Efficient interpretation of frequently repeated OBC 4D seismic monitors,

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Summary

A well2seis workflow is proposed to automatically correlate 4D signals from frequently acquired 4D seismic surveys to the corresponding well activities. It provides a framework for estimating the drainage radius of wells, and understanding the spatial reservoir connectivity for reservoir development purposes. By applying the workflow to a compartmentalized North Sea field, our study demonstrates that the workflow can efficiently assist in maximizing the value of frequently repeated OBC 4D seismic monitors.

Introduction

4D seismic has been widely used to monitor and manage reservoir development in the past few decades. Nowadays, seabed permanent reservoir monitoring with the OBC/OBN technology has been commonly applied to provide life-of-field 4D seismic surveys, to enhance the data quality, and obtain frequent seismic monitors in the long term. It is a common practice to interpret 4D seismic by referring to the field production and injection history. However, such evaluation of well influences on the 4D seismic is commonly conducted in a manual way. With more frequently repeated 4D surveys provided by OBC/OBN, the interpretation workload will increase dramatically if the analyses are still based only on the conventional 4D interpretation.

Here, we propose a well2seis technique to automatically correlate frequently repeated 4D seismic signals to their corresponding well behaviours. This technique is incorporated into a consistent workflow that assists 4D interpretation for the purpose of model maturation, well planning and reservoir management. By applying the workflow to a compartmentalized North Sea field, our study demonstrates that the workflow can assist in maximizing the value of frequently repeated 4D seismic and well performance data in the decision-making process.

The well2seis workflow

4D seismic signals cannot be unambiguously interpreted without a proper understanding of the production activity. To quantify this understanding, we make use of the frequently repeated 4D seismic surveys shot over the same area, to generate a number of 4D seismic difference maps for all paired combinations of the surveys. The cumulative volumes of a specific produced fluid (oil, water) over these time intervals constitute a parallel calendar time sequence to the seismic. The calculation of well2seis correlation coefficients between the seismic and production sequences directly identifies the reservoir connectivity patterns, and enhances the understanding of wells drainage radius (Yin et al., 2015). It also provides useful input to the different subsurface disciplines working on well planning and reservoir management. To properly make use of this technique, a workflow is established that efficiently handles frequently repeated 4D seismic and well production data loading and preconditioning, as well as the well2seis correlation computation. Having such a workflow gives us the flexibility to exploit the data and parameters to a larger extent during sensitivity studies and for testing hypotheses. As each field has specific challenges and questions that need to be answered, the workflow is adjusted accordingly for each field application.

Application to a North Sea field

The area of interest lies in a structurally complex mature field containing stacked reservoirs (Figure 1). Major faults divide the field into several rotated fault blocks of varying complexity. An oil-filled segment H3 of the reservoir is separated from the neighbouring segment H4 by a single major H3/H4 fault marked in red in Figure 1. The H3 segment will be drilled soon, and the drainage strategy will be affected by the sealing properties of the H3/H4 fault. The injector positioned in H4 may be able to support the pressure in H3 if the H3/H4 fault is open. However, if the segment is totally isolated from the rest of the field, a gas injector will be placed in H3 to maintain the production.

Several studies were conducted to understand the sealing properties of the H3/H4 fault. The previously work on streamer 4D seismic indicates that the fault be open or partially sealing in some areas (Ayzenberg and Yin, 2016). However, an agreement on the exact behaviour of the fault has not been reached.

Recently, the latest OBC monitor was acquired in 2016, and it was then co-processed with all the previous OBC vintages. There are now a total of six OBC seismic surveys in this study area over the field production history, which were shot in 2003, 2005, 2008, 2011, 2014 and 2016. Only one major producer P1 was continuously active in segment H4 since 2003, while H3 was not perforated. There was also one water injector I1 in the north of H4 block, but it injected for a limited period of time. As shown on the 4D seismic maps in Figure 1, due to a complex overburden, the seismic data are relatively noisy. This poses challenges for structural and 4D interpretation. A 4D signal can nevertheless be detected and understood in terms of the well activity. In particular, we observe development of the water flooding (the hardening signal shown in blue) in the H3 segment, which is likely due to the P1 production in H4, in particular during the period between 2005 and 2008 (Figure 1b). This observation alone suggests that H3 is not disconnected from the rest of the field.

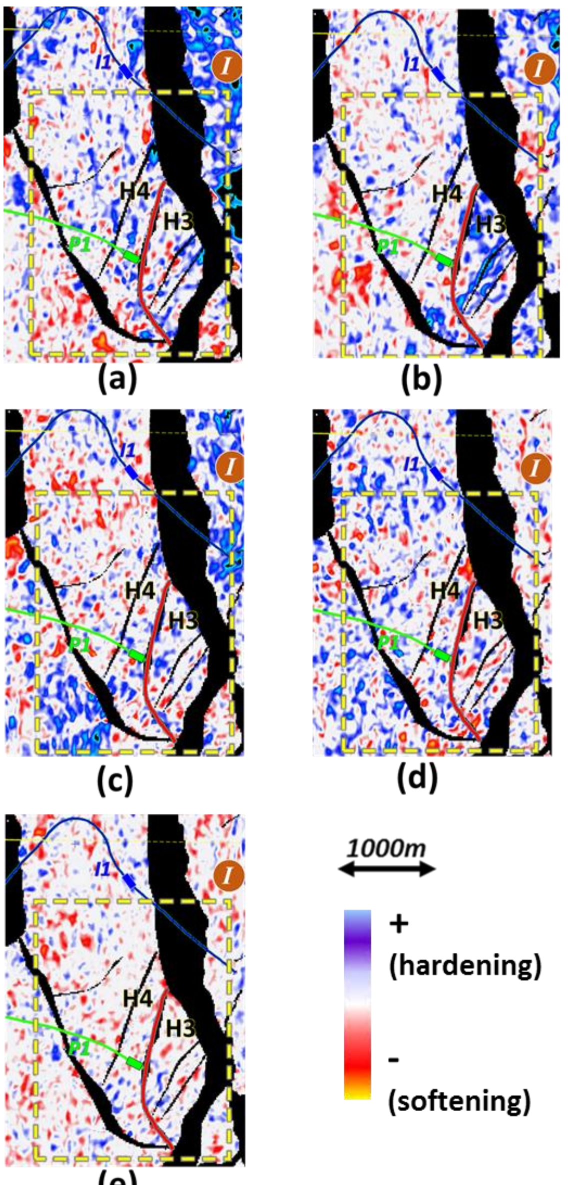

Figure 1 Consecutive 4D seismic difference maps of 2005-2003(a), 2008-2005(b), 2011-2008(c), 2014-2011(d) and 2016-2014(e), respectively. The yellow dashed box delineates the field study area, while the red line marks the main fault between H4 and H3. The green lines represent trajectories of producer P1, while the blue line represents the injector I1, and the thick lines on each well indicate the location of the well perforations.

In order to properly understand the 4D seismic signal development, we correlated all available 4D seismic differences to the oil production activity of well P1 (Figure 2a), and the calculated well2seis map is displayed in Figure 2b. As observed from the well2seis map, the production activities of P1 have caused high correlation near the well. More importantly, by correlating 4D seismic to the well in H4, a significantly high correlation is observed in segment H3. This correlation supports the current understanding that well P1 is influencing the segment H3, and it confirms that the H3/H4 fault is not sealing. This, in turn, suggests that the existing injector I1 has a potential of being used to support the planned in-fill well in H3. Compared to the individual 4D seismic maps in Figure 1, the well2seis correlation map significantly enhances the 4D seismic interpretation, and provides more detailed information on the reservoir development than each individual 4D seismic difference.

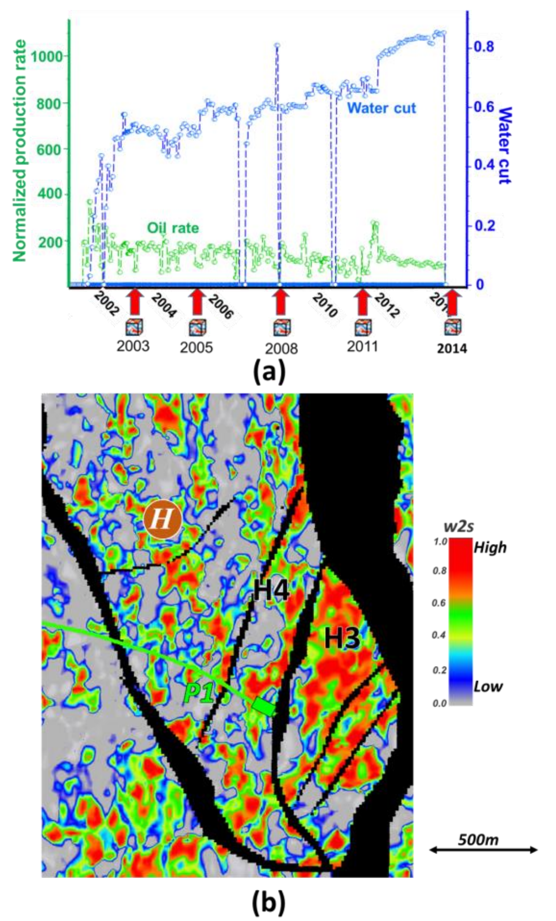

Figure 2 (a) Historical production history of well P1. (b) Well2seis map by correlating all 4D seismic surveys to the production activity of well P1.

The prospective segment H3 also locates next to a neighbouring Reservoir B across a major structural fault F (Figure 3b). F was previously believed to block the inter-reservoir communication. However, the sealing properties of the fault F have not been properly understood. As the H3 segment will be drilled soon, the drainage strategy can also be affected by the sealing properties of fault F.

In the neighbouring Reservoir B, there is a gas injector GI located next to the prospect H3. This well has been active from 2005-2016, covered by five OBC seismic monitors (Figure 3a). Similarly, all available 4D seismic differences are correlated to the gas injection history of GI from Reservoir B, and the calculated well2seis attribute is displayed in Figure 3b. This high well2seis correlation near the GI trajectory mainly highlights 4D responses caused by gas injection. More importantly, the high well2seis correlation extends to segment H3 by crossing the structural complex areas of fault F (pointed by the yellow arrows in Figure 3b). This is also consistent with the weak softening responses observed in H3 (Figure 1d and Figure 1e), but the well2seis significantly enhanced these 4D signatures. The interpretation provides us with important information that H3 is also in communication with the Reservoir B, which further confirms the previous work on the streamer 4D seismic data in this area (Ayzenberg and Yin, 2016). This inter-reservoir communication should be considered when designing the new well trajectory and the pressure support to this well.

Conclusions

This work demonstrates the value of a combined use of 4D seismic and production data for assessing the reservoir connectivity. It provides an efficient workflow to handle and interpret the frequently acquired 4D seismic surveys from OBC/OBN. In addition to an engineering consistent 4D interpretation, the dynamic data provide detailed insights into the well planning and reservoir management. In the field application of the well2seis workflow, we assessed the field connectivity and concluded that the prospective production area is in communication with the rest of the field. The study also suggested corrections to the planned well trajectory which we do not cover in this abstract. The findings on the sealing properties of the major faults, the proposed well location and trajectory have been communicated to the asset team and are being evaluated for further decisions.

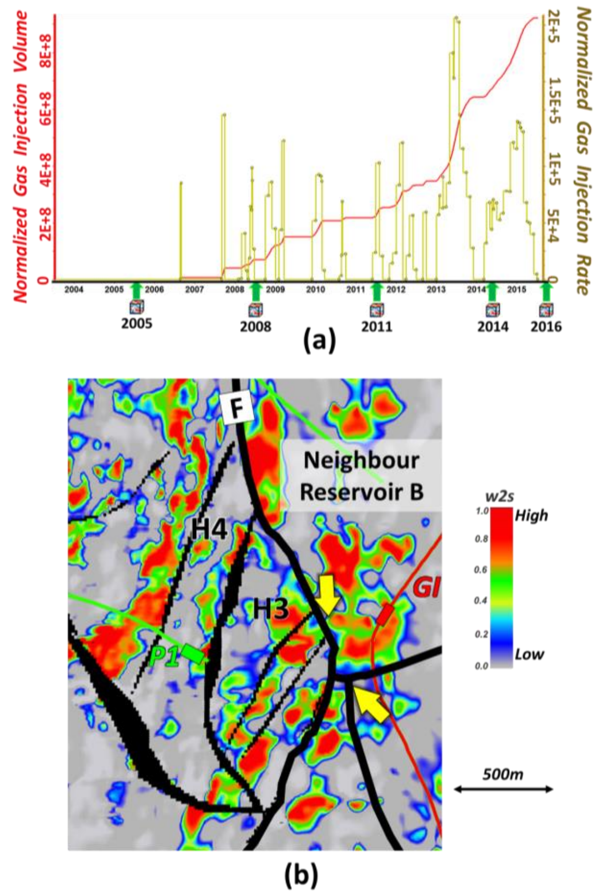

Figure 3 (a) Historical gas injection of Reservoir B gas injector GI located close to the prospective H3 segment. (b)Well2seis correlation by relating all the 4D seismic surveys to the gas injection history of well GI in Reservoir B. The thick line on the well trajectory indicates the location of the well perforations.

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Acknowledgements

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