High resolution 4D-friendly analysis: application to gas-oil contact monitoring at Troll West

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Abstract

A new workflow automatically providing high-resolution 4D-friendly attributes is applied to the Troll West Gas Province datasets (offshore Norway) to monitor the movement of the gas-oil contact. It consists in generating attributes of velocity and amplitude changes using enhanced resolution imaging and morphing. Morphing is used to remove velocity or noise-induced traveltime differences between the vintages, resulting in a 4D-friendly difference which reflects more genuine changes of amplitude.

These attributes are used to train a neural network scheme for estimation of gas-saturation changes and quantification of the gas-oil contact movement. The analysis shows coning along the tracks of a number of multilateral wells and identifies undrained volumes for infill drilling.

Introduction

In recent years, the focus of seismic reservoir monitoring is shifting towards quantitative studies aiming for example at estimating precisely the oil and water saturation changes or the amount of pressure depletion. These results represent information that can directly be used by the reservoir engineer and play a major role in reservoir management. In order to achieve these objectives, the quality of the 4D signal is key to the success, and in particular, repeatability between the seismic vintages is important. Furthermore, as repeat surveys are acquired more frequently and 4D seismic is applied to more complex reservoirs, the ability to image and quantify subtle production effects is becoming more important. This paper present a new workflow allowing better understanding of such subtle 4D effects.

The Troll West Gas Province

The Troll field is situated in the Norwegian North Sea at about 80 km northwest of Bergen (see Figure 1) in blocks 31/2 and 31/5. The field is divided into two main areas, Troll East and Troll West. Troll West is itself divided into the Oil Province and the Gas Province where the oil column is 22-26 m and 10-13 m thick respectively (Leiknes et al., 2004). It is the Troll West Gas Province that is the subject of the present study. In order to recover oil from the thin layer, it has been necessary to develop advanced drilling and production technology. Over 100 wells have already been drilled in the Troll Field, all of them being horizontal. 4D seismic also plays an important role in this process. It is used to understand the dynamic of the fluids and in particular map the movement of the gas-oil contact.

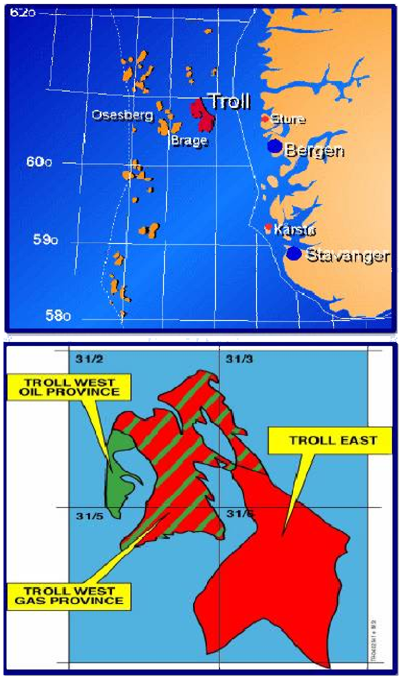

Figure 1: Location of the Troll field, offshore Norway (top) and of the Troll West Gas Province (bottom). Figure reproduced from Leiknes et al. (2004).

4D processing

The Troll field is covered by several vintages of seismic data. The match and merge of the 1989 and 1991 datasets (both acquired pre-production at Troll West) provided the base survey for a 4D study. Two further datasets have also been acquired in 2001 and 2003. The base and two monitor surveys were processed during 2003, first through a fast-track sequence that included Contribution Scaling DMO, and finally through an optimum sequence that included ADA (Acquisition Dependent Amplitude) compensation and preserved amplitude Kirchhoff pre-stack time migration. This method removes the requirement for a pre-migration regularization stage, honours the true source and receiver locations of the data, removes the acquisition footprint and inherently improves repeatability and the 4D response. This study focuses on the analysis of the baseline dataset and the 2003 monitor (after approximately 5 years of production).

Resolution enhancement

A major challenge to successful reservoir monitoring is the requirement to image and quantify subtle production effects. This ability is becoming increasingly important as repeat surveys are acquired more frequently and 4D seismic is applied to more complex reservoirs. Here, this issue is addressed using a new workflow automatically providing high-resolution 4D attributes and requiring no interpretation as part of the process. This workflow starts with the optimisation the vertical resolution through high-frequency imaging (HFI) (e.g. Torgersen et al, 2004). This process uses vector calculus to extract higher frequencies from the seismic data. Detailed explanations of the High Frequency Imaging can be found in Hirsch and Perry (2003).

This technique usually used in 3D to resolve thinner beds is applied to this 4D analysis in order to image and quantify more subtle 4D signatures.

Figure 2 (page 4) shows an example of improved 4D signature using HFI. In this example, the upwards movement of an interface cannot be imaged at normal bandwidth. This interface, invisible on the baseline data, becomes slightly visible for the monitor survey because the thickness of the layer increases, reducing the tuning effect and making the event possible to image. However, with higher frequencies, this event can be clearly imaged for both baseline and monitor data, and the movement is visible.

4D-friendly differencing

The second step of the 4D-workflow involves the application of 4D-friendly differencing: this method includes the morphing of the monitor dataset onto the baseline. This technique is similar to non-rigid matching (Nickel and Sonneland, 1999) or vertical-warping (Hall, 2002) but differs in the way that every single peak and trough from the monitor survey is matched to its baseline equivalent using pulse shape recognition criteria and by applying time-varying time-shifts. Note that since the magnitude and the direction of the movement of different events can vary very rapidly, cross-correlation cannot be used to determine very precisely the local misalignment of all events. Indeed, in the previous example, within about 15 ms, an upwards movement of about 1-2 ms and a downwards movement of 4-5 ms can be observed, which could not be estimated by cross-correlation (too short window, not enough samples).

The 4D difference after this morphing (referred as the morphed difference) therefore reflects more genuine changes of amplitude, as it is not corrupted by velocity or noise-induced traveltime differences. This procedure effectively decouples the effects of traveltime and amplitudes differences which are otherwise combined and usually difficult to separate and interpret. Figure 3 (page 4) highlights the benefits of 4D-friendly differencing over traditional differencing for an example from the Troll field. The effect of the removed traveltime differences is treated separately in the following step.

4D attributes generation

Using the time-shift volume required to morph the monitor dataset, the time-thickness changes can be calculated. These are then separated into velocity changes and/or actual physical movements due, for example, to interface movement or compaction. In addition, the changes in acoustic impedance can be estimated by directly inverting the morphed difference.

Quantitative gas-oil contact movement analysis using neural network calibration

One of the objectives of 4D reservoir monitoring at the Troll West Gas Province is to quantify the gas-oil contact movement in order to identify undrained zones for infill drilling and improve the understanding of the fluid movements across the field. In order to estimate those gas saturation changes, time-lapse logs are used to calibrate 4D attributes with neural networks. Neural networks have proven to be a popular tool to generate log-property volumes (e.g. Gawith et al, 2004). Here, three seismic attributes are used to train the neural network: the time-thickness changes described previously, which directly relate to interface movements and velocity changes; the changes of impedance, influenced by fluid changes; and the acoustic impedance itself, which provides an indirect estimate of porosity, obtained by coloured inversion (Lancaster and Whitcombe, 2000). The target property for the training is the change in gas saturation (ΔSgas). Vertical wells with high-quality data were selected for the training. The trained neural network is then applied to the entire datasets in order to obtain a ΔSgas volume and quantify the total movement of the gas-oil contact. Figure 4 (page 5) shows the map of the gas-oil contact movement across the area. It varies from 0 m in areas were no movement occurs to 10-12 m where the movement is maximum. As expected, areas where the movements are maximal correlate with the location of the wells tracks, owing to the drawdown in the vicinity. This maximum movement may indicate gas breakthrough as it corresponds to the whole extent of the original oil column thickness.

Conclusions

A new 4D workflow is presented. It includes high-frequency imaging and 4D-friendly differencing that allows time-thickness to be monitored and partitioned quantitatively between velocity changes and interface movements. True acoustic impedance changes are also obtained directly from the morphed difference volume.

This workflow has been applied to the Troll 4D datasets in conjunction with neural network calibration. The movement of the gas-oil contact is found to vary by up to 12 m in the vicinity of some wells. Zones of low movements represent potential undrained volumes for infill drilling.

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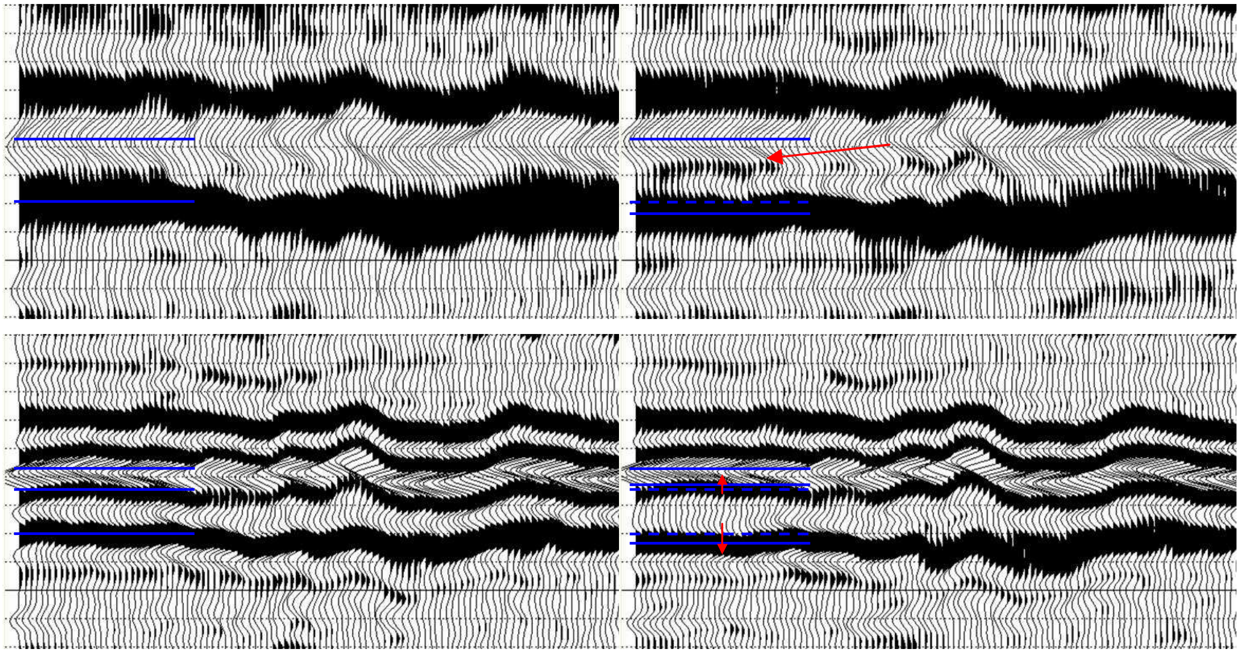

Figure 2 example of high frequency imaging in 4D. (Horizontal lines indicate 10 ms marks)

Top Left: Baseline data (at normal bandwidth). The blue lines indicate the approximate location of two events (through above peak).

Top Right: Monitor data (at normal bandwidth). The blue lines indicate the location of the same events. The dashed one indicates the original location of the peak event highlighting a downwards movement. Note the appearance of a new event indicated by the red arrow. The production effects have separated the through and the peak visible on the baseline data and reduced the tuning effect.

Bottom Left: Baseline data (after high frequency imaging). New events corresponding to thinner beds are revealed. The blue lines indicate the approximate location of three horizons (a through and two peaks).

Bottom Right: Monitor data (after high frequency imaging). The blue lines indicate the location of the same events. The dashed ones indicate their original locations. The top peak has moved up slightly while the bottom peak has moved down.

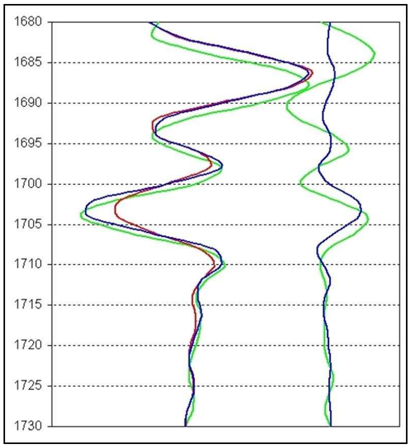

Figure 3: 4D-friendly differencing

The main visual differences between the baseline (red trace on the left) and the monitor (green/left) are the traveltime difference clearly visible at the main peak at 1687 ms and a smaller traveltime difference combined with an amplitude difference at the 1703 ms trough. After morphing, the monitor (blue/left) is aligned in time with the baseline. The traditional difference (green trace on the right) shows significant signal between 1680 and 1710 ms whereas the morphed difference (blue/right) only highlights the amplitude difference at 1703 ms.

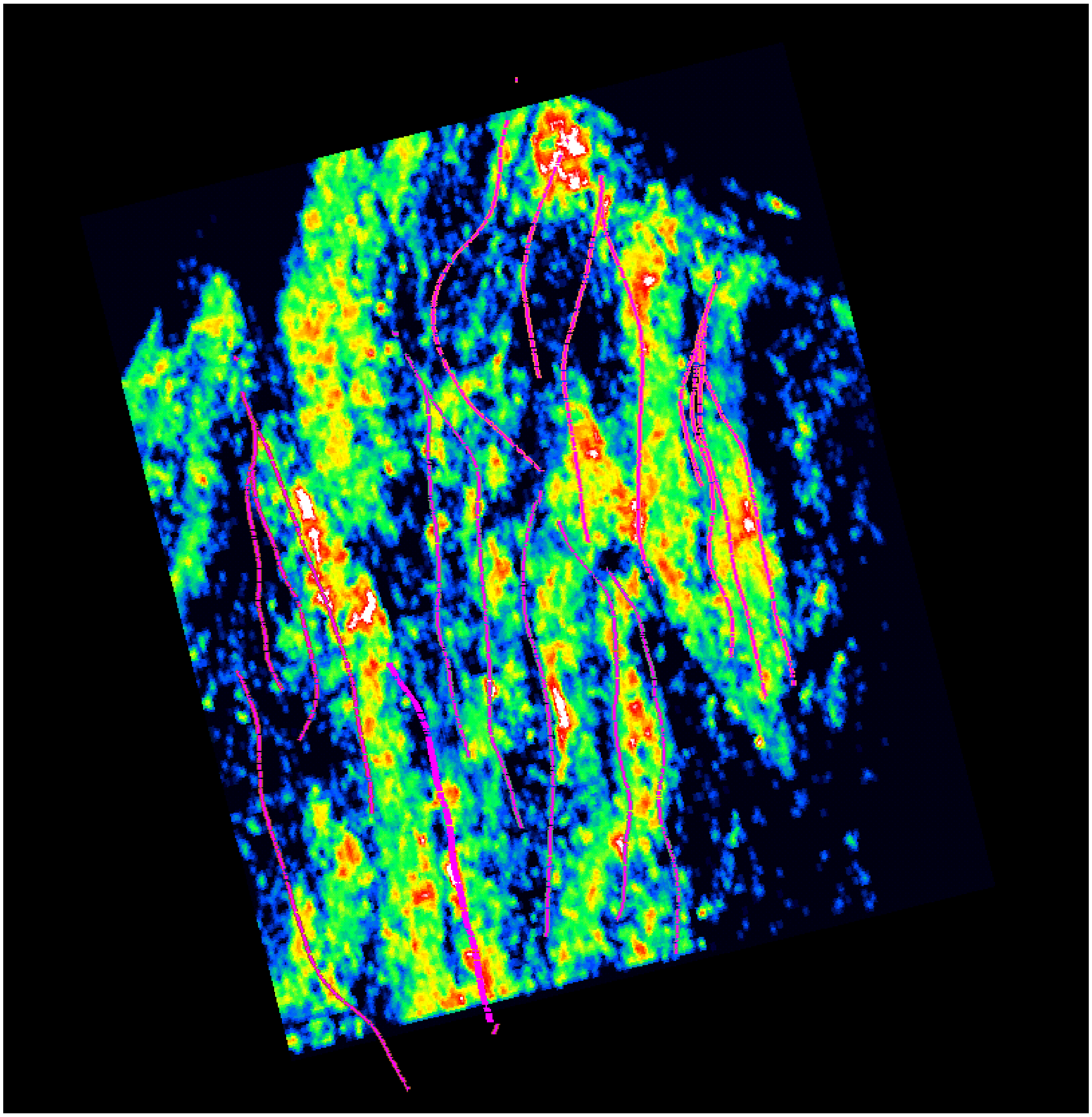

Figure 4: Map of the gas-oil contact movement

This map shows the gas-oil contact movement between 1991 and 2003 after 5 years of production. This movement varies from 0 (black/blue) in undrained areas to 10-12 m (red/white) in the vicinity of some of the wells, highlighting coning and possible gas breakthrough.