SBGf31399

Seismic Geoinversion as a Horizontal Well Positioning Tool: Applications in the Marlim and Barracuda Fields, Deep-Water Campos Basin.

Johann, P.R.S., Abreu, C.E.S., Alves, R.R.P., Bruhn, C.H.L., Freitas, L.C.S., Becker[+], M.R., Maciel W.B., Santos, M.B., Souza Jr., O.G., Sarzenski, D.J., Assis, O.C.

Petrobras E&P/Reserves and Reservoirs Management and [+]Petrobras Research Center, Brazil.

Abstract

Reservoir geological modeling derived only from seismic amplitude maps usually do not provide an efficient support for the planning and drilling of deviated and horizontal wells. A methodology for reservoir modeling based on the integration of high-resolution stratigraphic studies and seismic inversion (or geoinversion) allows better planning and positioning of deviated and horizontal wells. Seismic geoinversion requires the integration of different data types to define a more detailed and realistic interpretation of the reservoir architecture. Geological concepts, well logs and 3-D post-stack amplitude seismic data can be integrated to obtain 3-D acoustic impedance and associated seismic reflectivity images of Oligocene/ Miocene turbidite reservoirs. The study area comprises some of most important petroleum reservoirs in Brazil, the Marlim and Barracuda giant oil fields.

Seismic geoinversion is carried out in six main steps: (1) volumetric well-to-seismic quantitative calibration, (2) zero-phase deconvolution, (3) regional interpretation of 3-D seismic data, (4) 3-D acoustic impedance modeling, (5) seismic stratigraphic inversion, and (6) detailed interpretation of the external and internal reservoir architecture.

Introduction

Hydrocarbon production from thin and/or heterogeneous reservoirs poses serious problems in oilfield development, particularly in planning and drilling production or water injection wells. The characterization of reservoir architecture comprises the integration of different data types to define a more detailed and realistic geological model to support well drilling. 3-D seismic data plays a very important role in reservoir characterization. Seismic amplitude variations are linked to changes in acoustic impedance, and therefore to reservoir properties. This paper is focused on the use of 3-D acoustic impedance and associated reflectivity volumes to improve the seismic imaging of the reservoir architecture of Marlim and Barracuda turbidite oilfields, Deep-water Campos Basin. These enhanced images allow much better reservoir mapping and positioning of deviated and horizontal wells in the Marlim and Barracuda fields.

Challenges for seismic imaging

The main types of reservoir heterogeneities found in turbidites from Deep-water Campos Basin are interbedded mudstones and calcite-cemented horizons. These internal heterogeneities commonly show subtle responses in conventional seismic amplitude due their reduced thickness and/or low acoustic impedance contrast with porous horizons. Mapping the spatial extension of these heterogeneities is very important to define the production strategy, particularly regarding the positioning and completion of horizontal and deviated wells. The use of 3-D seismic geoinversion has been applied to improve reservoir characterization, by using both acoustic impedance and reflectivity images in the positioning of horizontal wells during their drilling.

Seismic geoinversion – principles of the methodology

The methodology of geoinversion, or model-based inversion, is carried out in six main steps (Johann, 1997). **(1) Well-to-seismic volumetric quantitative calibration**, aiming the extraction of a single calibration operator for well-seismic tie. Three main steps should be taken into account in this step: (a) power spectrum estimation, (b) linear phase estimation, and (c) definition of the single calibration operator (amplitude and phase). Possible solutions is reached considering the selection of a common phase rotation, a small residual time shift, and mean amplitude. **(2) Zero-phase deconvolution** with the operator defined in step (1). **(3) Structural and stratigraphic regional interpretation of 3-D seismic data** based on time position of marker beds and 3-D deconvolved seismic. **(4) 3-D acoustic impedance modeling**, which introduces and validates the structural and stratigraphic interpretation, and builds an initial 3-D acoustic impedance model from well logs. **(5) Seismic stratigraphic inversion**, with the initial 3-D image of acoustic model (Step 4) being improved by incorporating the 3-D seismic amplitude data. **(6) Detailed seismic stratigraphic interpretation of impedance/reflectivity images.**

Figure 1 shows the relationship between the average percentage of porous sandstones and average seismic acoustic impedance for the Oligocene/Miocene reservoirs from Marlim and Barracuda fields. In Barracuda field (sand/mud-rich turbidite system), the average acoustic impedance values decrease with increasing percentage of porous sandstones (linear correlation coefficient of –0.83). In Marlim field (sand-rich turbidite system), these values tend to be more homogeneous, with average percentage of porous sandstones typically higher than 80%, and average seismic acoustic impedance typically lower than 6500 m/s.g/cm^3. Lower values of acoustic impedance indicate the preferential position for oil producer wells.

Positioning of horizontal wells: Marlim and Barracuda Fields

Reservoir management has been increasingly made with the aid of inverted 3-D seismic data. Acoustic impedance and related reflectivity have provided important support in the establishment of stratigraphic correlation between widely spaced wells. These images have been used to drill deviated and horizontal wells in Marlim and Barracuda giant oilfields. Marlim and Barracuda are located in the central part of Campos Basin, at present water depths between 600 to 1500 m, and covering a total area of about 250 km^2. The fields combined contain a total in-place volume of 9300 MMBOE, and total proven reserves of 3000 MMBOE. The development of Marlim and Barracuda will involve the drilling of about 150 wells (100 deviated wells and 50 horizontal wells). Some of the horizontal wells are preceded by deviated pilot wells, which have helped to estimate the lateral continuity of each reservoir, to recognize reservoir facies, to detail the reservoir structural framework, and to calibrate acoustic impedance.

Case 1: Marlim Field (Oil Producer Well)

Marlim field reservoir is composed of Oligocene/Miocene, sand-rich turbidite lobes. The amalgamations of several lobes comprise an up to 125 m-thick sand-rich succession with sand/mud ratio typically exceeding 10:1. Porosities and permeabilities are relatively homogeneous, typically averaging 27-30% and 1,000-2,000 mD, respectively (Bruhn, 1998). The reservoir was subdivided into five production zones based on well logs and 3-D seismic data. Reservoir internal heterogeneities (such as mudstone and marl beds, and calcite-cemented horizons) can be recognized in well logs, but show subtle responses in conventional seismic amplitude data. Reservoir characterization studies conducted in Marlim field allowed the mapping of a few widely distributed mudstone beds that control vertical fluid flow within the thick, sand-rich reservoir. Oil gravity varies from 18 to 21°API, leading to a high water/oil mobility ratio. In order to improve sweep efficiency, horizontal water injection wells should be drilled immediately below the more continuous mudstone beds within the reservoir, whereas horizontal oil producer wells should be drilled immediately above these mudstone beds. Therefore, the seismic mapping of internal mudstone beds is very important to define well position in Marlim field, particularly the position of horizontal wells. Figure 2 is a seismic profile resulting from the geoinversion methodology, showing reservoir acoustic impedance and reflectivity. The trajectory of Well A (oil producer well) is indicated by a black line. The high production rates obtained by Well A (about 21,000 bbl/day) may have two explanations: (1) the seismic facies chosen for the well positioning suggest the presence of high-porosity sandstones, and (2) the drilling technology enables sand contention without any well damage.

Case 2: Barracuda Field (Water Injector Well)

Barracuda field reservoirs are Oligocene/Miocene and Paleocene/Eocene turbidites. Individual Oligocene/ Miocene reservoirs comprise lenticular and NW-elongated sandbodies; their amalgamation form up to 30 m-thick sand-rich successions. Eocene/Paleocene reservoirs are confined to a NW-oriented, fault-bounded through, reaching maximum net sand thickness of 100 m. The most important challenge in the field development is the positioning of horizontal water injection wells, since they are placed near the reservoir margins, and their 700 to 1300 m-long trajectory crosses sandstones thinner than 10 m.

The purpose of well B (Fig. 3) is to inject water in two adjacent, Oligocene/Miocene sand/mud-rich reservoirs. The hydraulic connection between these two reservoirs is considered restricted. Horizontal section of Well B is about 1200 m-long, crossing heterogeneous reservoirs composed of amalgamated lobes heavily dissected by channels. A deviated pilot well was drilled in the area before the drilling of Well B, in order to evaluate pressure depletion and connection between the two Oligocene/Miocene reservoirs.

Geoinverted seismic sections were fundamental to drill Well B through sandier horizons. Time-depth conversion also provided an important guide to drill Well B. Information from other wells drilled in the field, as well as from the pilot well, was used to achieve the most reliable time-depth conversion law.

Figure 3 shows the seismic acoustic impedance variation recorded in the Well B area. Drilling results confirmed the estimated net/gross ratio; however, Well B crossed some sandstones with relative high values of acoustic impedance, as also some mudstones with low acoustic impedance values.

Lithological interpretation from well logs of Well B allows to relate area A (Fig. 4) to low values of acoustic impedance (blue color) due to higher sand content. Area B (Fig. 4) is related to high values of acoustic impedance (green color) because of low to nil sand content. Area C (Fig. 4) has a poorly defined relationship between acoustic impedance and lithology; i.e. sandstones may display high acoustic impedance.

Conclusions

This paper demonstrates how the integration of high-resolution stratigraphic studies with 3-D seismic inversion (geoinversion) can guide the positioning of horizontal wells through thin or heterogeneous reservoirs. This methodology has been successfully applied in the development of Deep-water turbidite oilfields from Campos Basin, Brazil. The optimization of the calibration between acoustic impedance and small sandstone thickness (less than 5 m) along the horizontal well path still poses a very hard task for reservoir development. This optimization requires correct estimates of depths for thin sandbodies. An important remaining problem is the occurrence of low acoustic impedance associated with mudstones. These low impedance mudstones can be misinterpreted as reservoir sandstones, particularly in the outer limits of the field, where most of the horizontal water injection wells will be drilled.

References cited

Bruhn, C.H.L.., 1998, *Deep-water reservoirs from the eastern Brazilian rift and passive margin basins*: AAPG 1998 International Conference & Exhibition, Rio de Janeiro, Brazil, Short Course Notes, 187p.

Johann, P., 1997, *Inversion sismo-stratigraphique et simulations stochastiques: réservoir turbiditique, offshore du Brésil. Intégration géologique, géophysique et géostatistique en 3-D*, Ph.D. Thesis, Université de Paris VI.

Acknowledgements

We thank Petrobras for permission to publish this paper.

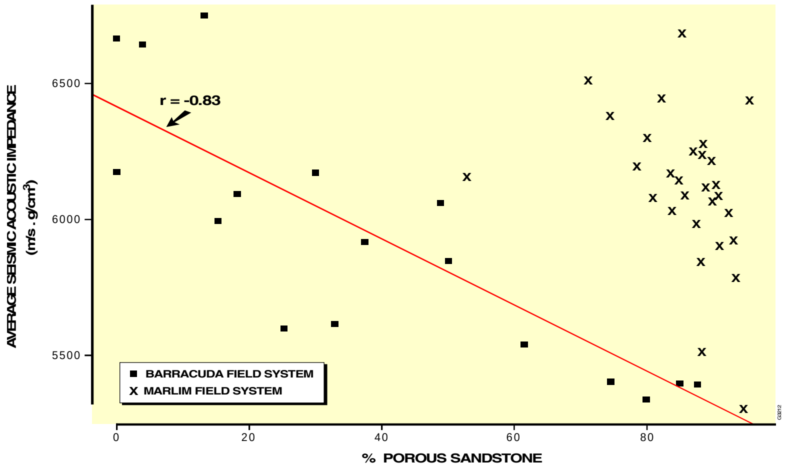

Figure 1. Relationship between average acoustic impedance and percentage of porous sandstones in the Oligocene/Miocene reservoirs from Marlim and Barracuda fields (46 well logs). In Barracuda field (sand/mud-rich turbidite system), the average acoustic impedance values decrease with increasing percentage of porous sandstones (linear correlation coefficient of –0.83). In Marlim field (sand-rich turbidite system), these values tend to be more homogeneous, with average percentage of porous sandstones typically higher than 80%, and average seismic acoustic impedance typically lower than 6500 m/s.g/cm^3. Lower values of acoustic impedance indicate the preferential position for oil producer wells.

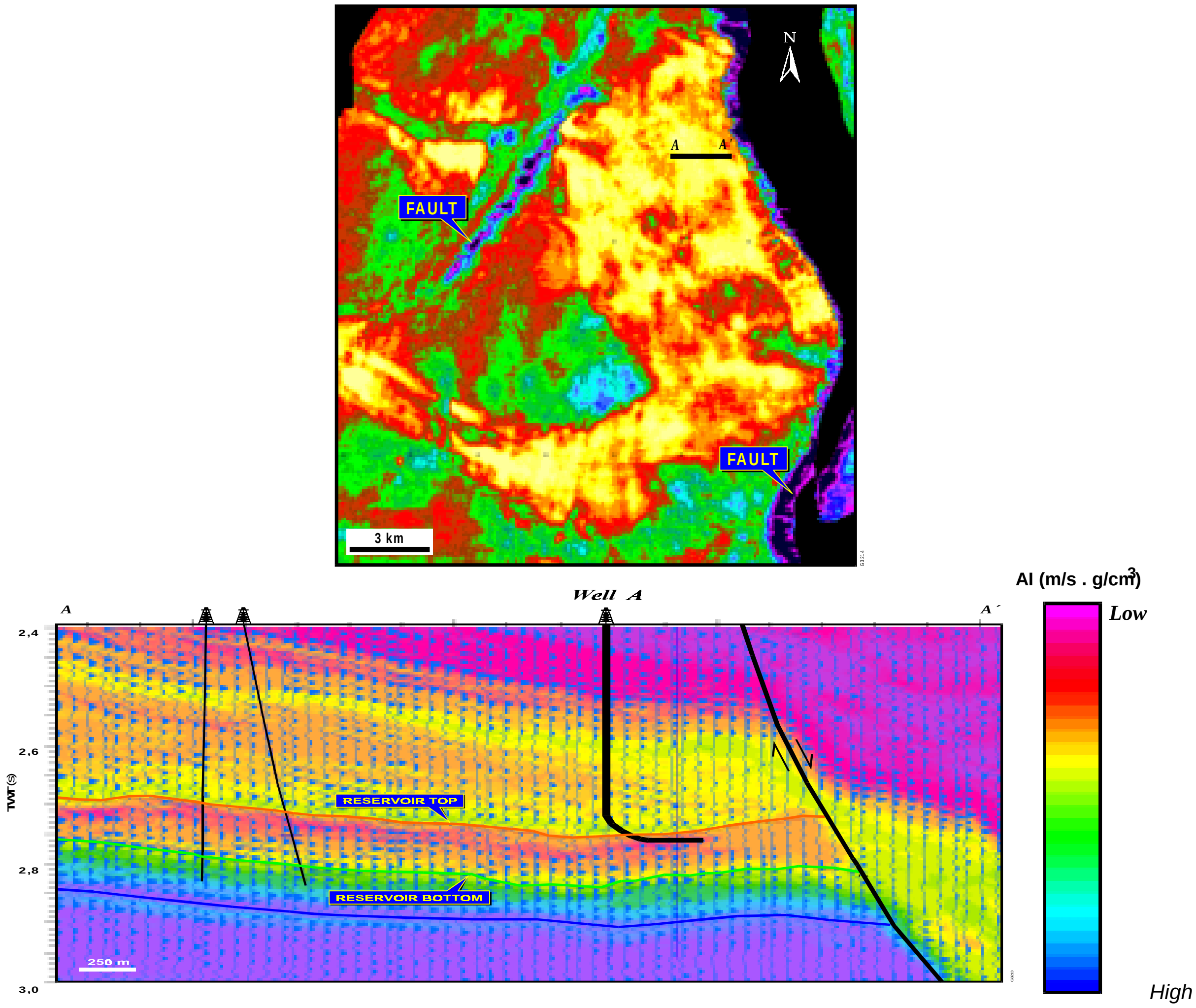

Figure 2. a) Acoustic impedance map of Marlim field. The external geometry of the reservoir is obtained from acoustic impedance interpretation, b) random acoustic impedance section showing the position of a horizontal oil producer well (Well A) in Marlim field. Low impedance values (yellow to red colors) indicate reservoir sandstones.

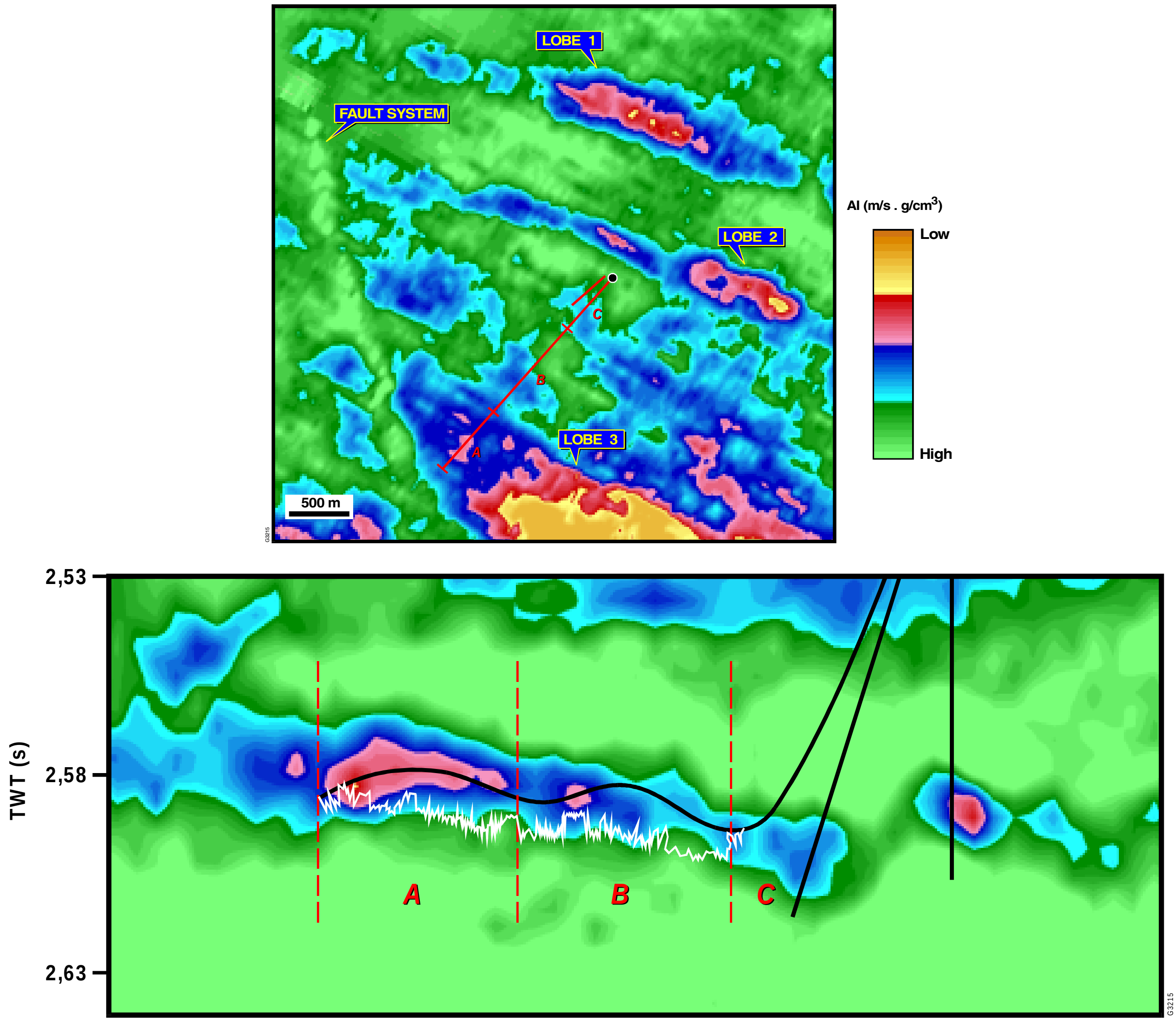

Figure 3. a) Acoustic impedance map of Barracuda field (Well B area), b) position of horizontal Well B in Barracuda field. Gamma ray logs discriminate different sandbodies thinner than 10 m, interbedded with mudstones. Well B crossed some sandstones with relative high values of acoustic impedance, as also some mudstones with low acoustic impedance values.

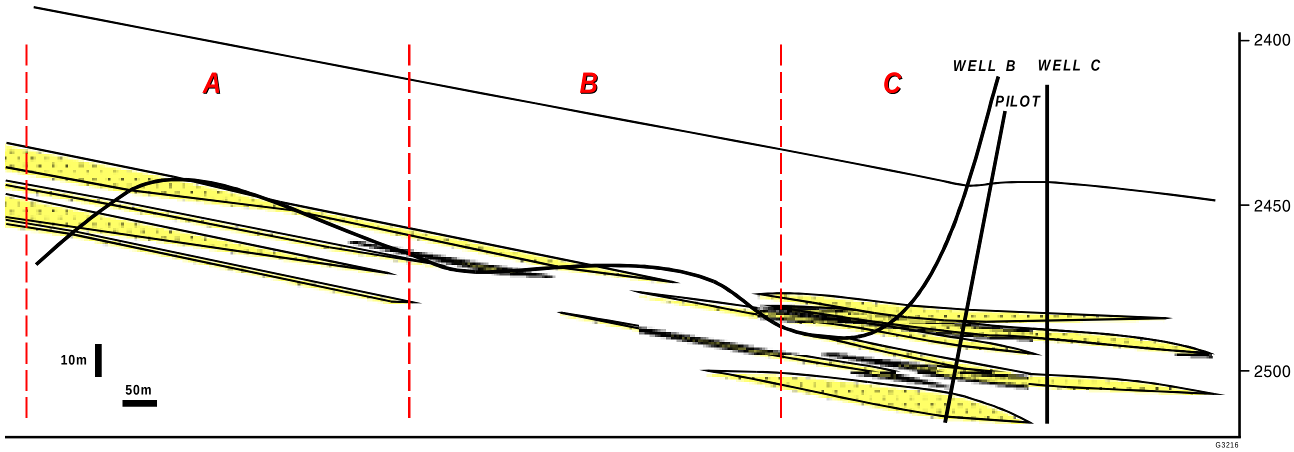

Figure 4. Sandbody distribution along Well B path according to well log interpretation. Areas A, B, and C are compared to acoustic impedance.