Initial Results on Permanent Reservoir Monitoring in Jubarte, Offshore Brazil

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Abstract

Jubarte PRM was installed in December 2012. It's a Petrobras pilot project using permanent optical ocean bottom cables for reservoir monitoring. The system covers approximately 9 sq km with 35 km of cables and 712 4C/4D stations. Base acquisition was performed in January 2013 and the two monitors in a 12 months interval. Acquisition parameters were designed in order to obtain an ultra-high density, full azimuth data. Despite the best processing flow are still under construction, it was achieved both requirements speed and quality (with a NRMS of 4% and data processed in six weeks). Although Jubarte has a small 4D feasibility, smaller than 4%, high quality of the seismic answer allowed the reservoir team to identify anomalies related mainly to saturation changes. Pressure and water salinity changes related to injection have secondary importance for anomalies generation. It was identified four classes of amplitude difference between surveys. The behavior of each class was understood modeling the wells production changes in a common midpoint gather, checking the changes for different incidence angles. The modeled data drove the interpretation, which integrated all available information, including flow model and production data. One important contribution of 4D interpretation was to identify a better location of a production well. Location was repositioned due to water indication in the 4D interpretation.

Introduction

Petrobras installed in the end of 2012 a PRM pilot project on Jubarte field using optical ocean bottom cables for reservoir monitoring. The system covers approximately 9 sq km with 35.6 km of cables and 712 4C-4D stations. Acquisition parameters were designed in order to obtain an ultra-high density, full azimuth data. First acquisition was performed in January, 2013. Processing delivered 4D volumes within 12 weeks. Interpreters applied a pre-defined interpretation strategy, and initial results were presented in May, 2014. A new monitor was acquired in January 2015 and the processing delivered six weeks after last shot.

System Design and Installation

In December, 2012 Petrobras installed its first PRM at Jubarte field, in the north of Campos basin, offshore Brazil. It is the world's first ultra-deep water system, with 2 arrays (north with 16.4 km and south with 19.2km) of cables in a 1.3 km water depth, distributed by eleven lines spaced by 300 m, with 2,848 sensors (3 accelerometers and 1 hydrophone per station) every 50 m (Thedy et al, 2013a). The subsea cables cover an area of approximately 9 sq. km and are connected to a FPSO, where a 4D room controls the fully optical (cables and sensors) system (Maas et al, 2008). Figure 1 shows the PRM design and its location in the field.

The project performed the following initial steps: (1) technical and operational feasibility studies; (2) project conception; and (3) equipment manufacturing and testing. The equipment was built in different factories and countries, assembled and tested in Texas and installed in 6 weeks, with great operational success. The final test (FAT, December 2012) confirmed that equipment was in perfect condition to start recording (Seth et al, 2013).

Data Acquisition and Seismic Processing

The base acquisition started just after the installation, also in December 2012. Shot lines were spaced by 25 meters, with shots every 25 meters, covering an area of 121 sq. km (11 x 11 km), characterizing a full azimuth acquisition with large offsets distribution and high fold.

The acquisition lasted 8 weeks. One of the identified risks was the presence of centrifugal pumps close to the wells, but these pumps do not affected the seismic data recorded. Another problem was the presence of obstructions related to drilling platforms and operational activities during shooting phase, what which reduced the shot position and acquisition direction repeatability (once the source is not completely isotropic).

Monitors surveys were planned to happen every 12 months, due to small 4D feasibility (around 3-4% for impedance change due to water replacing heavy oil). The first monitor happened from late December, 2013 to early February, 2014 (Thedy et al, 2013b). The second happened in the same period of 2014 - 2015. Despite the best processing flow is still under construction (Figure 2), it was achieved both requirements speed and quality (with a NRMS of 4%). New improvements are being tested and a new processing sequence was used for the second monitor, updating the previous ones and generating new difference volumes (M2-M1, M1-B and M2-B).

Interpretation and Results

The modelling carried out before seismic acquisition indicated that impedance difference would be small for the most of the area. The first step in the interpretation process was to establish the limit where the geophysicist could be confident that the anomaly is real, above the noise level. In Jubarte the 4D signal is very complex, associated to saturation, pressure and salinity changes, depending on the position in the field. It was identified 4 classes of amplitude difference anomalies: (i) increase of water saturation in production wells or (ii) above injection wells; (III) change of the water salinity around the injection wells; and (iv) seismic noise. The behaviour of each class was understood modelling the wells production changes in a prestack gather, checking the amplitude changes for different incidence angles. Seismic noise doesn't have a coerent AVO 4D behavior and shows high amplitudes mainly in the near offset.

Although Jubarte has a small 4D feasibility, high quality of the seismic response allowed the reservoir team to identify anomalies related mainly to saturation changes (**Figure 3**). Pressure and water salinity changes related to injection have secondary importance for anomalies generation.

In producing and injecting wells the most common anomaly is related to water replacing oil in the lower part of the oil saturated reservoir, close to the oil-water contact (**Figure 4**, wells B and D). Different swept areas produce different anomalies – close to well (**Figure 3**, well D, left) or only a ring that means the area close to the well were already swept (**Figure 3**, well D, right,). The injectors just start injecting so we don't have a long injection historic. **Figure 5** presents the 4D prestack modelling for water replacing oil in different reservoir positions.

In well D, injecting water in the oil close to the oil-water contact, the increase in water saturation generates the strongest 4D anomaly in all data, both in the synthetic model and in the real 4D. The opposite effect can also be observed, oil replacing water, below the contact. The pressure change is an additional effect that is dimming the upper anomaly and brightening the lower one, giving as result the 3 lobes aspect for the difference volume (Monitor minus Base): medium positive – strong negative – medium to strong positive.

For wells injecting water in the aquifer, the expected effect is different. The well A (**Figure 4**, left) is injecting water with 60.000 ppm salinity in the brine (140.000 ppm). The modelled effect in **Figure 6** can be observed in the real data, but the fact that the difference volume has some noise related to seabottom multiple, close to this position, makes the team initially not completely confident about this anomaly.

The 4D AVO anomalies (**Figure 4,** top) are very consistent with the modelled behaviour in the wells. The AVO analysis reinforces that the anomaly in well A is real. Anomalies related to seabottom multiple don't have an 4D AVO anomaly. In non-swept areas there isn't AVO anomalies (well C) too.

It's very important the integration of all available data. All the seismic anomalies are crosschecked with production information and with the conceptual geological model. All the available information, seismic volumes, geological model and flow simulator are visualized together. The understanding of the real saturation changes is then used to update the flow simulator, and if it is the case, the geological model, improving the models predictability. New wells position are reviewed according the new interpretation.

Conclusions

PRM Jubarte acquired a very high quality 4D data, with high repeatability and high signal-to-noise ratio (S/N), that was processed and interpreted in a fast track way. . It was possible to identify different production effects, despite the small impedance changes. Results allowed the team to improve the water front understanding in an integrated (geophysics, geology and engineering) interpretation. Flow model and production strategy of this portion of the field are being updated using this new methodology. The pilot test was very sucessful.

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References

Maas, et al, 2008, Fiber optic 4C seabed cable for permanent reservoir monitoring, OTC, 19445

Seth S, Maas S, Bunn B, Metzbower R, Wersich E, Johann P, Thedy E and Lisboa W, 2013, Full Solution Deep-water PRM Project in the Jubarte Field in Brazil for Petrobras by PGS, , Second EAGE Workshop on Permanent Reservoir Monitoring 2013 – Current and Future Trends, Trondheim.

Thedy EA, Johann PRS, Ramos Filho WL and Silva JGR, 2013a, Jubarte PRM: First Deep-Water Optical 4D4C WAZ and Microseismic Systems, Second EAGE Workshop on Permanent Reservoir Monitoring 2013 – Current and Future Trends, Trondheim.

Thedy, EA., Ramos Filho, WL., Johann, PRS, Seth, S.N, Souza, SC and Murray, PE, 2013b, Jubarte Permanent Reservoir Monitoring - Installation and First Results, XIIIth. Int. Congr. SBGf. Rio de Janeiro.

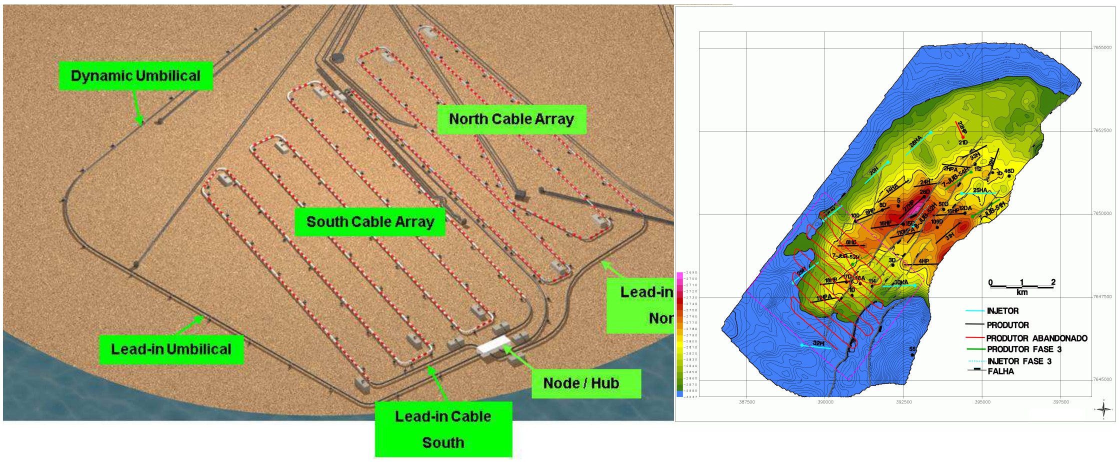

Figure 1 Left -Jubarte PRM schematic layout. The system, totally optical, is composed by 35.6 km of cables and 712 stations with 4 components each, and connected to a FPSO. Right – Jubarte structural map. The PRM was installed in the southeast portion of the field, in a water depth of 1.3 km.

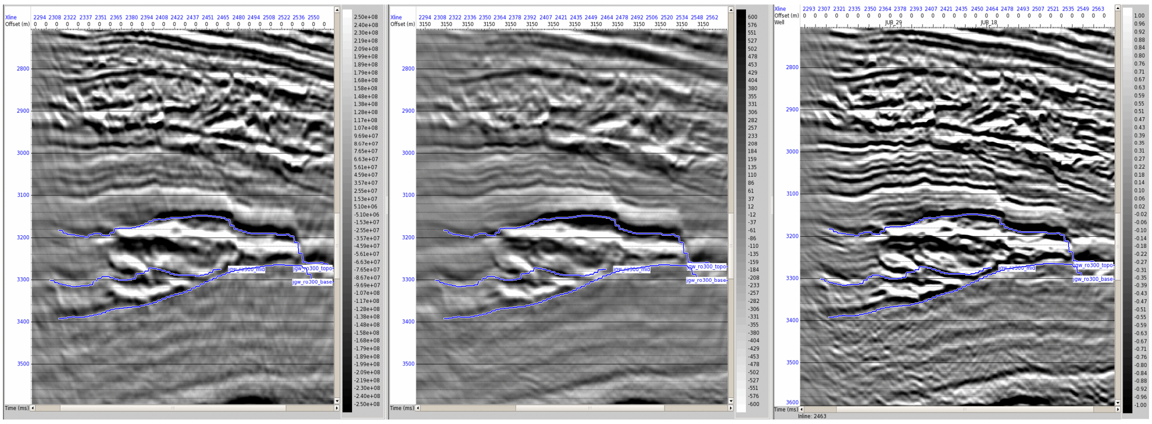

Figure 2 - Processing improvements between inicial results (left), increasing S/N ratio (center) and increasing resolution (right).

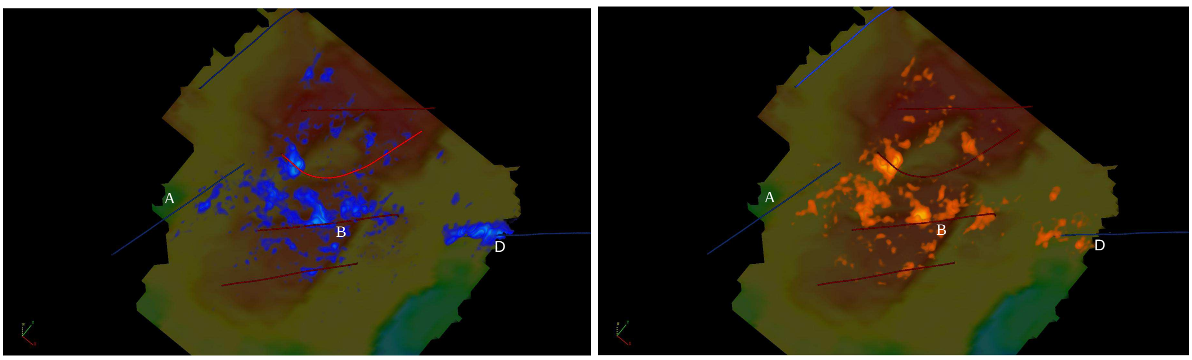

Figure 3 - Amplitude difference maps M2-M1 (left) and M1-B (right) and structural map of the top of reservoir in time. Producer wells are red and injectors, blue. All these anomalies are consistent with production curves. We can identify the waterfront moving from the injector B mainly to north, where we have production, from the aquifer to the center of the field and from the fault system to the higher area and to the producers. It can happen from the hanging wall to the foot wall when we have sandstone connected in both blocks

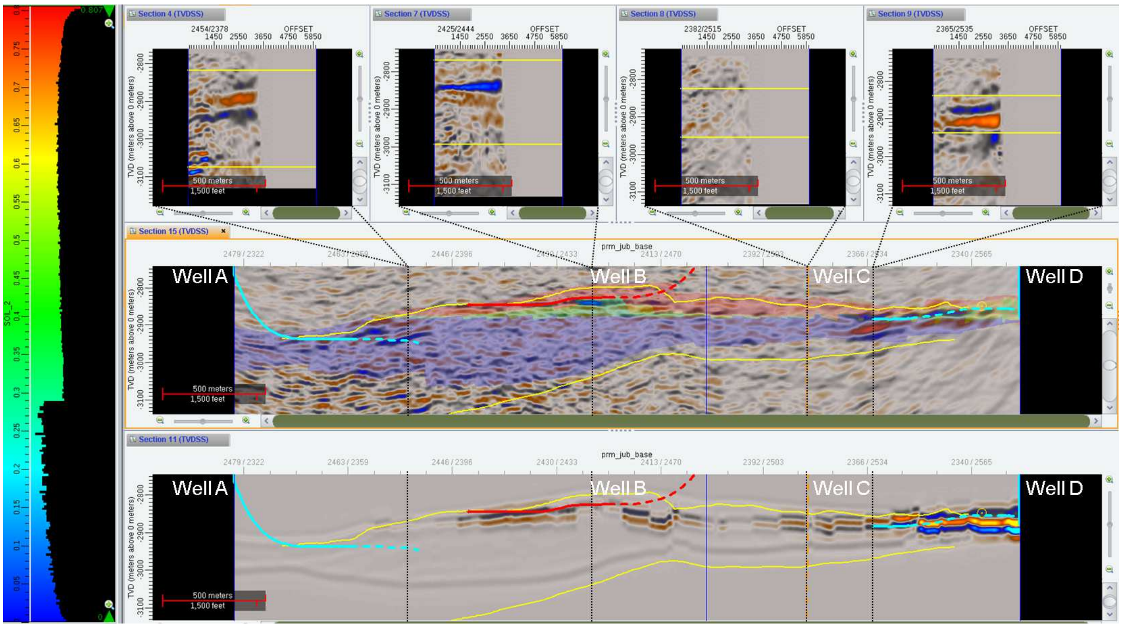

Figure 4 Top - Prestack gathers showing 4D AVO effects in wells A, B and D, and without anomaly in well C, where there's no production. Middle - arbitrary section crossing the field. The amplitude difference seismic section is overlapped by oil saturation from flow simulator – oil in red, water replacing oil in green and water in blue. Base – the same section showing the synthetic modelled results for fluid substitution and pressure changes from flow model. The salinity change in well A was not modelled in flow simulator and no effect was expected based in these data.

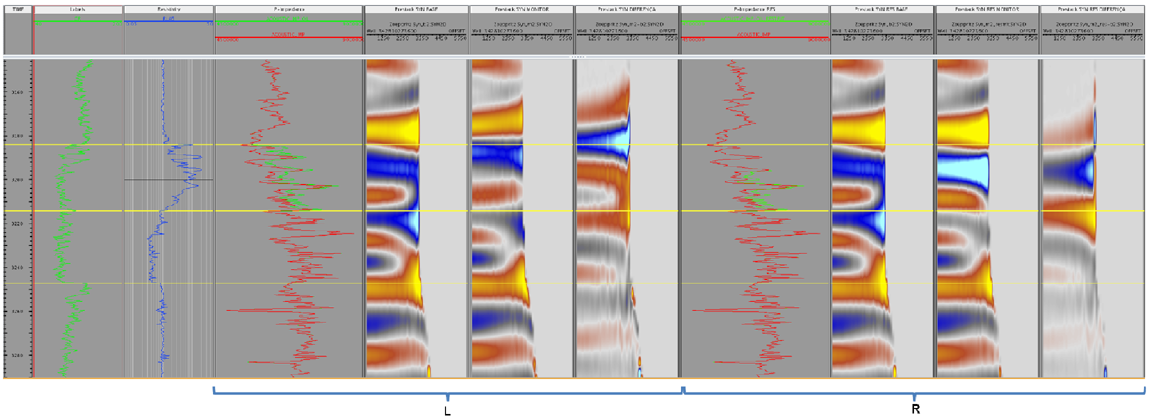

Figure 5 - Modelled answer (base – monitor – difference) for fluid substitution: oil by water in well C. Left – in the entire pay zone; Right – in the bottom of pay zone.

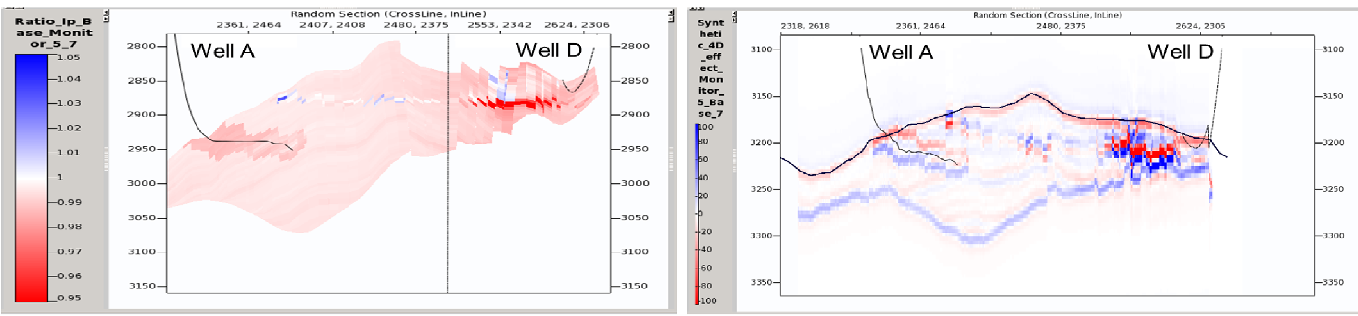

Figure 6 - Modelled answer for fluid substitution: original brine by injected water around the well A. Left – depth model for acoustic impedance changes; Right – time modelled seismic.