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Improving 4D Seismic Interpretation and Seismic History Matching Using the Well2seis Technique

Z. Yin* (Heriot-Watt University), M. Ayzenberg (Statoil ASA) & C. MacBeth (Heriot-Watt University)

SUMMARY

A well2seis technique is proposed to incorporate available reservoir data from both 4D seismic and well production domains through cross-correlation, to prevent biased reservoir interpretation. The subsequent well2seis attribute shows the capacity to enhance dynamic reservoir interpretations by quantitatively integrating 4D seismic responses with their corresponding well behaviours. It reduces the interpretation workload by avoiding the need to work on many individual 4D differences separately. A joint workflow is then proposed to close the loop between the observed data and the predictions from the simulation model using the well2seis results. This workflow sequentially makes use of direct updating (for updating static models) and assisted history matching (for updating dynamic models) procedures. In the assisted history matching stage, the well2seis correlation attribute successfully acts as an alternative history matching attribute to the conventional production or 4D seismic data. The application of the proposed approach to a North Sea field shows that both the seismic and production history matching results are simultaneously improved to a satisfactory degree when minimising the misfit between the observed and simulated well2seis attributes.

Introduction

Our study shows that dynamic reservoir interpretation can be enhanced by directly correlating the attributes from many repeated 4D seismic monitors to the production and injection behaviour of one or a group of wells. This 'well2seis' cross-correlation is achieved by defining a linear relationship between pressure and saturation-related 4D seismic responses and their corresponding changes in the cumulative fluid volumes at the wells. The spatial distribution of the well2seis correlation attribute can reveal key reservoir connectivity features, such as the seal of faults and intra-reservoir shale layers, fluid flows and pressure diffusion pathways, and communication between neighbouring compartments or fields. To make appropriate use of the well2seis interpretations, a workflow is proposed to close the loop between 4D seismic and reservoir engineering data. Firstly, the reservoir model is directly updated using the improved understanding of reservoir structure and connectivity. Next, an assisted history matching (AHM) is performed to quantitatively use the well2seis attribute to honour data from both seismic and reservoir engineering domains. Compared to traditional history matching approaches that attempt to match individual seismic time-lapse attributes and production observations, the proposed approach utilises the well2seis correlation attribute that effectively condenses 4D seismic and production data. In addition, the approach is observed to improve the history matching efficiency as well as the reservoir model predictability.

Methodology

4D seismic signals cannot be unambiguously interpreted without a proper understanding of the production activity. To quantify this understanding, we make use of the multiple surveys shot over the same area, to generate a number of 4D seismic difference maps for all paired combinations of the surveys. The net reservoir volume changes or the cumulative volumes of a specific produced fluid (oil or water) over these time intervals from the reservoir constitute a consecutive calendar time sequence to the seismic data. The computation of well2seis correlation coefficients (W2S) between these two sequences helps to identify reservoir connectivity patterns, and enhance the understanding of wells drainage radius (Yin et al., 2015). To properly make use of this technique, a workflow is established that efficiently handles multiple repeated 4D seismic and well production data together, including preconditioning as well as computation of the well2seis coefficients. Having such a joint workflow gives us the flexibility to perturb the data and parameters when running sensitivity studies and testing hypotheses.

Based on the enhanced 4D seismic interpretation from the well2seis technique, the reservoir model is then directly updated by positioning and inserting known flow barriers or conduits identified by the well2seis attributes. After this process, an assisted history matching (AHM) is applied to match the observed well2seis attribute. As W2S assimilates all of the generated 4D differences using well production data. History matching of W2S is found to improve the match to each individual time-lapse seismic data set as well as the production observations. To achieve such a history match, the objective function defined by Tarantola (2005) is employed to measure the misfit between observed and modelled W2S in each grid-block of the simulation model. Then the iterative Ensemble Smoother (IES) algorithm is the applied to minimise the proposed well2seis misfit objective function.

Application to a North Sea field

The approach outlined above is applied to data from a fault compartmentalised North Sea field. This area of study is covered by five repeated seismic surveys (2004, 2005, 2008, 2010, and 2011), with reservoir production starting in 2005. In the past, the reservoir simulation model has been history matched to a relatively high degree using 4D seismic survey 2004 and 2010, and production data. Despite this process, the fault sealing properties remain uncertain due to the limited information provided by the observation data. Furthermore, the communication patterns between the field of study and its neighbour Field A (Figure 1(a)) is still highly uncertain, which becomes a major problem due to the planned injection activity in the field A.

Due to the data availability, only the 4D seismic of 2010 and 2004 were originally used for reservoir modelling and model updating. As illustrated in Figure 1(a), the 4D seismic signatures between 2010 and 2004 are mainly dominated by water flooding, while the 4D seismic response on pressure changes remains relatively weak, as the reservoir pressure has recovered back to almost the initial value by 2011. Recently, high quality seismic for all the five 4D surveys has been reprocessed. They can be used to improve the understanding of the communication by leading to a more reliable reservoir model. The well2seis method is therefore applied to this field to make effective use of all the 4D seismic data.

The correlation attribute is firstly generated by linking 4D signature of the five surveys to the main producer P1. A layer view of this newly generated property is displayed in Figure 1(b), where the distribution of the W2S attribute is observed to be consistent with the location of the faults. This correlation property mainly explains the water flooding and pressure diffusion due to the volume extraction at this well. Comparing Figure 1(b) with Figure 1(a), it is observed that the correlation property not only clearly reflects the water flooding signal but also reveals extra information regarding the reservoir connectivity. In previous work on this field, each fault was assigned a single constant transmissibility multiplier along the fault plane during the reservoir modelling and updating process. However, as shown in Figure 1(b), lateral continuity of the W2S attributes along the faults is not homogeneous, especially for the faults separating the reservoirs under production from those of field A.

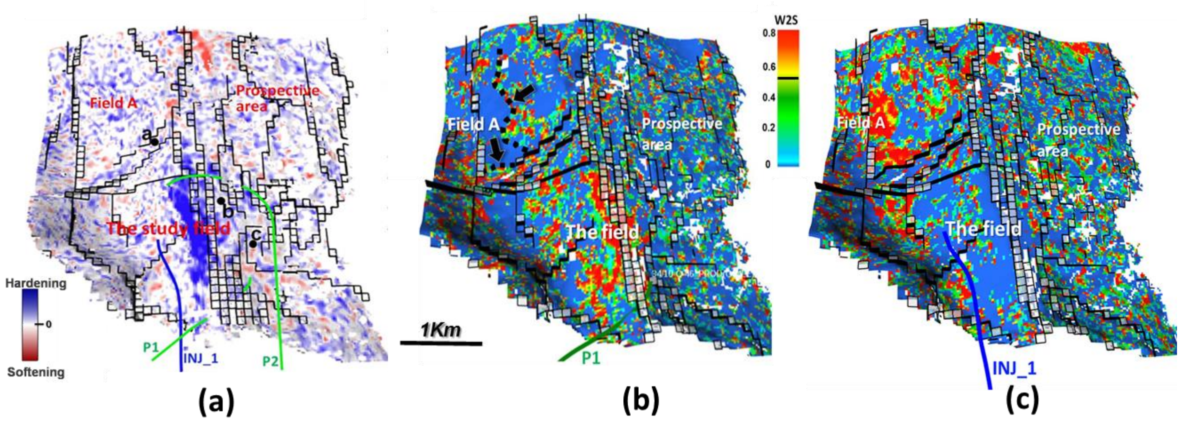

Figure 1 *(a) Observed 4D seismic difference between 2010 and 2004. Faults in the reservoir model are displayed using black lines. (b)&(c) Lateral view of observed well2seis correlation attributes for the major production well P1 (b) and the major injector INJ_1 (c) respectively.*

A second correlation attribute (Figure 1(c)) is calculated using the only water injector INJ_1. From this property, a brightening is observed in the region of Field A, which implies that pressure changes in this area are significantly correlated with the injection from INJ_1. Considering no production activity in Field A before the latest 4D monitor in 2011, it is likely that the water injection from INJ_1 has caused strong pressure changes, indicating a high level of communication between the field of study and Field A. This indicates that a large amount of water injected by INJ_1 moved into Field A region due to gravity effects.

After properly understanding the 4D seismic signatures via the well2seis interpretation, the proposed model updating workflow is applied to close the loop between the observed and model simulated data. Figure 2 illustrates the seismic match quality before and after applying the workflow. Figure 2(a) shows observed 4D seismic amplitude difference between 2008 and 2005. Figure 2(b) shows the simulated 4D difference for the same time interval from the simulation model which has been history matched to the individual seismic data of 2004 and 2010. Comparing Figure 2(b) and (a), there are two areas in the simulation model that are obviously not matched to the observations: area ***I*** where the hardening effect is found due to significant pressure depletion because of the production from the study field, while the simulation model shows no 4D response; and area ***II*** where the reservoir model predicts oil moving into water - shown as a softening effect in the synthetic, which is not observed from the seismic. Figure 2(c) shows the simulation model after the model updating stage which displays a good improvement in the quality of the match. By resetting the fault transmissibility multipliers, the simulated results become much more consistent with the seismic observations in both areas ***I*** and ***II***.

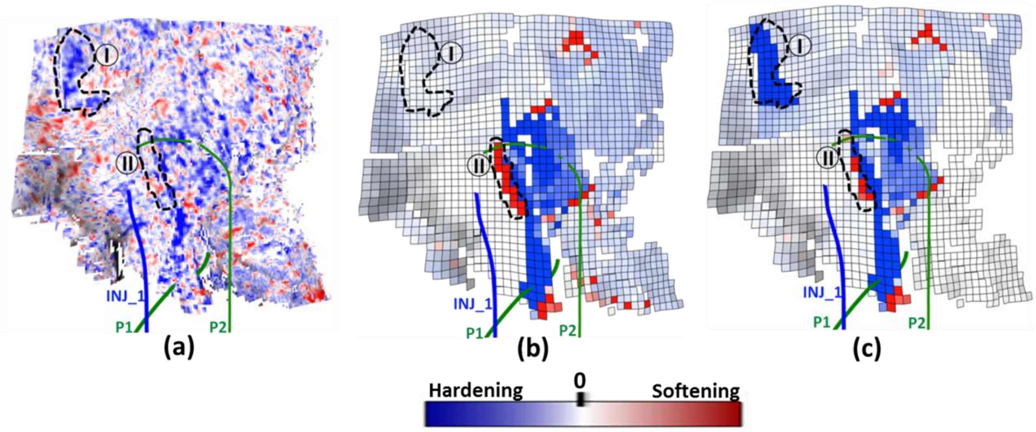

Figure 2 *(a) Observed 4D seismic difference between 2008 and 2005. (b) Simulated 4D seismic difference between 2008 and 2005 from the simulation model, which has been history matched to the 4D signatures between 2010 and 2004. (c) Simulated 4D seismic difference between 2008 and 2005 after direct updating and assisted history matching. The dashed black lines mark the two areas which are not history matched when using only 4D surveys of 2010 and 2004 and production data.*

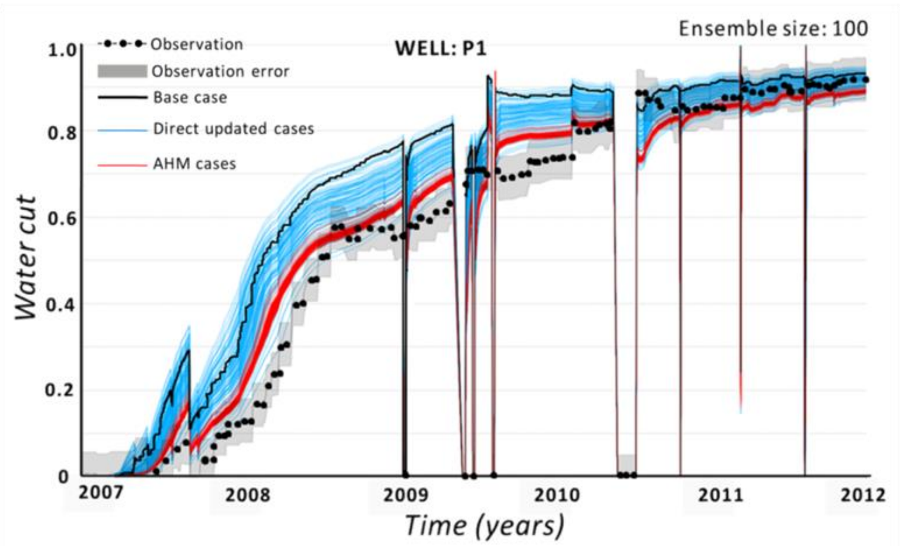

Figure 3 *Production history matching improvement for well P1 after applying the history matching workflow. Black dots correspond to the observed data; the grey area is the observational error; blue lines are the results from directly well2seis model updating, whilst the red lines are the results after the well2seis assisted history matching.*

The results of a match with the production data in Figure 3 also show drastic improvement from the base case. After the direct updating, the simulated production profiles from the entire one hundred directly updated models move from the base case towards the observations, becoming more consistent with the observed historic data. Nevertheless, as observed in Figure 3, even though the direct updating has achieved significant improvements, most of the directly updated simulation models are still far from the production observations in the main historical period before 2011. After the first iteration of IES in the assisted history matching (the red lines), the one hundred models converge quickly towards the observations, improving the match for each realization.

Conclusions

The results presented here demonstrate the value of a combined use of 4D seismic and production data for assessing the reservoir connectivity. In addition to an engineering consistent 4D interpretation, the well2seis correlation provides detailed insights to the reservoir model maturation. In the proposed workflow, the reservoir model is updated quickly and directly using information interpreted from the 4D signatures by the well2seis technique. At the end of the process, the assisted history matching is run to further optimize the history matching results. This workflow is capable of updating both static and dynamic models consistently, and also improves the history matching efficiency since the direct updating helps to reduce the amount of time-consuming history matching iterations. Here the well2seis attribute is introduced as an effective assisted history matching attribute for multiple 4D seismic surveys, improving the match quality in both seismic and engineering domains. Application of the well2seis approach to the North Sea field reveals the communication pattern with its neighbouring field, and also evaluates the sealing property of major faults. The proposed workflow efficiently closes the loop between modelled and observed W2S attributes based on this benefit. The multiple updated models from the ensemble method also make it possible to conduct risk assessment for effective reservoir planning and management.

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