P326

Quantitative Estimation of Pressure and Saturation Changes Using 4D Seismic - A Case Study in the Marlim Field, Brazil

R.C. Sansonowski* (Petrobras) & C. MacBeth (Heriot-Watt University)

SUMMARY

The technique of Floricich (2006) is used to estimate pressure and saturation changes from 4D seismic data without the need for rock or fluid physics. The methodology is applied to an Oligocene field, offshore Brazil, with encouraging results. Estimates of the amount of injected water in the system between the two vintages are obtained using the saturation maps and the simulation model, and the comparison is used to assess the material balance in the area.

Abstract

The technique of Floricich (2006) is used to estimate pressure and saturation changes from 4D seismic data without the need for rock or fluid physics. This methodology involves a multiple attribute approach in which a sequence of calibration, training and selection produces an optimal combination of the attributes for the final inversion. A Bayesian inversion from the 4D data is then performed taking into account the uncertainties related to the production data and seismic attributes. The methodology is applied to an Oligocene field, offshore Brazil, with encouraging results. Estimates of the amount of injected water in the system between the two vintages are obtained using the saturation maps and the simulation model, and the comparison is used to assess the material balance in the area.

Introduction

Time-lapse seismic reservoir monitoring or 4D seismic is a technology predominantly applied in offshore Northwest Europe, in particular the North Sea, where more than 80 percent of seismic expenditure is carried out. In South America, offshore Brazil, the first survey designs for this purpose have been acquired only recently, and the initial results from this technique (Oliveira *et al*. 2007) indicate a successful application even in areas where most of the oil produced is considered heavy.

The EPASS (Engineering Approach for Pressure and Saturation Separation) technique developed by Floricich (2006) has been successfully tested before in the Cormorant and Schiehallion fields, both located in the North Sea, in the context of high porosity and permeability sandstone and also light oil. Here, the methodology is now applied to one of the most important fields offshore Brazil, which has a heavier oil. The field was monitored with a seismic acquisition in 2005 and the results illustrated in this paper are the combination of the parallel processing of the 1997 and 2005 datasets.

Field Description

The giant Marlim field is the one of largest producing oilfields in South America (average 370.000 bbl, presently), with the original oil-in-place volume of 6.4 billion STB. The field was discovered in 1985, and started production in 1991 and injection in 1994. The reservoir is a turbidite of Oligocene/Miocene age with excellent rock characteristics. Relative permeabilities are favourable to water injection and the well productivities in the area are very high. The field has an area of 145 km^2 and the water depth ranges from 600 to 1100 m. The oil gravity varies from 18^o to 24^o API. The original pressure is 4082 psi (28.1 MPa) and the saturation pressure is 3770 psi (26.0 MPa). Figure 1 illustrates the location of the field in the context of the Campos Basin.

For this study, an area of 8.0 km^2 was selected to perform the inversion. The area is part of the south turbidite system, where porosity and net-to-gross ratio have the highest values in the field. Also, the average thickness in the study area ranges from 35 to 45 m, so that we avoid potential problems related to tuning on the amplitude maps. Figure 2 illustrates the positioning of the area in the field.

Pressure and saturation inversion methodology

The method provides a fairly simple and practical way of calibrating individual 4D seismic attributes of any nature to the changes in pressure and saturation in the reservoir, using direct engineering data from the wells. It works by considering that if seismic attributes can respond in different ways to the variations in the reservoir state, then they can also provide an inversion for pressure and saturation between the survey times. The field under study is a classical siliciclastic reservoir in which only two phases, oil and water, coexist. The oil is undersaturated and hence above the bubble point, and the reservoir is non-compacting, so that production and injection induce only pressure and saturation variation, with no changes in porosity or thickness. The 4D change as recorded between the baseline amplitude and the monitor amplitude can now be approximated by the equation for an oil-water system (MacBeth *et al*., 2006).

$$\Delta A(x,y) \approx C_S \Delta S_o(x,y) + C_p \Delta P(x,y) \qquad (1)$$

where, ΔA represents a change in the seismic attribute, ΔS_o and ΔP are the changes in oil saturation and reservoir pressure respectively, and C_s and C_p are constants to be determined. The second step is to analyse the 4D differences for various seismic attributes to select the most suitable for the inversion. This is achieved by training different combinations, and then inverting the result at several selected wells where the pressure and saturations are relatively well determined. Next, the values for C_s and C_p are calculated for each seismic attribute assuming equation (1). Finally, a Bayesian inversion is applied to generate maps for pressure and saturations together, and probabilistic maps used to quantify the uncertainties.

Application to the dataset

Amplitude maps from the base of the reservoir, extracted from four angle stacks volumes (0-10, 10-20, 20-30 and 30-40 degrees) are loaded. Figure 3 shows the average amplitude maps for a window of 10 ms around the base of the reservoir. The choice of these particular maps and also the parameters used to generate them is based on a visual comparison with those extracted from the top, and also because the water breakthrough expect has a preference to flow in the lower levels of the reservoir.

Qualitative interpretation suggests that the decrease in amplitude values (hardening of the reservoir and blue colours) is related to water injection diminished in magnitude by the pressure increase – particularly around the injector wells. On the other hand, the increase in amplitude (softening of the reservoir and red colours) might be related to the liberation of gas into the reservoir offset by the depletion in pressure. Both pressure and saturation changes are observed at the wells in these areas, but the 4D amplitude differences do not entirely reflect either pressure or saturation. Thus, further quantitative analyses should be made in order to separate the individual contributions of pressure and saturation. Information from 2 injectors and 1 producer well are used to calibrate the seismic amplitudes. The pressure and saturation changes are taken from the numerical simulator, averaging the predictions in cells around each well location. These values represent important information with which to transform the seismic into a quantitative product.

Evaluation of the quantitative analysis

The results from the inversion are shown in Figures 4 and 5 for changes in the reservoir between 1997 and 2005, at a confidence level of 50%. The white arrows in Figure 4 show the position of the three wells used to calibrate the seismic information (2 injectors and 1 producer). The map of saturation changes is quite consistent with the results from the numerical simulator. However the new maps indicate preferential flow from Injector 4 to the Producers 2 and 5, and also from the Injector 1 to Producer 6 - as marked by the blue arrows in Figure 4. These preferential paths can help to achieve a better history match on all the surrounding producer's wells, and a modification to the simulation model.

The next step is to understand the size of the anomalies and compare the results with the amount of water injected during the period under investigation. The injection in the south area of Marlim starts in 2001, so this is after the base acquisition. Under this condition the 4D signature should be a helpful tool to understand the water drive mechanism. Figure 6 cross plots the seismic estimates of water volume with the actual volumes of water injected into the reservoir. The volumes (V) from the saturation maps are calculated according to the following:

$$\mathrm{V} = \mathrm{A} * \mathrm{Gross} * \mathrm{NTG} * \phi * 0.65 \qquad (2)$$

where, A is the calculated area on the saturation map, *Gross* is the average value from the isopac map, NTG is the average net-to-gross from the wells, ϕ is the average porosity from the wells and 0.65 is the estimated oil saturation change.

A reasonable match can be achieved at most wells (except the one depicted by the black arrow, which is anomalous owing to the well conditions). The results are further corrected by taking into account the amount of water that has been produced during the period (approximately 8% of the injected amount). This then produces a better correlation (as shown by the blue triangles on the same graph). The blue line drawn represents the linear regression between these two variables and now provides a closer intercept with the origin of the system.

Conclusions

The time-lapse seismic is an important instrument to access quantitative results in the Marlim field, particularly in the south area. Even in such a field where repeatability is a challenge and the oil density is considered low, the results obtained at the moment have made many improvements to the reservoir simulator. A technique is used to invert the seismic data calibrated with a hard engineering data to generate maps and provide a better decision for the reservoir team management. This methodology can now be applied to other areas of the field.

Acknowledgments

The authors would like to thank Petrobras for the provision of the information and permission to publish the paper. RCS also acknowledges the sponsors of the Edinburgh Time Lapse Project (ETLP), Phase III, for funding the research.

References

Floricich, M. (2006). *An engineering-consistent approach for pressure and saturation estimation from time-lapse seismic data.* PhD Thesis, Institute of Petroleum Engineering, Heriot-Watt University.

MacBeth, C., Floricich, M. and Soldo, J. (2006). *Going quantitative with 4D seismic analysis*: Geophysical Prospecting 54 (3), 303-317.

Oliveira, R., Bampi, D., Sansonowski, R. C., Ribeiro Junior, N., Johann, P. R. S., Santos, M. S. and Ferreira, D. M. (2006) *Marlim Field: Incorporating 4D Seismic in the Geological Model and Application in the Reservoir Management Decisions*. SPE 108062.

Sansonowski, R. C.,Oliveira, R. M., Bampi, D., Ribeiro Junior, N., Camarao. L. F. (2007). *4D Seismic Interpretation in the Marlim Field, Campos Basin, Offshore Brazil*. 77th SEG Conference, Expanded Abstracts.

Figure 1 – The Marlim field location in the Campos, Basin.

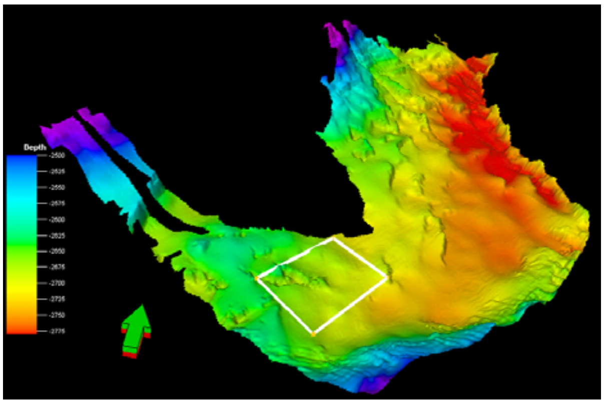

Figure 2 – The reservoir surface with the selected area to perform the inversion.

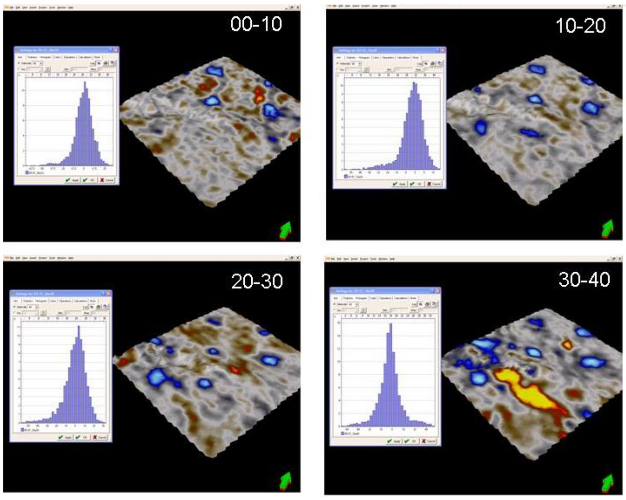

Figure 3 – Amplitude difference maps from 4 angle stacks extracted from the Base of the reservoir.

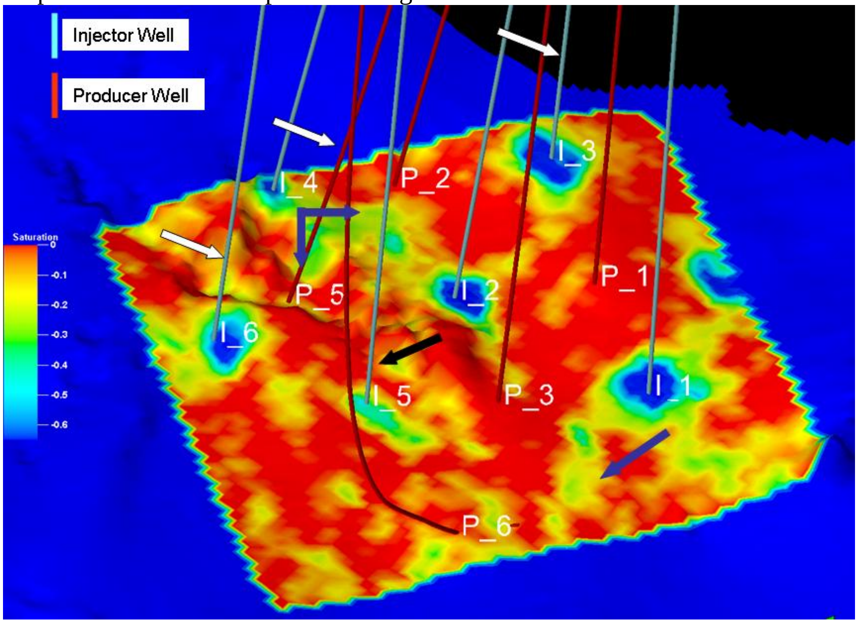

Figure 4 – Saturation map resulting from the inversion. The round shapes around the injectors show the areas swept by the water.

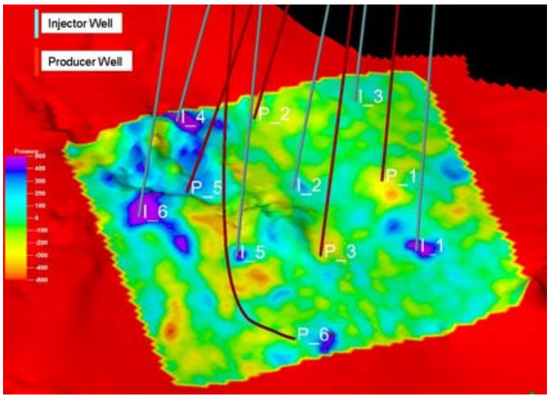

Figure 5 – Pressure map resulted from the inversion.

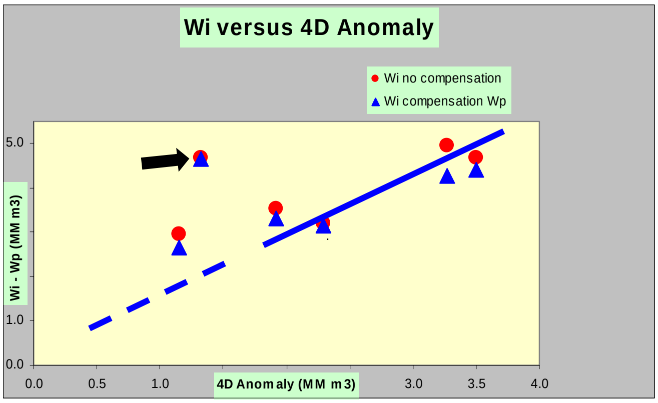

Figure 6 – Cross plot between the water injected and the amount of water calculated from the saturation map. The red dots represent the amount of water calculated directly from the size of the anomalies. The blue triangles represent the same values after compensation by the water produced in the same period.