Time-Lapse Seismic*-Concept, Technology & Interpretation

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Abstract:

Time Lapse seismic studies proved to be an important reservoir management **technology** over the past few years as success reported in many basins around the globe. Brief attempt made in this paper to discuss the concept, technology and interpretation of time lapse data along with the CGGVeritas **novel approach, 4D Global Inversion.** Comparison between traditional time lapse inversion and 4D Global inversion shows the superiority of this new technique over the traditional inversion. Bayesian Litho-Classification technique for interpretation of time lapse data also discussed along with associated uncertainties.

Key words: Time-Lapse Seismic, 4D Global Inversion, Time-Lapse Interpretation, Bayesian Litho Classification

Introduction

Time lapse seismic measurement proved an important reservoir surveillance tool as success has been reported in various basins all around the globe. Seismic surveys recorded over the period of time in hydrocarbon producing field have the capability to record the production related changes in the field. Analyzing the difference in Seismic surveys provide the vital information about the dynamic properties such as Saturation, Pressure and Temperature. In this paper a brief attempt made to discuss about the Time-Lapse concept, Technology and interpretation of time-lapse data.

Concept: Hydrocarbon production affects the following reservoir properties.

- Saturation (gas, oil & water)
- Pressure
- Temperature

Saturation, pressure and temperature directly affect the following seismic parameters.

- P-Wave
- S-Wave
- Density

For time lapse to be effective, changes in the reservoir properties must cause a detectable change in the seismic parameters. With this concept seismic surveys are recorded over the time span in a hydrocarbon producing field to measure elastic changes and transferring the knowledge into dynamic properties such as Saturation, Pressure and Temperature.

A time lapse study relies on two factors, called **repeatability** and **detectability.** Below is the brief description of various factors which should be considered during acquisition and processing of the surveys for time-lapse studies.

Repeatability is the indicator of how identical base and monitor surveys acquired and processed. Repeatability can be divided in two categories which are related with acquisition and processing.

Acquisition Repeatability

- Shooting directions
- Acquisition systems
- Geometry/positioning
- Seasonal

Processing Repeatability

- Processing algorithm
- Processing software
- Processing hardware

For good time-lapse surveys, we should have two above mentioned component as identical as possible. If seismic surveys are repeatable then they should have almost identical traces at respective locations.Repeatibility can be measure by a factor termed as NRMS (Normalized Root Mean Squre). This factor measures the relative difference between two traces and sensitive to time, phase and amplitude differences.

The normalized RMS amplitude (NRMS) of two traces A and B within a given time window is expressed as (Kragh and Christie, 2002):

NRMS=RMS (B-A)/1/2{RMS (B) +RMS (A)}

The values of the NRMS are limited to the range of 0-2. If both traces are anti-correlated (i.e., 180 degree phase shift, or if one trace contains only zeroes), the NRMS equals 2. If the amplitude of one trace is half that of the other trace, the value of NRMS is equal to 0.667.

NRMS tracking at various 4D constrained processing stages is an important step to QC the improvement in repeatability factor. **Figure 1** shows one such measurement at various processing stages. As indicated in figure 1, NRMS should have a decrease nature as we advance in processing project. **Figure 2** also shows the NRMS values extracted within a certain interval of 4D interest. Low values of NRMS in area of interest suggest the good repeatability. High NRMS can indicate poor repeatability, production signal or low RMS amplitude levels in the Base and Monitor surveys. In Summary, few factors which could be considered for 4D constrained processing are listed below.

- Keep processing simple and deterministic
- Same software and algorithm
    - o Simultaneous processing
- Make data as similar as possible as early as possible
- QC 4D signal at each stage

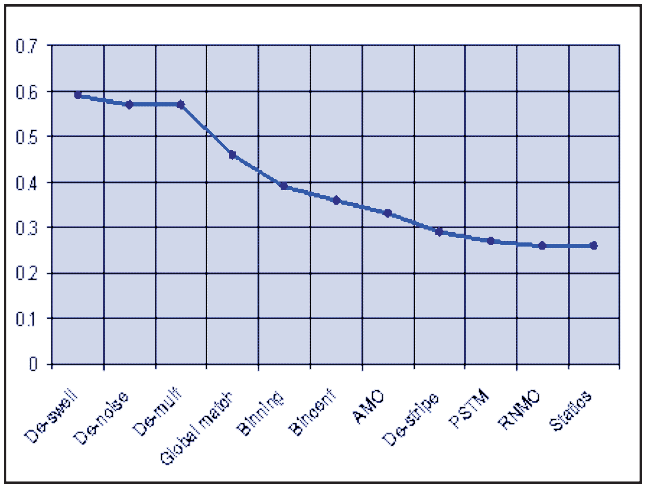

Fig. 1: NRMS tracking at various stages of 4D constrained processing

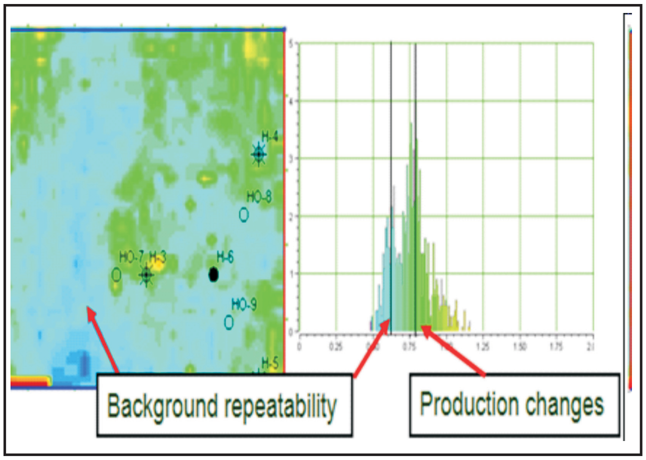

Fig. 2: NRMS map in the 4D interval. Blue numbers indicate the low values of NRMS and suggest the good repeatability in the area of interest

Term delectability denotes the ability of the reservoir parameters such as Pressure, Saturation and Temperature to create appreciable change in seismic parameters i.e. P-wave, S-wave and Density. Fundamental constants which are affected by production are Bulk modulus, Shear modulus and Density, which subsequently affects P-wave, S-wave and Density. First attempt should be made to understand the influence of saturation, pressure, temperature on these elastic constants. Biot-Gassman equations (1951 and 1956) provide the platform to understand the lithology, fluid and reservoir parameters effect on seismic parameters for saturated rocks.

$$V_{P\_sat} = \sqrt{\frac{K_{sat} + \frac{4}{3}\mu_{sat}}{\rho_{sat}}} \qquad V_{S\_sat} = \sqrt{\frac{\mu_{sat}}{\rho_{sat}}}$$

Two important terms in above equation are related with the matrix (Lithology) and fluid. During sensitivity analysis matrix properties should be estimated with right mixing rule which suites to specific area. In case of fluid properties, someone should take care of method i.e. Batzle-Wang, FLAG model and type of saturation i.e. Homogenous, Big patches or medium patches. **Figure 3** shows the two cases for saturation that could occur in a producing field. First case when reservoir flooded with water and second when gas come out of the solution as bubble point exceeded. Part (a) in **Figure 3** show the water flooding case where P-wave and density increases as water replaces hydrocarbon. Part (b) show the gas out of solution case when bubble point exceeded and velocity and density drop occurs. As production scenario is quite complex and variety of scenarios should be modeled to understand the multiple reservoir parameter effect on seismic parameters. **Figure 4** shows three scenarios for pressure and temperature variation and subsequent changes in synthetic seismic. In figure 4, first scenario shows constant pressure 0.5 MPa, temperature variation (10-2500 C) and corresponding synthetic seismic. At 0.5 MPa pressure, the oil is below bubble point and gas is liberated for all temperatures. In second scenario as pressure increases to 1.0 MPa, it requires higher temperatures before free gas or steam can occur and shift the seismic events downward (Marked in red rectangle) as result of lowering in velocity. Similar case is shown in scenario 3 for higher pressure 2.5 MPa. Depending on the production scenario in a particular field, similar observation can be carried out with the variation of Saturation, Pressure and Temperature.

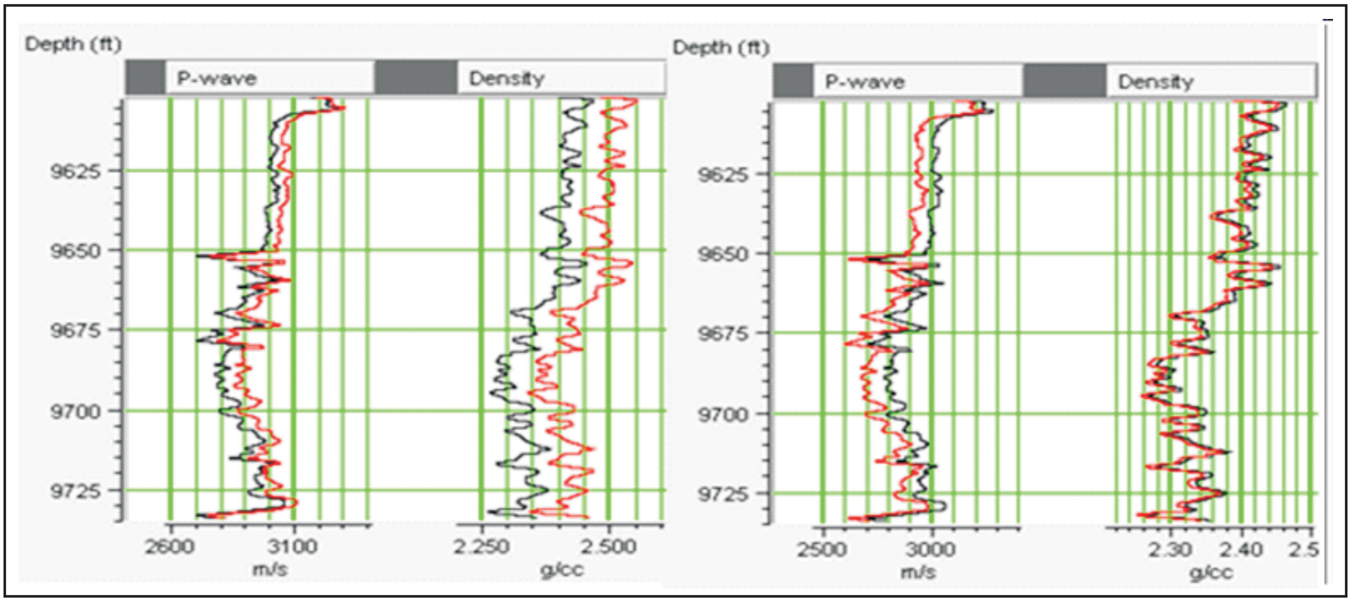

Fig. 3: Sensitivity of seismic parameters to reservoir parameters (a): Water flooding case (b): Gas out of solution as bubble point exceeded. Recorded curves are in black and estimated curves are in red.

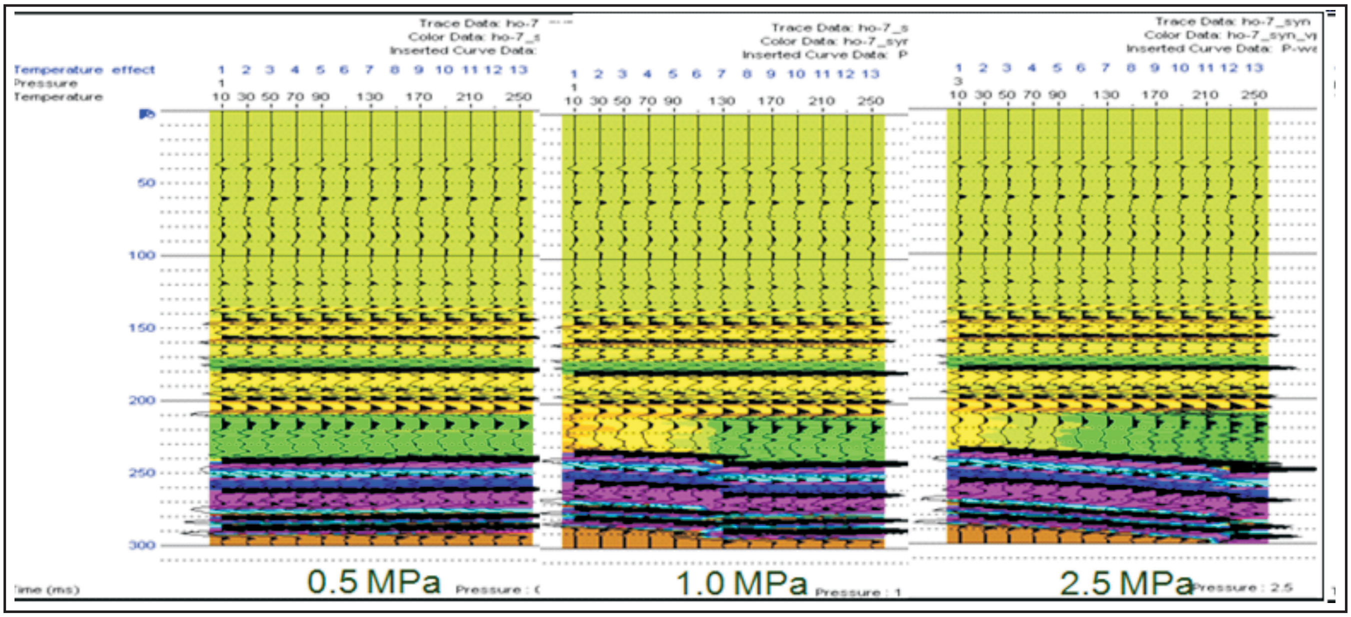

Fig. 4: Sensitivity of seismic parameters to reservoir parameters: pressure and temperature variation and corresponding synthetic seismic.

Static models, dynamic reservoir models along with Rock-physics models should also be used to model the baseline and monitor reflectivity for capturing the pressure, saturation and temperature effects. There are several direct and indirect advantages of this integration. For example, modeling of baseline reflectivity utilizing the static, dynamic and rock-physics suggest the validity of static model (Geological model) and ultimately in better history match.

In summary following datasets can be used for sensitivity analysis.

- Well-Logs
- Ultrasonic measurements
- 2D-modeling
- Static model, Rock-Physics model and Dynamic information

Technology:4D-Global Inversion

Traditional approach for the 4D inversion is to invert base and monitor survey independently and subtract the elastic results to infer the change from production effect. This approach results in the complexity for 4D anomalies interpretation. Difference arises from independent inversions may not be related with production. Rather, these artifacts are likely to be a consequence of individual inversion converging to different solutions in model space that are not necessarily consistent with each other. **Figure 5** below shows the approach for independent inversion for time lapse data. **Figure 6** shows problem associated with the independent inversion approach for theoretical water flooding case. As we can see with increase water saturation, impedances should increase in theoretical case but independent inversion results (Bottom left corner) show the scatter in various direction and can be attributed to various reason which is difficult to interpret as 4D anomalies.

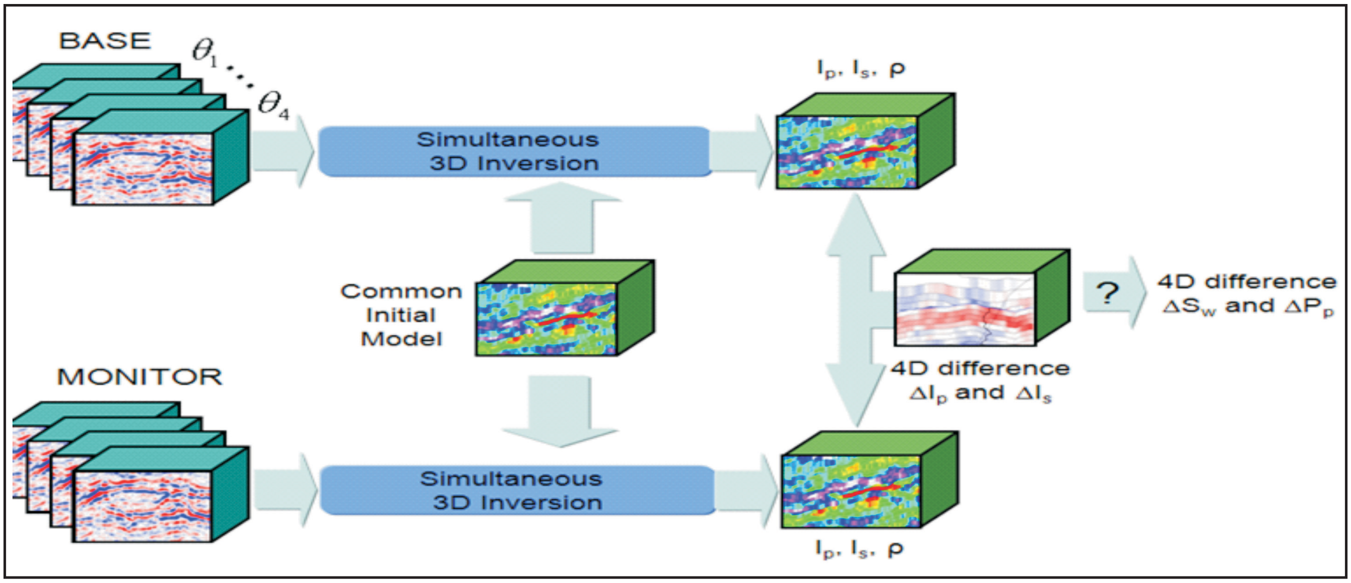

Fig. 5: Traditional independent inversion workflow

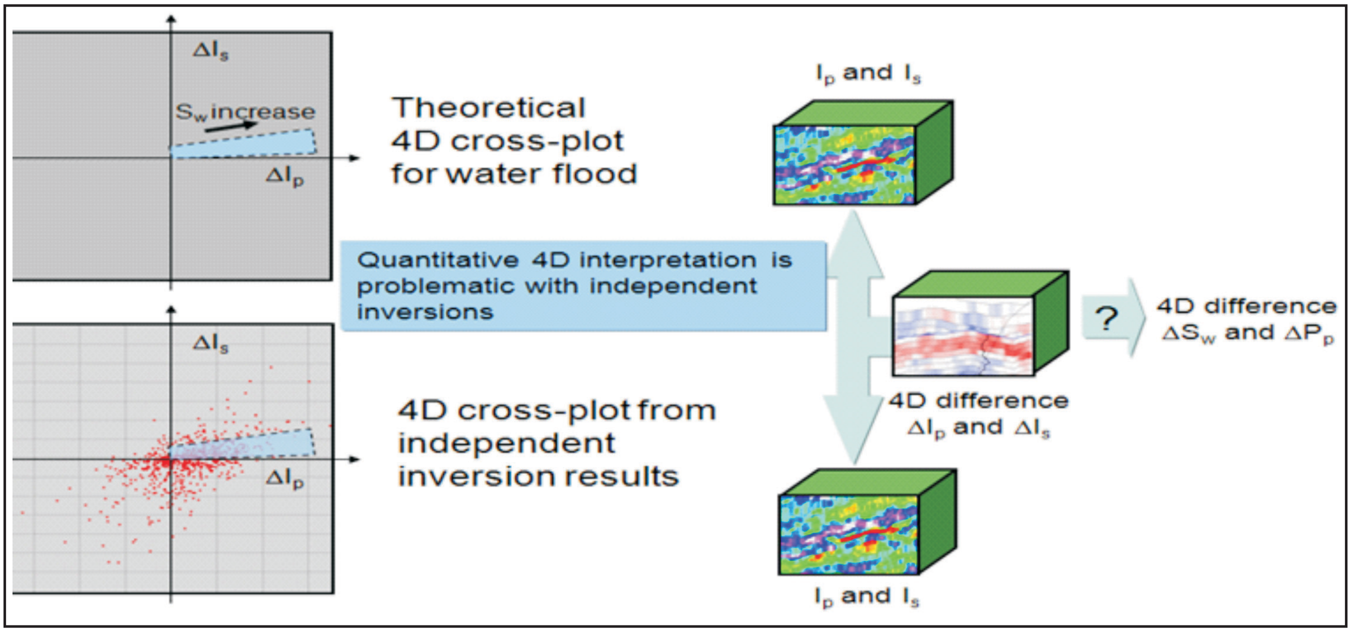

Fig. 6: Theoretical water flooding case comparison with the traditional 4D time lapse inversion results

CGGVeritas developed the propriety method of inverting the base and monitor survey together constrained by the Rock-Physics information to reduce the independent inversion uncertainty. **Figure 7** shows this approach and superiority of this approach over the independent inversion. In this approach initial model for different monitor vintage updated as per the monitor seismic change and expected Rock-Physics changes. MASK is generally built to update differently the inversion results inside/outside the zone where we expect the production related effects.Geologist, Geophysicist and Reservoir Engineers can make the decision on the mask with the help of base and monitor seismic and dynamic simulation information. **Figure 7** show the comparison of results of independent and 4D-Global inversion (Lafet et al., 2009). It is observed that 4D-Global inversion simulate the effect of theoretical water flooding case thus reducing the ambiguity in 4D interpretation of the anomalies

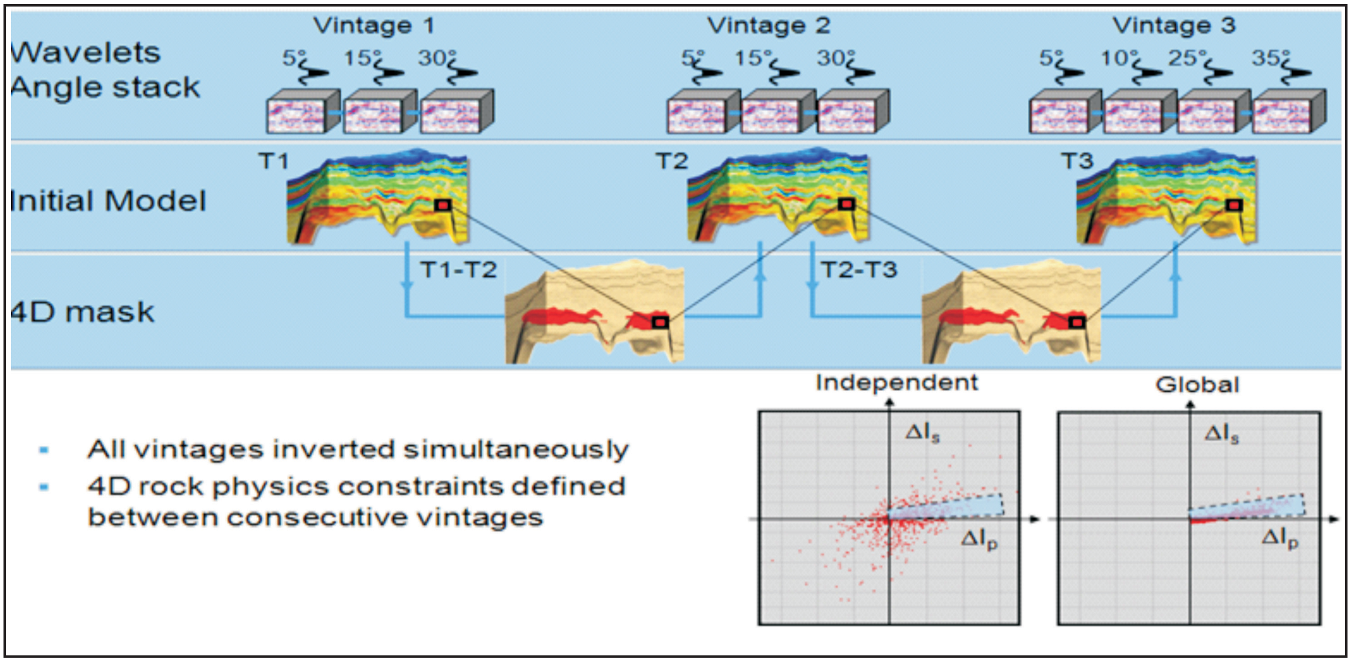

Fig. 7: 4D Inversion workflow and comparison of traditional independent and Global 4D inversion results

Time-Lapse Interpretation

Time lapse surveys can be interpreted in qualitative as well as quantitative way. One way of interpreting the time lapse anomalies is to compare the difference of amplitude and time shift from actual 4D datasets. Quantitatively, rock-physics information can be applied to 4D inversion results to capture the time lapse effects. This paper mainly describes the quantitative approach for 4D interpretation calibrated against the petro elastic modeling.

CGGVeritas uses the Bayesian classification approach to interpret the 4D inversion volumes. First step in this approach is to define the training datasets. For Bayessian litho-classification. Following datasets can be used for training purpose and generation of probability density functions.

- Well-logs
- Upscaled Logs
- FRM logs
- Seismic attributes
- Inversion attributes

Best datasets could be one which separates the different lithology and fluid with minimum overlap in attribute space. Once this stage is over, Probability density function can be defined for the base survey. These probability density function freeze for monitor survey and applied directly to monitor inversion results to see the relative movements of fluid with respect to base survey.

Figure 8 show the probability density function using the Impedance and VpVs attribute for three lithofacies i.e. Water Sand, Oil Sand and Shale for a field in Norwegian North Sea (Lafet et al., 2009). Bottom and extreme right portion of this figure show the Oil-Sand probability in cross-section and map view for base survey.

Figure 9 show the results from the application of base probability density function to monitor survey. It is quite clear from Figure 8 and 9 that areas under high oil probabilities shifted towards the brine probabilities, suggesting that oil replaced by water because of water flooding (Lafet et al., 2009). **Figure 10** shows the oil sand probability and measured Sw in deviated well which show the good correlation between measured Sw and predicted oil sand probability (Lafet et al., 2009).

This particular interpretation scenario is specifically restricted to water flooding case. If water flooding and pressure depletion co-exist in the field then separate mechanism should be used to decouple the pressure and saturation effect and it continues to be much more difficult to set.

One way could be to use separate training datasets for pressure and saturation sensitivity to classify the inversion results and would require calibration against petro elastic modeling.

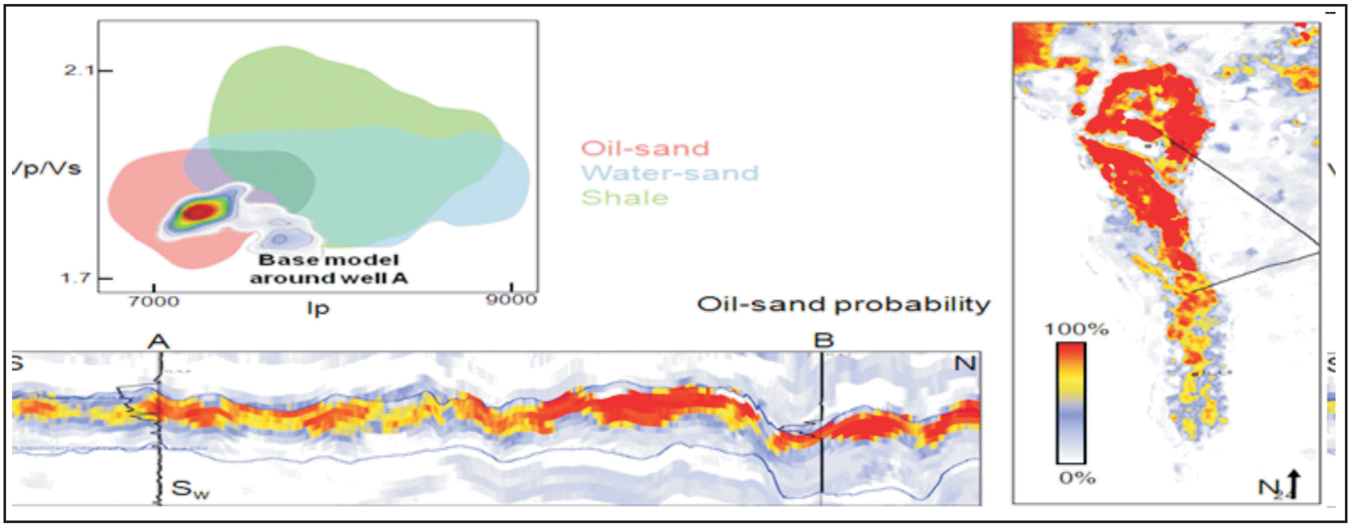

Fig. 8: Base Oil sand probability after application of base probability density function. Top left portion is the probability density function using the P-impedance and VpVs elastic attributes. Bottom portion is Oil sand probability in section view running South-North. Extreme right portion is the Oil sand probability in map view.

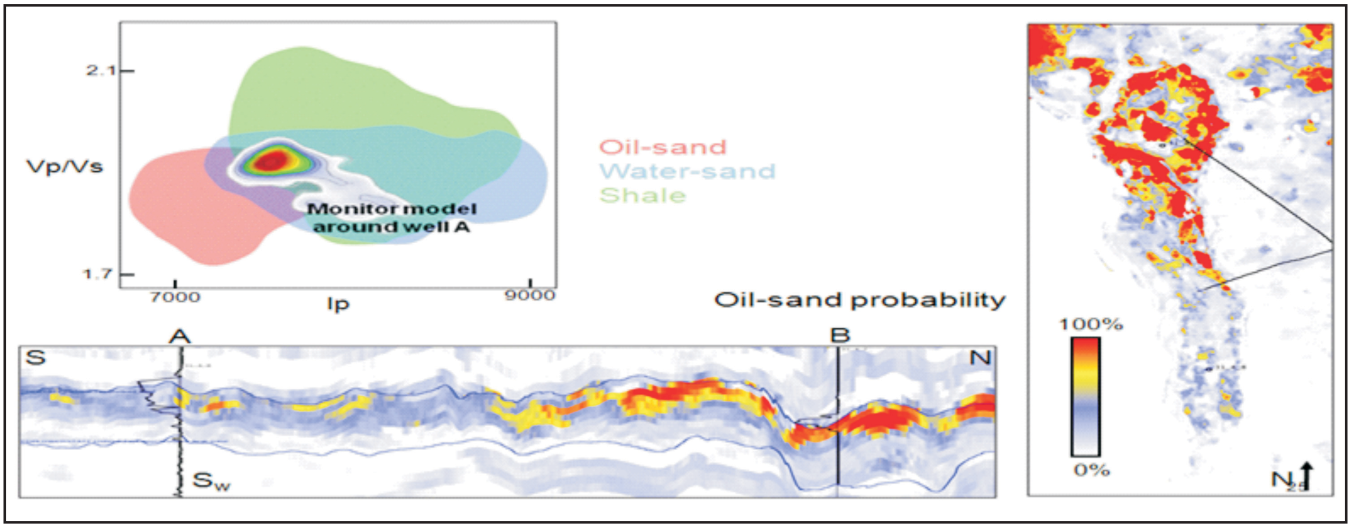

Fig. 9: Monitor Oil sand probability after application of base probability density function. Top left portion is the probability density function using the P-impedance and VpVs from base survey. Bottom portion is Oil sand probability in section view running South-North for monitor survey. Extreme right portion is the Oil sand probability in map view for monitor survey.

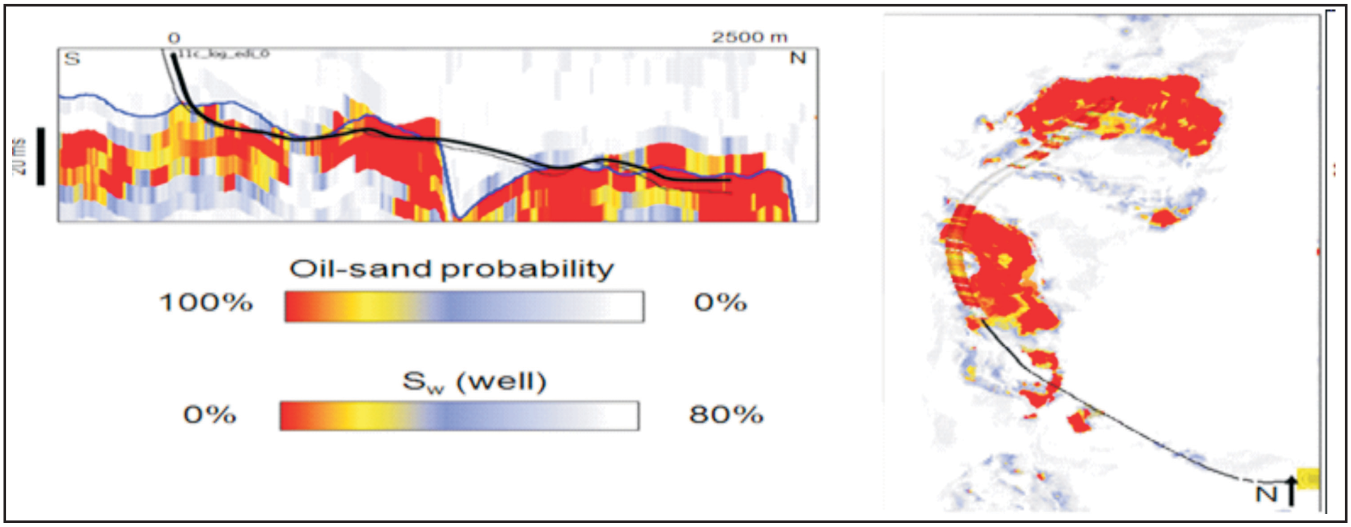

Fig. 10: Oil sand probability against the measured Sw in deviated well

Conclusions

Concept, technology and interpretation of time lapse anomalies discussed in this paper.4D Global inversion discussed in detail in comparison with the traditional inversion approach. It is proved that 4D-global inversion approach is inclined to bring information which is related with production changes rather than the noise or convergence of inversion model space. Bayesian litho-classification is powerful tool to interpret the time-lapse inversion data but should be used carefully with appropriate information for particular production scenario.

Acknowledgements

Authors would like to thank CGGVeritas for permission to present this paper

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