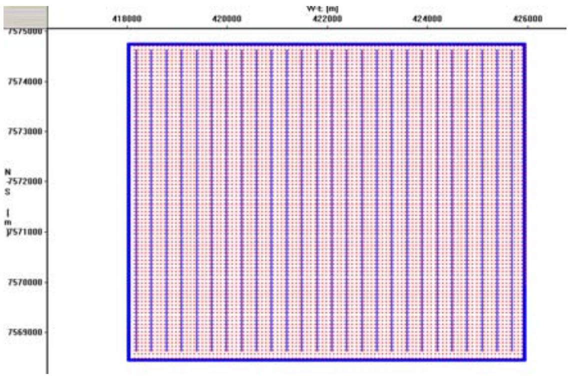


Figure 5 – Shot grid (red) and receiver lines (blue) planned for the Roncador 3D-4C OBC survey. The dark blue rectangle represents the receiver area limit

PP-wave data flow will include dual sensor scaling and summation (hydrophone and vertical geophone) after initial pre-processing, computing and applying residual statics and pre-stack Kirchhoff time migration (from actual shot and receiver elevations to a final datum).

PS-wave data flow (inline and crossline horizontal components) will include receiver re-orientation using direct arrivals, rotation from inline/ crossline to radial/ transverse components, computing and applying shear wave receiver statics, rotation to PS1 (fast) and PS2 (slow) components (if required) and converted-wave prestack Kirchhoff time migration

Preliminary processing work (P-wave data) shows promising results. Dual sensor summed data from Violão exploratory lead area produced a cleaner and more "reliable" seismic section (figure 6). Good frequency content and energy penetration are observable. Note that the "hydrophone minus vertical geophone data" section (shown for QC purposes) enhances the sea-bottom multiple reflections, whose attenuation is not always fully feasible by current methods.

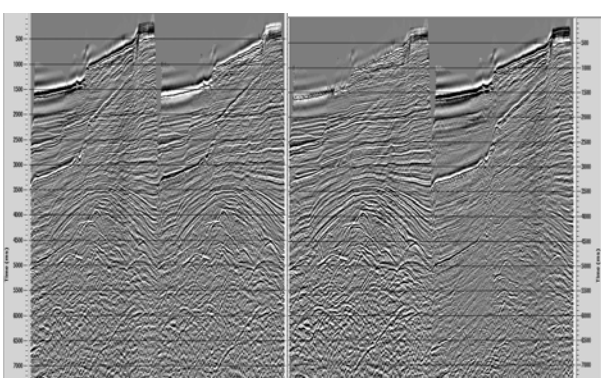

Figure 6 – Preliminary seismic OBC sections on Violão area, from left to right: hydrophone data, vertical geophone data, hydrophone plus vertical geophone data; hydrophone minus vertical geophone data; each panel is about 25 km long and vertical scale is from 0 to 7 s two-way transit time; left is south and right is north

**Conclusions**

Four different areas were defined for a 4C experimental survey offshore Eastern Brazil, taking into account technical, operational and economical aspects. The technical aspects focused mainly on geophysical problems that would be potentially solved by converted, PS-wave data.

A common geophysical problem in these areas, to variable degree, is the occurrence of P-wave transparent reservoirs. However, several other motivations, including multiple reflections, validation of amplitude anomalies and imaging issues are also being addressed.

Preliminary seismic processing work for P-wave data shows promising results. Dual sensor summation seismic data reveal a "cleaner", higher signal to noise ratio image, than currently available data. On the other hand, converted-wave data are also expected to provide superior quality images in the areas and intervals affected by the above problems, given the nature of these.

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