Reservoir characterization using high frequency seismic data in Roncador, Campos Basin

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Summary

Based on a detailed mapping of surfaces and faults (accomplished with high resolution seismic) and the use of seismic attributes, geological models are constantly updated, to better estimate reservoirs spatial distribution and their petrophysical properties at Roncador (Campos Basin). Such models are used in fluid flow simulations. The results present significant improvements on detailing the characteristics and properties of reservoirs compared to conventional seismic data. Also, a brief discussion about resolution and detection is included.

Introduction

Discovered in 1996 by well RJS-436A, Roncador field is located 130-km offshore Rio de Janeiro, Campos Basin, at 1500-1900m water depths (Figure 01). The current oil production is around 95.000 b/d.

The main accumulation is of Maastrichtian age, with OIP and recoverable volumes of 7.8 billion and 3.1 billion boe (barrels of oil equivalent), respectively. Roncador is characterized by the presence of compartments with different OWC and GOC and oils of API varying from 18 to 31. The geological modeling results suggest a dominant depositional control for petrophysical properties and a tectonic control for the compartments, through several mechanisms.

Geological aspects

The field possesses thick arcosian turbidite sandstones reservoirs divided in three cronostratigraphic intervals: RO200, RO300 and RO400. Those sandstones, which present very good porosity (27-30%) and permeability (200-4.000 mD), are separate in layers by shales of great lateral continuity and a complex fault system. The main structural elements include sub-vertical normal and listric faults, decoupling and folds associated to halocyneses (Barroso *et al.*, 2000).

The combination of structural (among them a 15-km long NW-SE sub-vertical normal fault with throw from 40 to 200m) and stratigraphical elements resulted on a compartmentation in four main blocks. From pressure data and characteristics of the fluids present in each block, it can be conclude that they are hydraulic isolated.

Module 1A, in the hanging wall, is located at northern and eastern portions of the field, being characterized by the occurrence of 27^0-31^0 API oil. The other portion of the field, in the footwall, includes Modules 2 and 4 with 18^0 oil, and Module 3 (22^0 API) (Figure 02).

Seismic considerations

Roncador area is covered by two 3Ds, one acquired in 1992 and the other in 1999. Those data were acquired in the E-W direction and PSTM Kirchhoff processed through an algorithm developed and applied in PETROBRAS (Rosa *et al.*, 1999).

Now (April/2005), it is being accomplished by PGS a new acquisition of high resolution 3D. Parameters as shot point and receiver interval, cell size, line distance and coverage, among others, are much more appropriate to reservoir characterization. It is expected from this data both seismic resolution and geological models improvement. This data will also serve as base for comparison with future 3Ds (4D seismic).

The main reservoirs tops are in general seismically characterized by an acoustic impedance decrease. The base (when not associated to a strong acoustic impedance increase) is defined mainly by an erosive surface, which is more visible when the reservoir top is flattened (Rodriguez *et al*, 2003).

Detection *vs* resolution on seismic data

Despite the frequent use of the seismic method in exploration and reservoir characterization, it possesses some limitations, as the vertical resolution (mainly in situations of thin reservoirs).

It is common there are some confusion between the concepts of detection and vertical resolution. ***Vertical Resolution*** is the capacity to identify in a section individual seismic reflections of top and base of a layer, or, in other words, the necessary minimum separation between two interfaces so that their individual characteristics are not lost during an observation. This is probably one of the largest limitations of seismic data, especially for reservoirs studies. This happens because layers thickness are usually smaller than $\lambda/4$ (λ the wavelength) causing an envelop of successive reflections, usually of difficult individualization. A unique relationship does not exist to determine the resolution limit, nor the existent equations are rigid. This limit depends on the quality of the data, reflections intensity and interpreter's structural and stratigraphical knowledge (Rodriguez, 1995). In his classic article, Widess (1973) observed that theoretically for a layer to be detectable, its thickness should be at least $\lambda/8$. However, in real situations, the author considered that this thickness had to be twice this value, with the limit of seismic vertical resolution close to $\lambda/4$. Such difference was attributed by Widess mainly due to the presence of noise.

Detection is the capacity to discern a thin layer, independently of identifying top and base reflections. Kallweit and Wood (1982) affirm that detection is simply the registration of a pulse with enough signal to noise ratio, and that it could go down as much as 1/30 of the dominant wavelength. This means some reservoir aspects can be distinguished even when they are far below the resolution limit. An example of this difference is a pinch, when reflections from both top and base affect the signal, despite they are not individualized. In this way, a detectable geologic event can be below the resolution limit.

With the objective of improving the vertical resolution of the available seismic data, two methodologies to recovery high frequencies content were applied. One was HFI® (High Frequency Imaging), a *Geotrace Technologies Inc. Company* algorithm and the other a Petrobras technique. These processing had good results, providing a significant improvement in the mapping of horizons and structural features, allowing subzones distinction (thinner reservoirs, not previously mapped in seismic) (Figure 03). Even in the cases where the impedance contrasts are less pronounced (footwall), gains were observed in reservoir delimitation. In addition, seismic attributes associated to 'old' horizons became more reliable and attributes from 'new' events became available, generating a larger application in petrophysical properties determination.

However, some undesirable effects that the applications of these techniques produced on the data have to be mentioned. In some cases, it was identified the decrease of lateral continuity. In areas with pronounced impedance contrast, the presence of artifacts was observed – namely, a duplication of events. That makes us to conclude that such processing should be used with care, and the original data must always be used.

Engineering aspects of Roncador

The footwall is characterized by the presence of oils varying among 18^0 API, in Modules 2 and 4, and 22^0 API, in module 3 (Figure 2). Also, a great variation on CO_2 content: occurs: 0,8% in Module 2, around 2,5% in module 4 and 4% in Module 3. Based on the observed OWC variations in oil characteristics, a seal behavior is attributed to the N-S fault that separates Modules 2 and 4 from Module 3. For the same reasons and based on fluid data and well information, Modules 2 and 4 were considered as constituted by five hydraulic isolated blocks.

In Module 3, well F confirmed the seal character of the fault that separates wells F and G blocks and occurrence of partial communication among the blocks at well F and well H (Figure 04).

Pressure data registered in wells E (Module 2), F and G (Module 3) indicated tiny communication between modules (depletion less than 4 kgf/cm^2) and confirmed hydraulic isolation between Module 1A and Module 3.

Other important aspect revealed by pressure data in well E and others wells drilled in Module 2, is the absence of vertical communication between top (RO330a) and bottom (that now includes RO330b and RO330c) zones.

With this information, a single fluid-flow model was built for Modules 2, 3, and 4. In this model, besides the main fault that separate the modules, some small vertical throw normal faults were included. Transmissibility values for these small faults will be obtained by material balance (calculated from production data) from wells E and F, in addition to RFT data (Figure 05).

Petrophysical Parameters and Seismic Attributes

In Roncador footwall the main reservoir is the sandstone RO330, subdivided for geological modeling in two intervals, base upon an unconformity: RO330s (interval above) and RO330i (below it). These two intervals are different in several characteristics. RO330s has an average NTG ratio of 80%; average VSH of 21%, porosity of 24% and horizontal permeability 265 mD. The interval RO330i shows NTG of 91%; average VSH of 9%, average porosity of 23% and horizontal permeability 828 mD.

After the seismic interpretation, several attributes for both RO330 intervals were obtained. Correlation coefficients among petrophysical parameters and the available seismic attributes were obtained and analyzed, with the most significant attributes being selected. In this way, for RO330s the following attributes were used: *integrated seismic amplitude* to map VSH (correlation coefficient of 73%), *volume reflection spectrum* (VRS, which are polynomial decomposition terms) for NTG (r=70%), *minimum amplitude* for PHIE (porosity effective) in porous part (r=69%), and *amplitude difference* for KINT (arithmetic average of estimated permeability) in porous part (r=80%). In RO330i interval the following attributes were used: VRS for VSH (r=99%) and NTG (r=90%); *maximum amplitude* for PHIE in porous part (r=91%); and VRS for KINT in porous part (r=91%). Although good to excellent correlation coefficients are obtained, an always-present issue is the reduced number of wells (less than 15).

The geological models are constantly adjusted to new seismic interpretations and well information. In this way, the use of seismic attributes on petrophysical properties determination (mainly with the use high frequency data), became more important and allows a more robust and trustful modeling (Figure 06).

Conclusions

High frequency seismic data have being regularly used in reservoir characterization, given significant earnings in geological modeling, petrophysical properties spatial distribution, and fluid-flow simulation models. However, one should always question the reliability of those processing, through studies and comparisons with original data and well information.

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Figure 01: Location map of Roncador Field (Campos Basin).

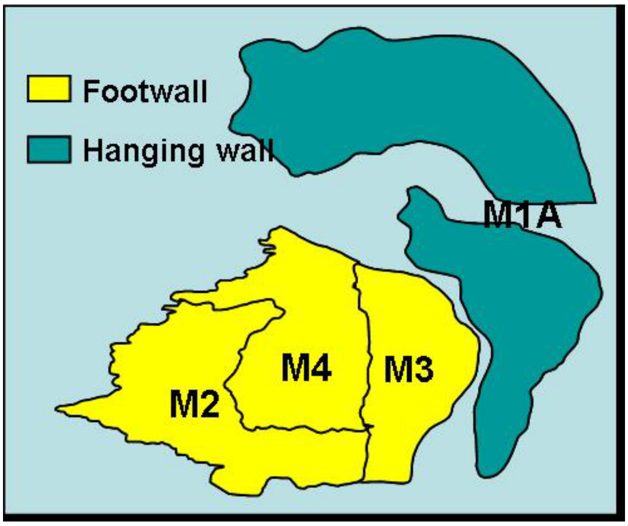

Figure 02: Roncador field and its modules division.

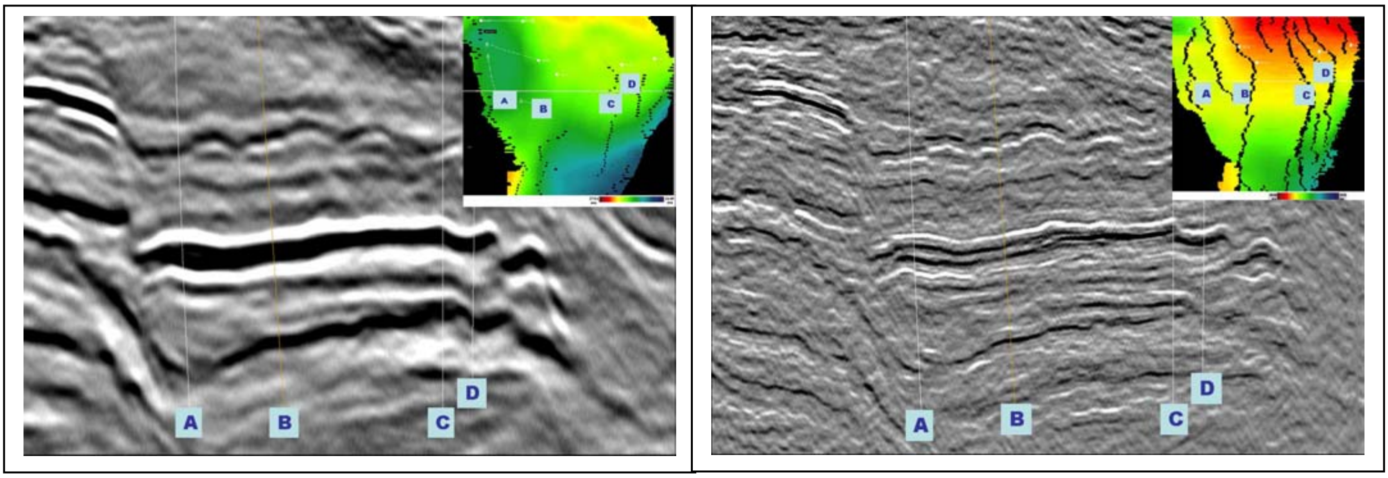

Figure 03: Seismic sections before (left) and after (right) application of an intern Petrobras technique for high frequencies recovery. Observe several surfaces and structures that can be mapped only in the high-frequency data.

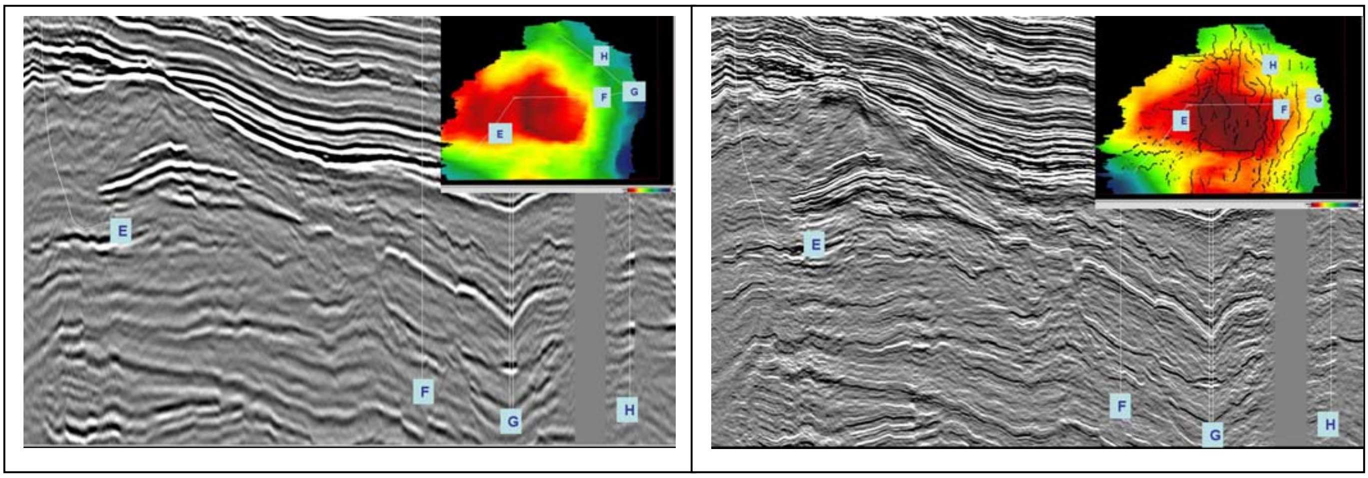

Figure 04: Seismic sections showing Modules 2, 3, and 4. On left, conventional seismic and at right, seismic with high frequencies, where a better structural compartimentation is observed.

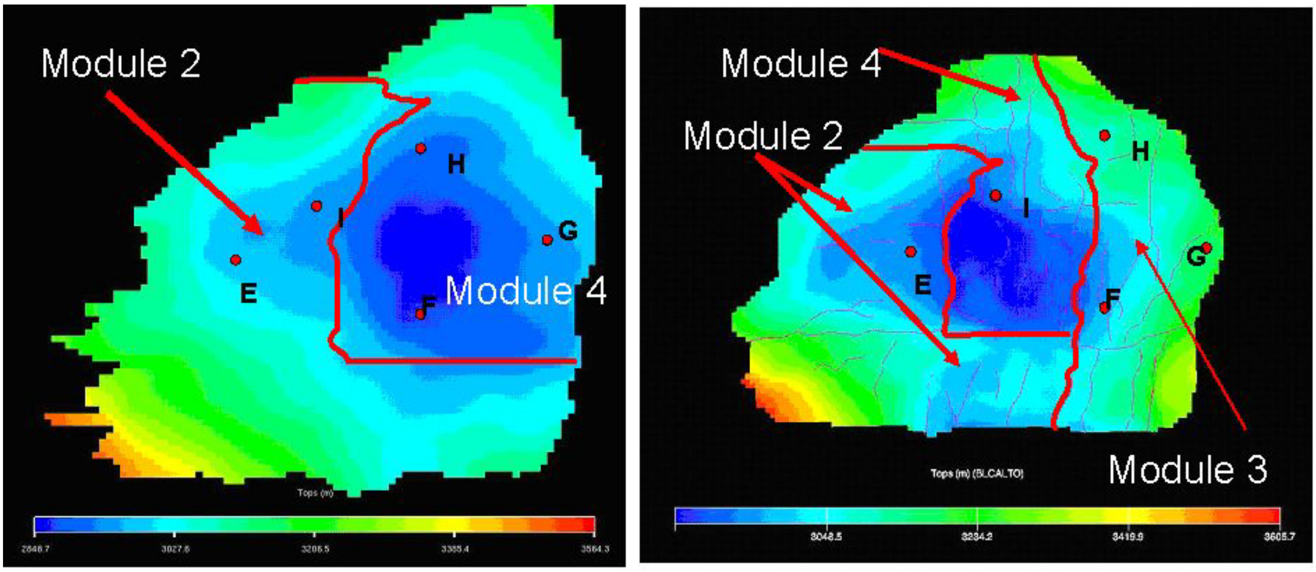

Figure 05: Models of fluid-flow simulations. On left, previous model with only two compartments (modules 2 and 4). At right, more detailed model (modules 2, 3, and 4) based on high-resolution seismic mapping.

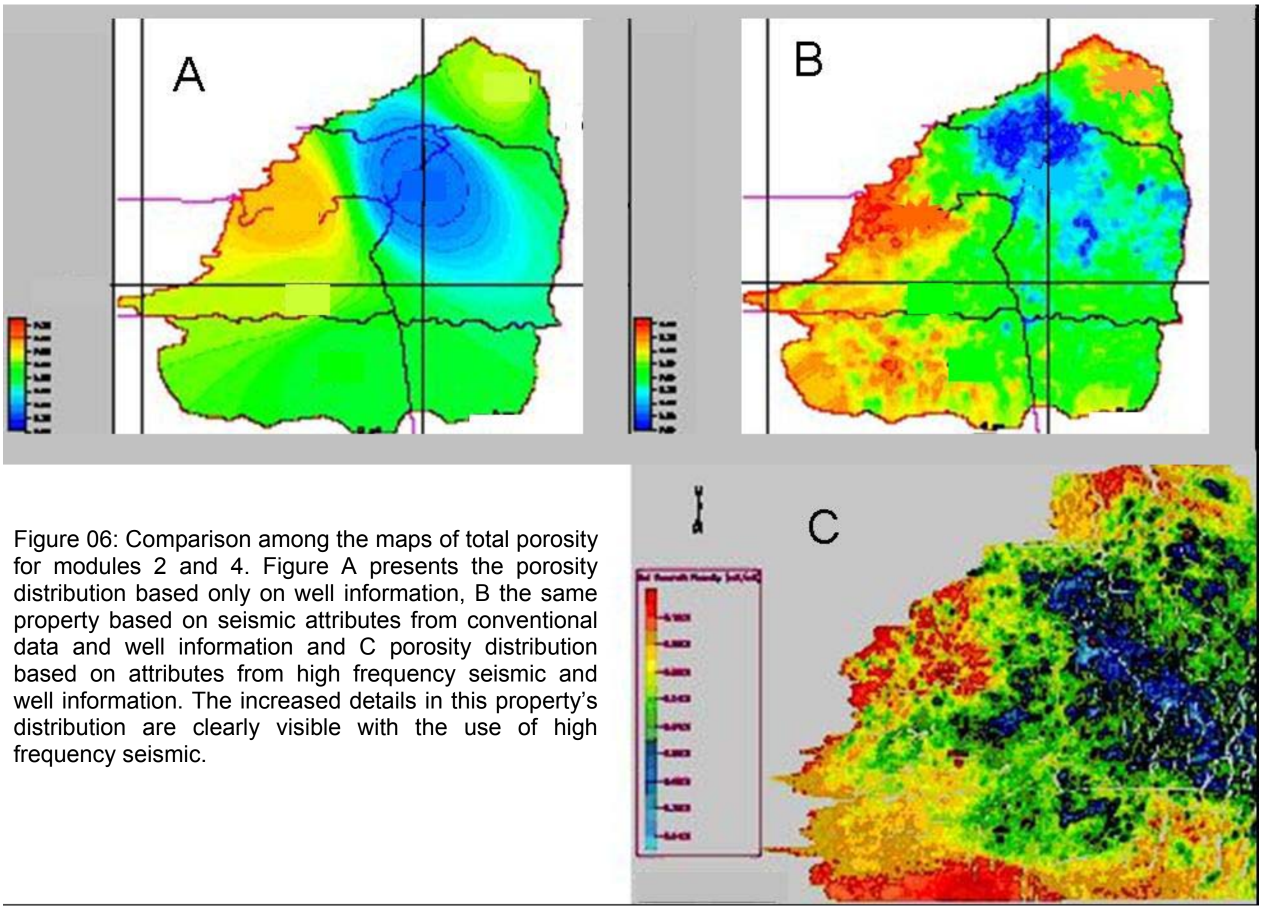

Figure 06: Comparison among the maps of total porosity for modules 2 and 4. Figure A presents the porosity distribution based only on well information, B the same property based on seismic attributes from conventional data and well information and C porosity distribution based on attributes from high frequency seismic and well information. The increased details in this property's distribution are clearly visible with the use of high frequency seismic.