3D Seismic Interpretation and its Implications to a New Structural Model on the South of Santos Basin, Brazil

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Abstract

In the south of Santos Basin, on the coasts of Santa Catarina and Paraná States, there are light hydrocarbon fields named Tubarão, Estrela do Mar, Coral, Caravela and Cavalo Marinho. Reservoir rocks are mainly constituted by oolitic grainstones, generally dated as Meso Albian and interpreted as oolitc bars grown over rool-overs crests. The structural model adopted here defines structural traps, perfectly closed in all directions, in which each field has an ellipsoidal configuration with major axis on NS direction and minor axis on WNW-ENE direction. The NS ellipsoidal axis is precisely the NS roll-overs axis, related to normal faults and salt tectonics. The WNW-ENE ellipsoidal axis is due to NW and NE lineaments that crosscut and, thus, deform the normal faults, leading to interference fold pattern Type 1 and an *en echellon* distribution of the hydrocarbon fields in map view. This group of structural features represents a characteristic strike-slip system, composed by NW sinistral faults and NE dextral faults. Within this strike-slip system, the hydrocarbon fields are interpreted as independent structures, corroborated by independent oil/water contacts that they present. These NW-NE faults seem to be masked when observed in black/white seismic sections, frequently causing misinterpretation of the structural pattern. The better observation of these features became a seismic interpretation task, and many different visualization/processing techniques were employed (changes in color bars, Semblance, RMS, Dip, Relative Acoustic Impedance, Dip-Azimuth, etc., Chen and Sidney 1997, Masaferro *et al*. 2003; Taner *et al*. 1979). The best results, which allowed the further mapping of the NW-NE faults, were provided by the use of a multi volume visualization, where different seismic attributes could be combined in the same image, and properly manipulated in order to enhance the NW-NE fault system. This volume interpretation allowed also the best stratigraphic interpretation, enabling even the recognition of individual oolitic bars.

Introduction

The observation of faults on seismic images is easily made when the structures are determined by dip-slip movements (normal and reverse faults), and when displacements are greater than dozens of meters. Lateral faults, known as strike-slip faults, are much more difficult to be seen, especially if their displacement is equivalent to a few hundreds of meters, because they are juxtaposing the same lithotype, side by side, so they can not be easily traced in cross sections.

Another aspect that may influence the observation of faults is their intrinsic characteristic to be narrow, and develop a fault plane, or large, and develop a fault zone. It is commonly accepted that the fault zone will be as much larger as greater is the displacement of the fault. However, it is also accepted that, on wrench tectonics regime, the greatest displacements are going to be observed on the basement of the strike-slip system and, upwards in the stratigraphic section, the stress tends to be accommodated in minor fractures, such as R fractures, causing the fault zone to be diffuse and not well defined in seismic images.

If there are no great displacements, if the fault plane is materialized as a diffuse fault zone and, above all, if the target structures are close to vertical, the only way to recognize and map these structures is to find contrasts in the amplitude sign. Those contrasts, more than show a tectonic surface, can reflect subtle changes in physical properties, such as *in situ* pore pressure, density, fluid entrance on the system, etc.

This paper intends to show how moldern techniques of 3D visualization can improve the recognition of stike-slip faults and, thus, modify the current structural model for a given area.

Method

All seismic interpretation starts with a traditional black/white seismic section. Since this regular method has proven to be inefficient in this case, recognition, identification and mapping of strike-slip faults with minor displacement, the first solution that has been tried was the change of the color bar. A different black/white color bar has been applied, with the white applied to the most positive or the most negative amplitude, and the black applied to amplitudes close to zero. This color bar allowed the better observation of the mentioned strike-slip faults in section view. However, in map view these faults continued to be difficult to identify.

Semblance, RMS, Dip-Azimuth and other techniques were also applied. All of them presented almost the same characteristics of the change in color bar, the faults became clearer in section view, but were still hard to be seen in map view.

Different seismic attributes were generated in order to choose the best response to the proposed objectives, structural/stratigraphic analysis (Damasceno *et al*. this volume). The geometric attributes, such as semblance and dip, were the ones which provided the expected images for structural interpretation, delineating the NW-NE fault system with high resolution. The best results were obtained when different attributes were combined in a same volume, such as dip with amplitude or relative acoustic impedance. The volumetric interpretation of these data permitted a fast and global understanding of the area structural framework.

Results

Structural analysis based on seismic, from common seismic to multi volume interpretation, lead to the recognition and organization of two families of structures.

The first family is due to normal listric faults, with a general NS trend, dipping eastward and dying at the base of the Aptian salt. These faults have acted as growth faults from the final sections of Meso Albian up to the top of the Cenomanian sections. Large roll-overs have resulted from this movement, allowing the growth of oolitic bars on their crests (Fig. 1).

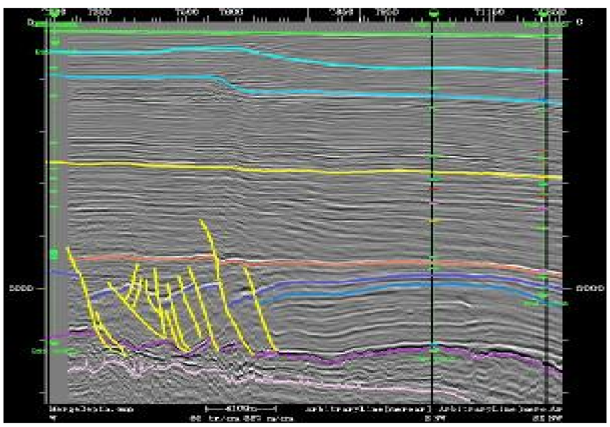

Figure 1- Black/white traditional seismic. On the left, the normal listric faults, to the right, the roll-over structure. From base to top reflectors represent: light pink – base of Aptian salt; purple – top of Aptian salt; light blue – top of Albian oolitic shoal #2; deep blue – top of Albian oolitic shoal #1; orange – top of Cenomanian section; yellow – top of Cretaceous section; very light blue (both) – Tertiary carbonate platforms; green – bottom of the sea.

The second family is related to NW and NE faults, which can barely be seen on section view (Fig. 2). Only in map view it is possible to identify their transcurrent character, with sisnistral sense for the NW faults, and dextral sense to NE faults (Figs. 3 and 4). It is important to note the difference on images from exactly the same area. The traditional seismic suggests the presence of NW-NE lineaments, but only by the use of a multi volume (dip + relative acoustic impedance) they could be traced. It is also important to note that these NW and NE faults have been active since the Meso Albian, because they play a significant control on oolitic sedimentation (Fig. 4).

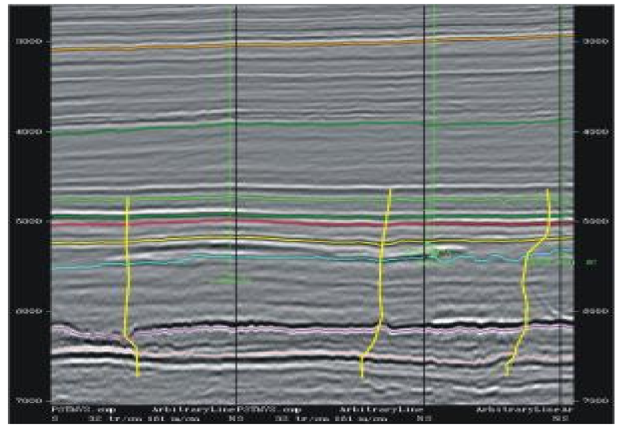

Figure 2- Black/white traditional seismic. Subvertical yellow traces represent NW sinistral strike-slip faults. Note very gentle perturbation of the seismic sign. The major interference of the faults that can be seen on this section is a small displacement of the base of the Aptian salt. From base to top reflectors represent: light pink – base of Aptian salt; purple – top of Aptian salt; light blue – base of Albian oolitic shoal #3; yellow – base of Albian oolitic shoal #2; red – top of Albian oolitic shoal #2; green – top of Albian oolitice shoal #1; light green – top of Cenomanian section; medium green – base of Juréia progradation; orange – top of Cretaceous section.

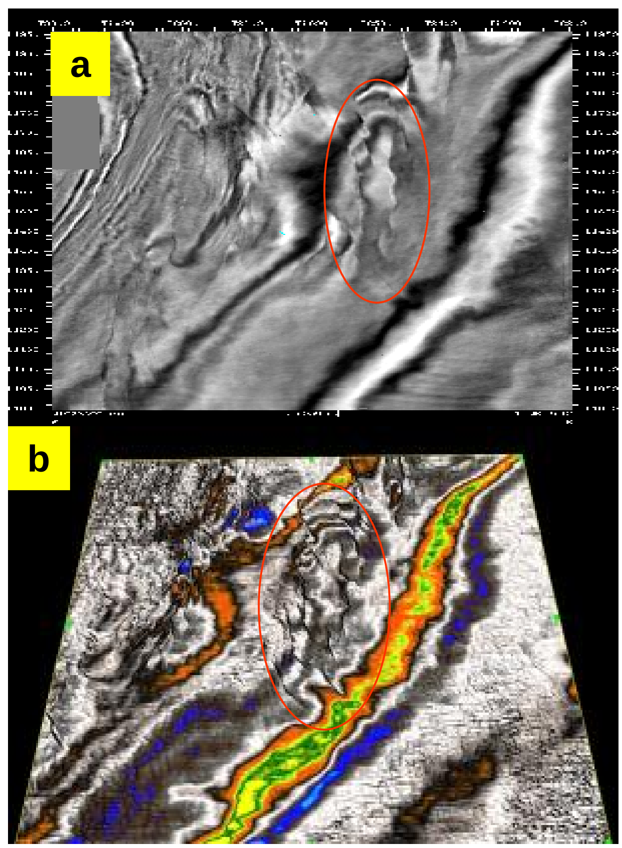

Figure 3- (a) Black/white traditional seismic. The red ellipsis shows two NS-trending normal faults, forming a small graben. Observe the NS-trending trace is undulated, but no displacement can be seen. (b) Multi

volume dip + relative acoustic impedance image. The red ellipsis shows the same two NS-trending normal faults, forming the mentioned graben. Observe that the NS-trending trace is segmented, forming S-like structures, which indicate its deflection due to strain of the previous NS fault surfaces. The displacements indicate sinistral sense for the NW-trending faults.

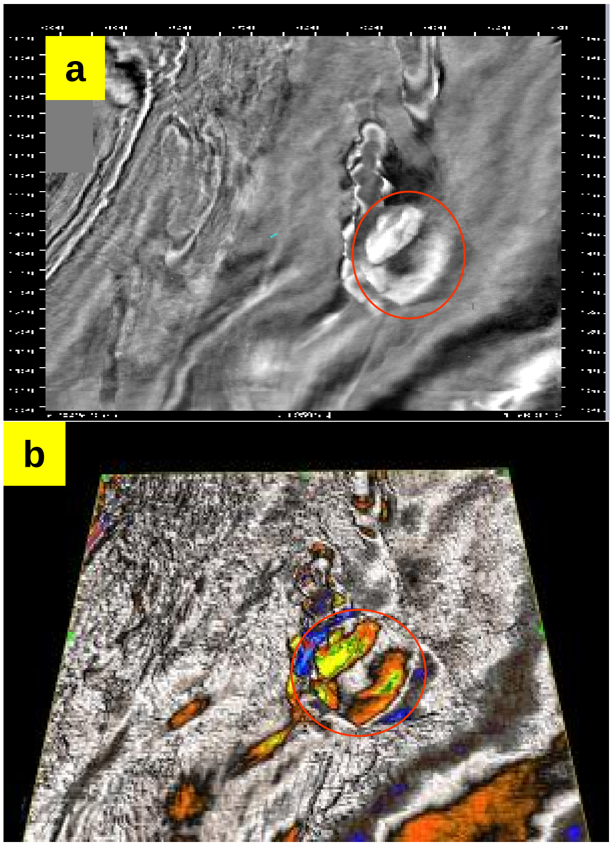

Figure 4- (a) Black/white traditional seismic. The red ellipsis, with high amplitude sign, indicates the formation of an oolitic bar. Observe there are NW and NE traces on the bar, but it is not clear if they are interfering on the bar growth or not. (b) Multi volume dip + relative acoustic impedance image. The red ellipsis, with high relative impedance sign and yellow/green/orange colors, indicates the formation of the same oolitic bar. Observe that the NW and NE faults limit the growth of the oolitic bar, suggesting those faults have been active since the Meso Albian. Note also the NS-trending graben, westward of the oolitic bar, and how sinistral sense of NW faults is evident.

Conclusions

The interpretation developed up to now has revealed two important families of structures. The first family is dominated to NS-trending normal listric faults, with eastward vergence and related to the salt movement. The second family is constituted by NW-sinistral and NE-dextral strike-slip faults, related to the drift of the South American Plate to the west, and responding to regional compression.

Those NW and NE faults have been active since the Meso Albian, suggested by the controls that these faults have played on the growth of the oolitic bars.

It is proposed here that such a complex structural analysis of the southern part of Santos Basin can only be made by the use of modern structural/stratigraphic attribute images and multi volumetric interpretation.

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