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Correlation of Well Activity to Time-lapsed Signatures in the Valhall Field for Enhanced Dynamic Interpretation

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SUMMARY

We propose an innovative approach that uses well data to constrain the 4D seismic response and help reduce noise levels. Implementation of this well-centric approach requires multiple seismic surveys shot at frequent intervals over the same reservoir. There are now many fields for which such datasets have become available. One such example has been shown previously by Huang and MacBeth (2009) for the non-compacting Schiehallion field. Here we show a further application to the Life of Field Seismic (LoFS) data acquired over the compacting chalk of the Valhall field. The resultant signals identify only those areas of the seismic which are strongly consistent with the well activity, and hence define portions of the reservoir connected to the wells. This information unites the seismic and well domains without the use of the simulation model. The signal tends to be robust and have a much lower noise when compared to the individual 4D seismic difference signatures. This seismic attribute can be used as a diagnostic tool for examining reservoir connectivity and constraining the simulation model.

Introduction

A common objective in the workflow of many time-lapse projects is the need to establish a relationship between the processed 4D seismic products and fluid flow simulations. This objective is typically met by matching observed and predicted 4D seismic, either at a qualitative level or quantitatively via a seismic history match (Stephen and MacBeth 2006). As observed seismic data are generally not yet sufficiently calibrated to warrant detailed quantitative inspection, we believe the key to bridging these two domains is the understanding that 4D seismic signatures must respond directly to changes in well production and injection during the time periods over which the 4D surveys are shot. Well data used predominantly for history matching in the reservoir engineering domain can now also be used to constrain the 4D seismic response and help reduce noise levels. Implementation of this well-centric approach requires multiple seismic surveys shot at frequent intervals over the same reservoir. There are now many fields for which such datasets have become available. One such example has been shown previously by Huang and MacBeth (2009) for the non-compacting Schiehallion field. Here we show a further application to the Life of Field Seismic (LoFS) data acquired over the compacting chalk of the Valhall field.

Method

In a hydrocarbon reservoir the 4D signature is driven by changes in pressure and saturation due to the production and injection activity. Thus at any particular location in the reservoir, the 4D signature is a direct function of the nearby well activity. More specifically, by modifying the proposed pressure-saturation equation of MacBeth et al. (2006) to involve only well activity, the pressure dominated 4D signature of a particular seismic attribute at a specific location and between a fixed time period can be related to the cumulative injected or produced volumes from the wells. At and in the neighbourhood of well *j*, the pressure-driven 4D signature may be linearly correlated to the cumulative fluid volumes produced or injected, when observed as a function of elapsed time. We postulate that seismic data acquired from multiple repeated surveys can exploit this concept. For many vintages of survey shot over the same location (x,y) at different intervals ΔT_k , where $k=1,N$, in calendar time, it is possible to form a time sequence of mapped 4D signatures ΔA_k associated with a sequence of cumulative volumes ΔV_j (ΔT_k) from the production/injection data such that

$$\Delta A(x, y; \Delta T_k) = G\Delta V_j(\Delta T_k), \qquad (1)$$

where the lumped term *G* on the righthandside contains information about the geology, connectivity and compartmentalisation. In practice, for each well a map of the normalised cross correlation coefficient between the 4D seismic signatures and the change in well volumes can be calculated. Thresholding the normalised correlation coefficients appropriately defines a new dynamic seismic attribute associated with the particular well of interest. This exercise can now be repeated around the neighbourhood of each well in the field. The technique has particular merit for those 4D signatures that are noisy, and has the potential to enhance interpretation.

Application to the Valhall field

The approach is applied to two areas, one in the south and one in the north flank of the Valhall field. This is a chalk reservoir, located in the southern part of the Norwegian North Sea. The field has been on production since 1982 and the pore pressure has been reduced from around 41MPa to 14MPa in some parts. This reduction in pore pressure has led to compaction of the chalk reservoir rock (Barkved, et al. 2003, van Gestel et al., 2008). Across the field, the seismic response is strongly related to the pressure reduction and resulting compaction. The field is produced by many long reach horizontal wells, and 4D signatures can be observed to be associated with individual perforations. At some of these well perforations it is known that gas comes out of solution due to localised pore pressure decline below bubble point. However the exact location of these is difficult to detect in conventional 4D seismic differences due to the masking effect of compaction and well to well interference. A second problem is the dense positioning of the wells which also renders precise resolution of the individual well responses difficult to observe in conventional 4D seismic attributes. We tackle these two issues using our proposed technique, where we use the following two seismic attributes: 1. the AI difference obtained through the process of coloured inversion (Connolly et al. 1999) plus a calibration step and 2. time-shift attributes that are extracted from the overburden and can be correlated to compaction using an R-factor. These data are obtained for ten LoFS seismic surveys in total, shot between November 2003 and April 2008 at varying time intervals ranging from 2 to 10 months (Figure 1). The ten repeated seismic surveys studied produce sequences with a total of forty five time steps derived from the various combinations of differences for each of the two surveys. Using the well data provided, the cumulative produced or injected volumes for each time interval are computed (Figure 2). Cumulative volumes are calculated based only on the produced oil and water phases, or injected water. The surface volumes are corrected to volumes at reservoir pressure using the relevant volume formation factors.

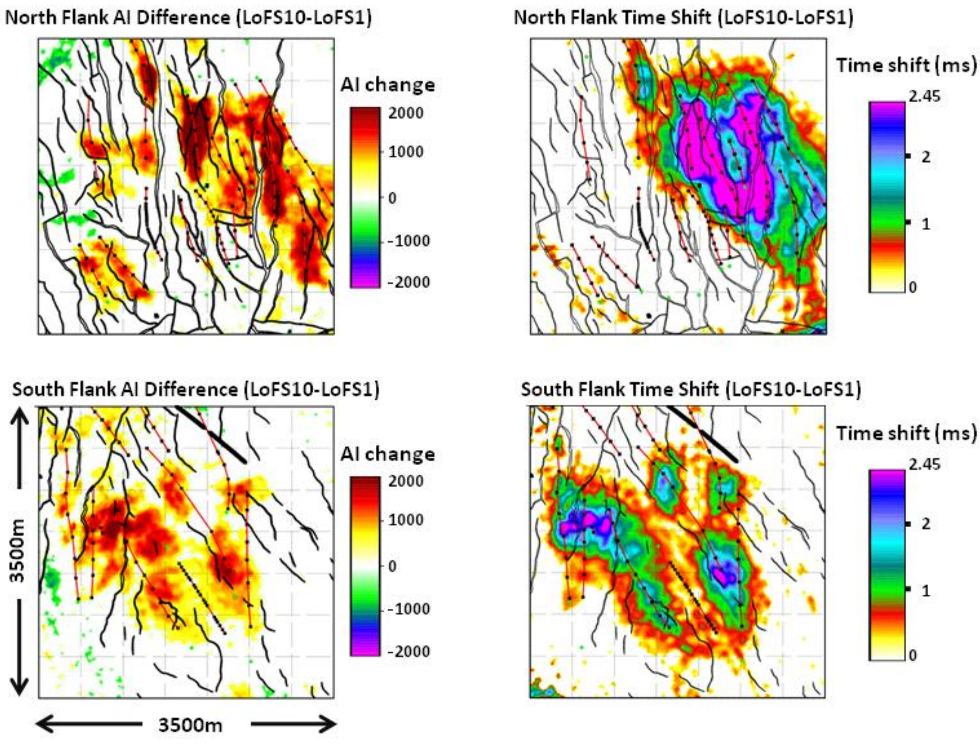

Figure 1. *In this work use is made of the AI and time-shift attributes for the LoFS difference data. Here, the differences between surveys 1 (November 2003) and 10 (April 2008) are shown. Red lines are horizontal producers where the black squares indicate perforations. Black lines are interpreted faults.*

All wells have strong time-lapse signatures, which are quite unique when plotted over calendar time. However in the North flank, different groups of wells have similar patterns of activity suggesting that resolution between wells may be problematic. There are larger differences between groups of well activity in the south flank. As a consequence inter-well cross correlation is calculated as a reference point for the study. For the seismic, the normalized cross-correlation is calculated for both the AI and the time-shift attributes. Both of these attributes correlate remarkably with the well activity as defined by the cumulative volumes (Figure 2). The AI and time-shift results show differences in detail yet similarities in the overall pattern. Interestingly, low cross-correlation regions are visible at perforations (white dashed lines) in the AI response that do not exist in the time-shift response (Figure 2). This suggests the location of gas breakout has been pinpointed as the anomalies correlate with the active and competent perforations. Compared with the conventional 4D seismic maps in Figure 1, we see that overall there has been an enhancement in the information content and in particular a crisper response related to each individual well (Figure 2).

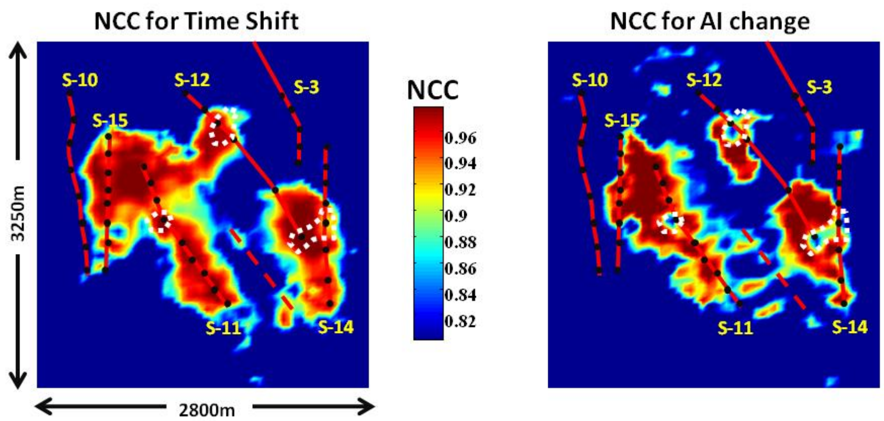

Figure 2. *Normalised cross-correlation (NCC) maps for a group of wells on the South Flank of Valhall. Lefthand results are the time-shift attribute which is not sensitive to gas, whilst the AI difference in the righthand map is sensitive to both gas and pressure. Gas breakout around three of the perforations (white dashed areas) has been detected.*

Two distinct groups of wells are defined for those wells in the South Flank of Valhall according to inter-well cross correlations. Using any well in the same group will yield very similar NCC maps. In these maps, the boundary of the areas influenced by two closely spaced wells S-10 and S-15 can be distinguished (Figure 3). Moreover, the 4D response as outlined in the polygon around S-3 was previously considered as a joint effect of S-3 and S-14's activity. However, the NCC maps (Figure 3) calculated for both groups of wells suggest this 4D response is only related to S-3. It was also found that outside the producing zone there were large areas of negative cross correlations – these are thought to relate to geomechanical extension effects.

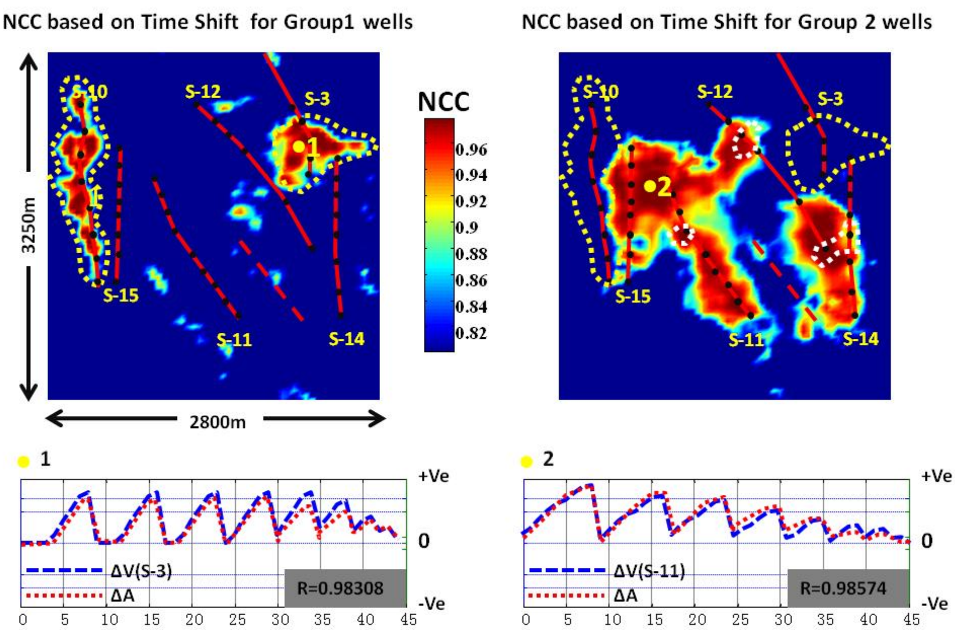

Figure 3. *Normalised cross-correlation (NCC) maps for the two groups of wells (Group 1: S-10 and S-3, and Group 2: S-11, S-12, S-14 and S-15) on the South Flank of Valhall. There is a strong correlation between the 4D seismic (ΔA) and the well activity (ΔV).*

Discussion

Application of the method for correlating 4D seismic to well activity reveals strong, localized, and low noise signals around the wells in Valhall. The spatially confined nature of these signals are quite specific to Valhall as previous applications of the technique to Schiehallion have revealed a different and more extensive character. The cause of this localisation is probably the low permeability of the chalk and perhaps the compaction mechanism. The shape of the Valhall anomalies has been verified by comparison with results obtained from synthetic seismic for the field (not shown). Importantly, the unique well signatures on Valhall give rise to higher cross correlation coefficients than seen previously, and a very robust and low noise result. Such signatures may permit analysis of drainage patterns and conditioning of the simulation model to avoid well failure. They also suggest that more attempts should be made to fluctuate well production and injection if possible to aid frequent seismic survey analysis.

Conclusions

It is possible to correlate mapped 4D seismic signatures from multiply acquired repeat surveys with the cumulative volumes produced at wells over these time periods. The resultant signals identify only those areas of the seismic which are strongly consistent with the well activity, and hence define portions of the reservoir connected to the wells. This information unites the seismic and well domains without the use of the simulation model. The signal tends to be robust and have a much lower noise when compared to the individual 4D seismic difference signatures. This seismic attribute can be used as a diagnostic tool for examining reservoir connectivity and constraining the simulation model.

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