Time-Lapse Processing and Interpretation: two highly successful case studies

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Introduction

Time Lapse seismic is now becoming a commonly used tool for optimised hydrocarbon field management. In this paper, we present two case studies coming from different geological and economical environment: the first one deals with a deep offshore west African oil field, at an early stage of its production. The second one presents a North Sea field whose production started 15 years ago.

First case study: Girassol field

Since the discovery of the giant Girassol oil field in 1997 and the series of later discoveries, Block 17 offshore Angola has become a vast seismic laboratory for Total and CGG who have been working closely, each in their own specialised area, to design and implement specific techniques for the development of these fields. The 1996 seismic dataset had shown its limitations for defining and understanding the geometry of the various reservoirs encountered during exploratory drilling. Because of the high production cost of the deep offshore Girassol field (1500m), a work plan was drawn up in which seismic would play a key role in optimising the development strategy and reducing risks.

4D seismic

The field development plan took into account the local constraints imposing the "clean" recycling of production gas. Re-injection of the gas into the reservoir is a way of achieving this and the injection must be controlled and monitored. Time-Lapse or 4D seismic surveys offered the solution by providing a seismic image which could be used to monitor the changes and movement of fluids in the reservoir. Dynamic reservoir modelling simulated the pressure variations within the reservoir (depletion) and allowed modelling of the corresponding seismic responses. The results clearly showed a definite "4D response" and indicated pressure variations from 25 to 40 bars. On the strength of these results the reservoir monitoring project was defined.

Very Fast Track (VFT) Processing

The initial development plan for Girassol required delivery of a preliminary representative 4D result within four weeks of the last shot being fired. The aim was to visualize the impact of six months of gas injection on the dynamics of the fluids in situ during the initial production phase. To do this, the sequence designed in 2002 for the reprocessing of the 1999 data was, after being checked and validated, deliberately simplified. This was fully justified by the weak lateral variation in the velocities and the weak dips in the zone and the effect on quality was perfectly measured and controlled. This simplified sequence, known as Very Fast Track processing, was applied to the 1999 base survey data prior to the start of the acquisition. The availability of this VFT processing sequence and the swift response of operations in Luanda between the acquisition vessel and the processing centre led to the delivery of the "Monitor" stack cube in less than two weeks. The post-stack operations involving geostatistical destriping (Figure 4) and matching between the "Base" and "Monitor" cubes was performed rapidly. The 4D signature was produced and delivered in less than four weeks after the final shot.

The very short turnaround time required the use of effective 4D control tools to monitor the convergence of the "Base" and "Monitor" results at each processing stage to guarantee the validity of the results. The tools were so effective that it was possible to monitor how the progression of the intermediate results (Figure 1) followed the fundamental principle of 4D seismic, which asserts that no signal should be seen above the reservoir (Figure 2).

Main results

A clear reservoir signature is visible on the 4D difference (Fig. 3) and a high degree of confidence that there is valuable reservoir information to be extracted from the 4D signature to help further optimise the development of the Girassol field. Interpretation of these results has brought a significant amount of information, including responses and validations/invalidations to the questions and hypotheses formulated by the reservoir engineers. These include:

- Most of the injected gas remains on the top of the B3 system
- The 4D response shows clearly the injection and depletion zones
- The injection is chiefly propagated towards the south, contrary to simulations which had predicted a propagation to the North as well
- 7 % depletion was measured in an injection zone contrary to a prediction of 40 %.
- The highlighting of a non-produced massive sand zone
- Confirmation of the nature of an erosive terminal channel acting as a barrier to the propagation of the injections and to the draining of the oil.

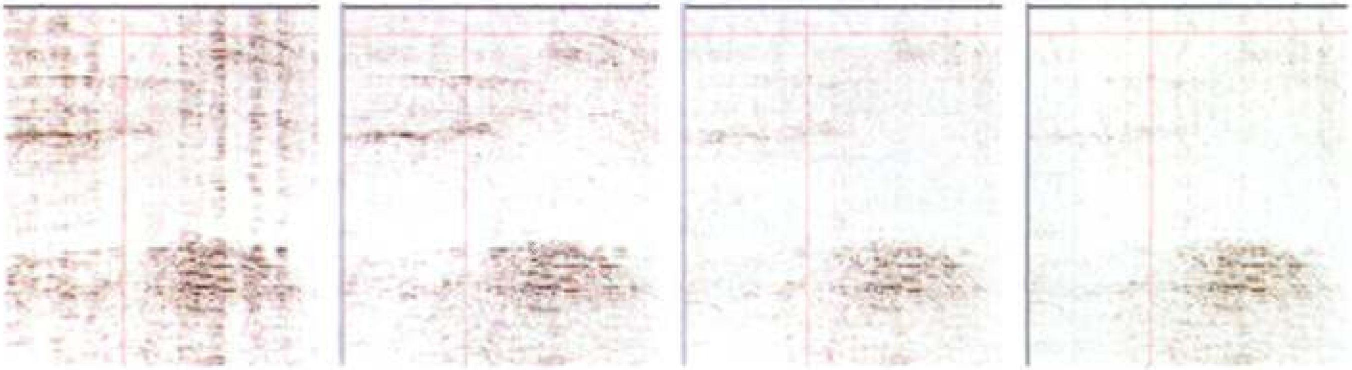

Fig.1: Evolution of the 4D signature during the VFT flow: from raw stack (left) to final migration (right)

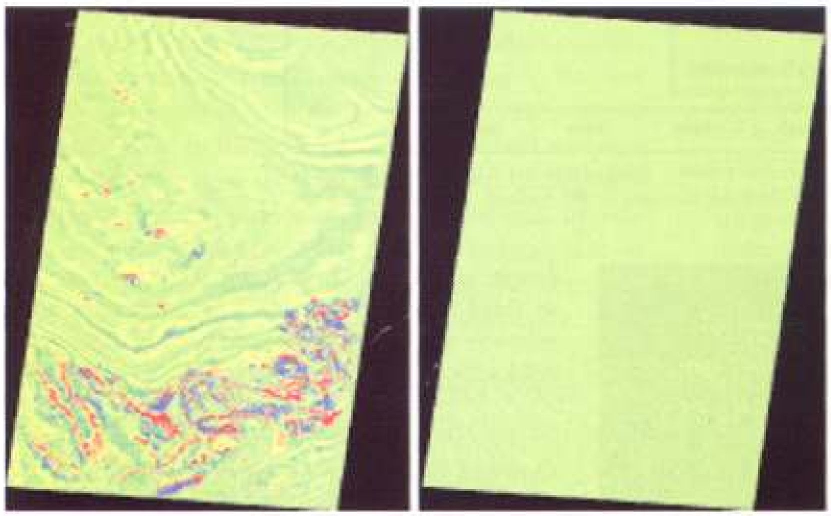

Fig.2 : Amplitude time slice just above top B3 reservoir : Base (left) and difference (right)

Second case study: Oseberg field

The Oseberg Field is a major oil and gas field located in the North Sea some 140 km off the coast of Norway. The production from Alpha North started late 1991 with a two front production drive system; gas injection in the initial gas cap and water injection in the water leg. As an IOR initiative in the decline phase of the production, a time-lapse seismic survey was acquired in 1999 to be compared with the base survey from 1992. Here we focus on the results provided by a 4D elastic inversion. Currently, close to 85% of the initial oil reserves have been produced and these results have been successfully used for infill drilling.

Data processing and elastic inversion

We used a 3D stratigraphic elastic inversion (StrataVista™) on near, mid and far offset cubes. Estimates of elastic impedance (Connolly, 1999), acoustic impedance and Poisson's ratio in thin layers were obtained for each seismic vintage. The average thickness of each layer was typically 10 ms TWT, however, both layer thickness and impedance vary laterally and are estimated by the inversion. The workflow consisted of four steps: (i) data processing and preconditioning; (ii) wavelet estimations; (iii) building the prior model and constraints; (iv) parameter testing and inversion.

4D Interpretation

Inversion results are 3D volumes of rock properties (impedances, Poisson's ratio, etc.), as opposed to seismic amplitude data, which are related to seismic reflectivity between layers. Experience at Oseberg has shown the benefits of integrating inversion results with reservoir models and well data through a 3D VR visualisation system. Prior to the interpretation, the acoustic impedance (AI) and the Poisson's ratio (PR) cubes from the different vintages (1992 and 1999) were depth converted and integrated with well data and reservoir model. While the individual parameter cubes (the PR and AI cubes) are used in reservoir characterisation, the difference cubes (1999 – 1992) have been investigated for 4D response. Screening of the individual difference cubes revealed that the PR difference cube had the largest potential with respect to 4D responses. An east-

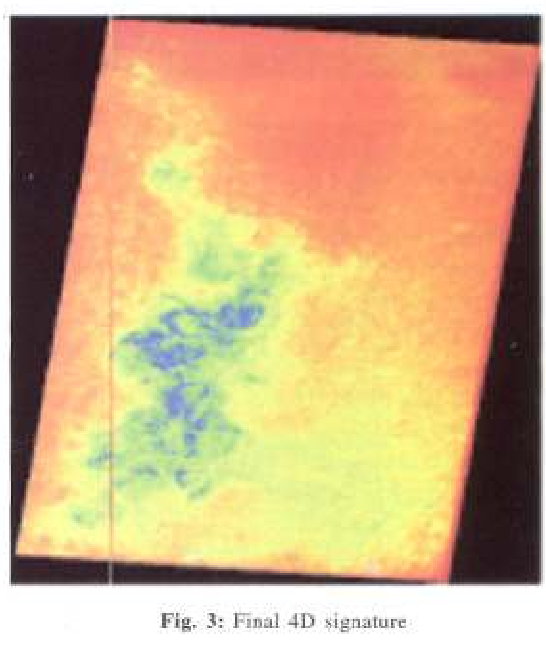

Fig. 3: Final 4D signature

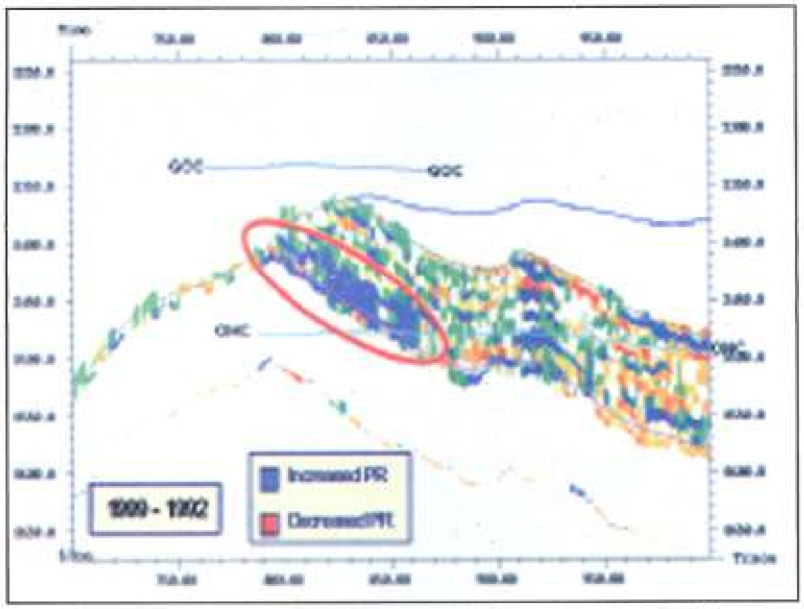

Fig.4: PR difference cross-section (1999 – 1992) from the Alpha North Structure of the Oseberg Field. Note the increase in PR upflank from the initial oil/water contact.

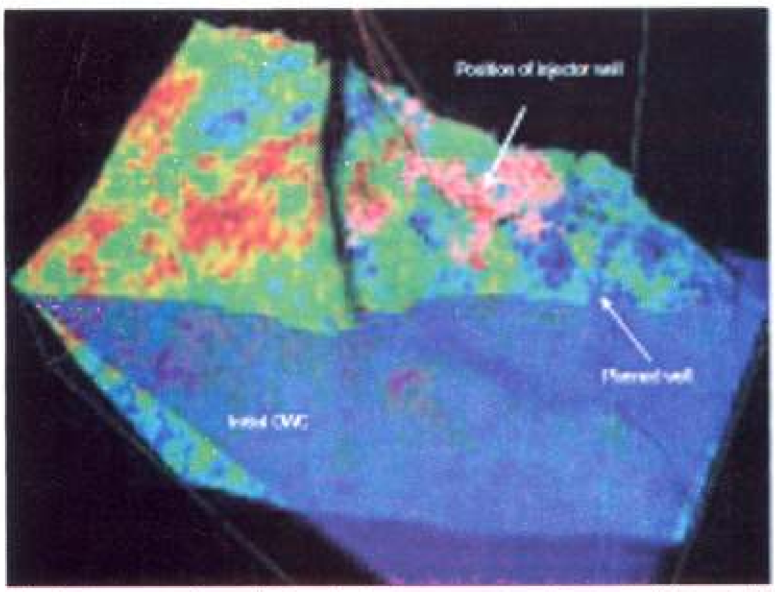

Fig.5: A grown volume (light red colour) representing reduction in PR from 1992 to 1999 corresponds to injected gas. The 3D volume is overlaid an AI surface attribute map within Upper Ness. The blue surface represents the initial OWC. The location of a planned well is indicated.

west PR difference section (1999 – 1992) is shown in Fig. 4. A fairly strong increase in PR for the 1999- relative to the 1992 cube corresponds quite well to the expected displacement of oil by water.

Within the 3D cubes, anomalies in the PR difference cubes associated with water- and gas displacement from 1992 until 1999 can be observed for the different reservoir. A voxel growing technique has been applied to create 3D volumes of connected voxels. These features can be compared to fluid saturation changes as output from the reservoir simulation model and used in planning of infill wells

An example from the Ness Formation is shown in Fig. 5. A 3D body grown within the PR difference cube is overlaid an acoustic impedance map. For this specific exercise a seed point was placed on an anomaly within the 3D cube corresponding to injected gas. All connected voxels with values within the predefined constrains (both in parameter values and reservoir zone) are detected and displayed. It is observed that the detected volume more or less follows the low acoustic impedance zones, indicative of channel sands, in Ness. The data have been used to plan the location of an oil production well in the northern part of the Alpha North Structure, to be drilled early 2002. Based on the elastic inversion data, the well is expected to penetrate an undrained channel in the Ness Formation.

Main results

The method of time lapse elastic inversion combined with modern 3D visualisation techniques has demonstrated to have a potential in supporting the reservoir history matching process and detecting areas of undrained reserves. The data have been used to guide the positioning of many infill wells. These new wells have so far produced excellent performances.