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4D Seismic Interpretation with Frequently Acquired, Multiple Time-lapsed Surveys

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SUMMARY

Permanent installations delivering frequent multiple time-lapsed seismic surveys offer many advantages to data processing and seismic inversion. It is natural that provision of seismic data at a time-scale scale closer to the production/reservoir engineer should open up a range of innovative technologies for 4D seismic interpretation such as pressure-saturation change estimation, connectivity analysis and history matching. However, these dynamic data must also be interpreted to ensure the time constants of the reservoir processes involved with production and injection are properly factored into the analysis. Whilst operational practicalities and budget usually determine the exact frequency and timing of survey shoots, the benefit of understanding the processes we discuss is that they help to further constrain the key controlling parameters of the reservoir fluid flow simulation model, and improve its ultimate forward predictive capability.

Introduction

The popularity of reservoir monitoring by the repeated acquisition of seismic surveys has grown steadily over the past five years. Indeed, there are now many good examples of multiple towed streamer repeats over the same field (see for example, Sandø et al. 2009). The increasing use of permanent reservoir installations has also opened up the possibility of acquiring highly repeatable seismic surveys on a frequent basis. One particular example is the Life of Field Seismic project that has been implemented on the Valhall field (Barkved et al. 2009) which has delivered over twelve (as of September 2012) 3D seismic surveys shot at a time interval of 2 to 10 months apart. Similar projects have been implemented on the Clair field, Ekofisk field, Jubarte field (Brazil) and the Azeri-Chirag-Gunashli field (Azerbaijan) (EAGE workshop on Permanent Reservoir Monitoring (PRM) using seismic data, 28 February – 3 March 2011, Trondheim).

From the interpretational perspective, multiple frequently acquired surveys offer the many obvious benefits that come with the added dimension of time. Thus, it is already known that frequent repeats can be beneficial when filtering out undesirable noise such as water bottom multiples or when overlapping coherency signals for identifying compartmentalisation (Stammeijer and Hatchell 2011). There are also gains to be made when performing seismic inversion using multiple vintages of seismic (Doyen 2007) or seismic history matching (Fursov 2010). However, when such 4D seismic data are interpreted for reservoir management purposes, an important consideration is the time scale of the changes in well activity. Equally important are the time constants of the physical effects of production and injection such as waterfront movement, gas exsolution/dissolution and pressure diffusion across the reservoir. This link between the frequency of shoot and the timing of reservoir effects was first made apparent by Watts and Marsh (2011). Here, the intention is to illustrate this point by considering three dynamic interpretation scenarios in which timing appears to be critical at the scale of the PRM.

Dynamic connectivity revealed by linking well to seismic data

It has been shown by Huang et al. (2011) that well production history and time-lapsed seismic data can be reconciled without the need for a model. This approach involves correlating changes in the mapped seismic attributes directly to the fluid volumes injected and produced from the wells. Well data normally used exclusively for history matching in the reservoir engineering domain can now also be directly integrated with the time-lapse seismic data. The reservoir signal extracted from the seismic is a robust and informative image of the dynamic connectivity (see Figure 1). Using this approach, areas can be identified that are strongly consistent with the well activity, and hence directly connected to the wells. This has been shown to benefit the Valhall, Schiehallion and Norne fields, where connected regions around closely spaced wells can be observed. The approach improves with the number and frequency of surveys, but also requires distinct changes in well activity over the period of interest. The approach has been demonstrated to be of benefit to history matching.

Monitoring gas exsolution and dissolution

Falahat et al. (2013) found that the 4D seismic signatures associated with the processes of gas exsolution and dissolution are controlled mainly by gas accumulations distributed in two discrete saturation states – the critical and the maximum gas saturation. This understanding simplifies quantitative interpretation of the 4D seismic (see Figure 2), and allows estimation of the liberated and dissolved gas volumes, and evaluation of these saturations directly from the 4D seismic. The work leads to a method for history matching using gas saturation distributions. Critically, however, the time period between the seismic baseline and successive monitors relative to the time taken to attain steady state also has an impact on the application of these findings. For 4D seismic surveys with a repeat time of one to several years this time scale may not be important, but for repeats with permanent sensor arrays of 3 to 6 months a re-think may be required. Possible implications are considered, and major issues are highlighted.

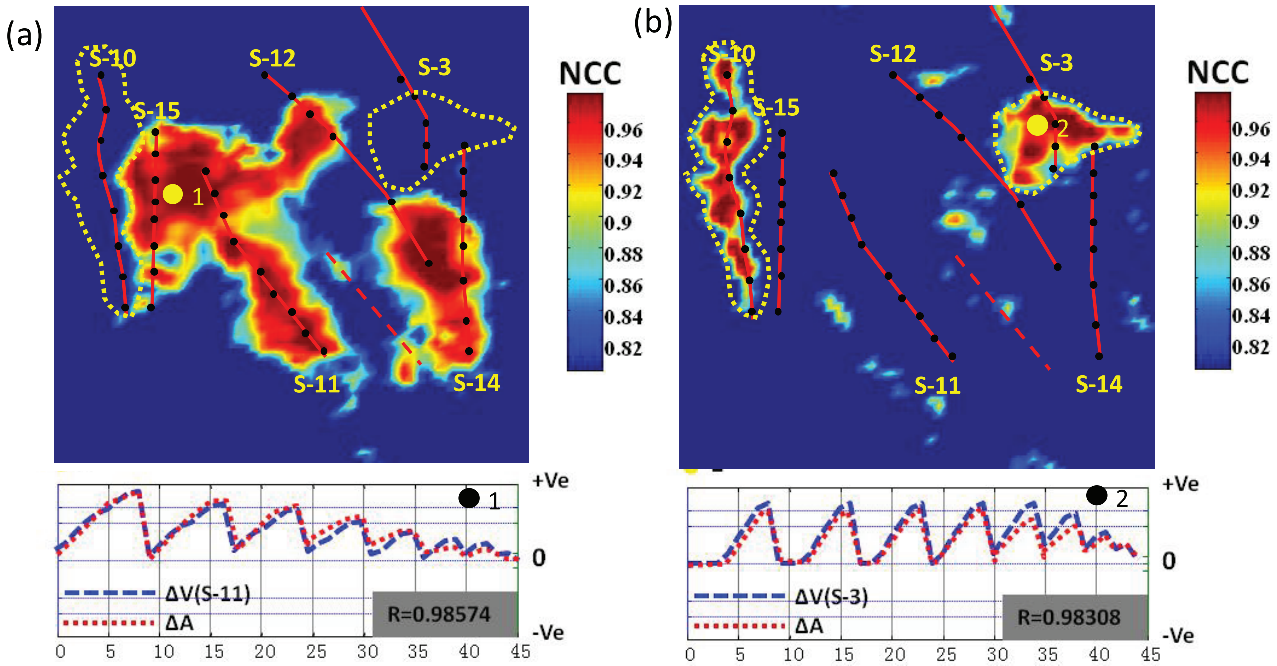

Figure 1 *Result of applying a correlation technique to multiple surveys to the south flank of the Valhall field. (a) Normalised cross-correlation (NCC) maps based on the time-shift attribute for two groups of wells: Group 1: S-10 and S-3, and (b) Group 2: S-11, S-12, S-14 and S-15. There is a strong correlation between the 4D seismic amplitudes and the well activity (defined by net volume change) at and around the wells. Figures after Huang et al. (2011).*

Reservoir-related shale

HajNasser (2012) has determined that pressure diffusion into a shale sideburden or intra/inter-reservoir may prove to be important in understanding the 4D seismic response over a production time scales from months to several tens of years. This diffusion process interacts with the known, and fairly instantaneous, geomechanical effects (MacBeth et al. 2011, Ricard et al. 2012). The problem is highlighted by calculations which show that a 1m thick shale can take less than 3 months to pressure equilibriate whilst thicker shale layers of 10m can take up to 20 years. It appears that reduced or anomalous stress sensitivity is likely to be more important for frequent acquisitions of 3 to 12 months, but is of less concern when seismic is repeated on time periods of 5 to 10 years. However the exact time scales of this, and related processes, are currently uncertain as they depend on shale accumulation thickness, permeability and the internal sedimentological character of the shale. The precise description of reservoir-related shales is problematic due to the lack of reliable core data and measurement techniques, but also the associated cost in obtaining accurate and representative laboratory measurements. Although the relative inter-play of pressure diffusion and geomechanics in and around the reservoir is currently unclear, the phenomena will certainly behave differently at monthly rather than yearly time periods. Here, the consequences of this behaviour are considered.

Conclusions

Permanent installations delivering frequent multiple time-lapsed seismic surveys offer many advantages to data processing and seismic inversion. It is natural that provision of seismic data at a time-scale scale closer to the production/reservoir engineer should open up a range of innovative technologies for 4D seismic interpretation such as pressure-saturation change estimation, connectivity analysis and history matching. However, these dynamic data must also be interpreted to ensure the time constants of the reservoir processes involved with production and injection are properly factored into the analysis. Whilst operational practicalities and budget usually determine the exact frequency and timing of survey shoots, the benefit of understanding the processes we discuss is that they help to further constrain the key controlling parameters of the reservoir fluid flow simulation model, and improve its ultimate forward predictive capability.

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References

Barkved, O.I., Van Gestel, J.P., Bergsvik, L.S., Stockden, I. and Kommedal, J.H. [2009] Seismic PLT – linking seismic time-lapse responses to production and injection data. *71st EAGE Conference & Exhibition*, Extended Abstracts, R033.

Doyen, P., [2007] Seismic Reservoir Characterization: An Earth Modelling Perspective, EAGE Educational Tour II.

HajNasser, Y. [2012] The implications of shale geomechanics and pressure diffusion for 4D interpretation, PhD thesis, Heriot-Watt University.

Huang, Y., MacBeth, C., Barkved, O, van Gestel, J-P., and Dybvik, O-P. [2011] Enhanced dynamic interpretation from correlating well activity to frequently acquired 4D seismic signatures, *The Leading Edge,* September Issue, 1042 – 1050.

MacBeth, C., HajNasser, Y., Stephen, K., and Gardiner, A. [2011] Exploring the effect of meso-scale shale beds on a reservoir's overall stress sensitivity to seismic waves, *Geophysical Prospecting,* **59**, 90–110.

Falahat, R., Shams, A., and MacBeth, C. [2013] The interpretation of 4D seismic amplitudes due to gas exsolution and dissolution, Geophysics, In Preparation.

Fursov, I. [2010] Forward prediction of reservoir behaviour using frequently acquired 4D seismic data, ETLP Annual Meeting, Edinburgh, June 2010.

Ricard, L.P., MacBeth, C., and HajNasser, Y. [2012] An evaluation of pore pressure diffusion into a shale overburden and sideburden induced by production-related changes in reservoir fluid pressure, *J. Geophys. Eng.* **9** (2012) 345–358.

Sandø, I., O.-P. N. Munkvold, and R.M. Elde [2009] Two decades of 3D geophysical developments—experiences, value creation, and future trends. World Oil, 230, (10).

Stammeijer, J. and P. Hatchell [2011] Opportunities and challenges from bringing PRM to the field: EAGE Workshop on Permanent Reservoir Monitoring, Abstract 10389.

Watts, G.F.T. and Marsh, M. [2011] How often should you acquire 4D seismic surveys to optimize value*? EAGE workshop on permanent reservoir moitoring (PRM) – using seismic, 28 February – 3 March 2011, Trondheim.*

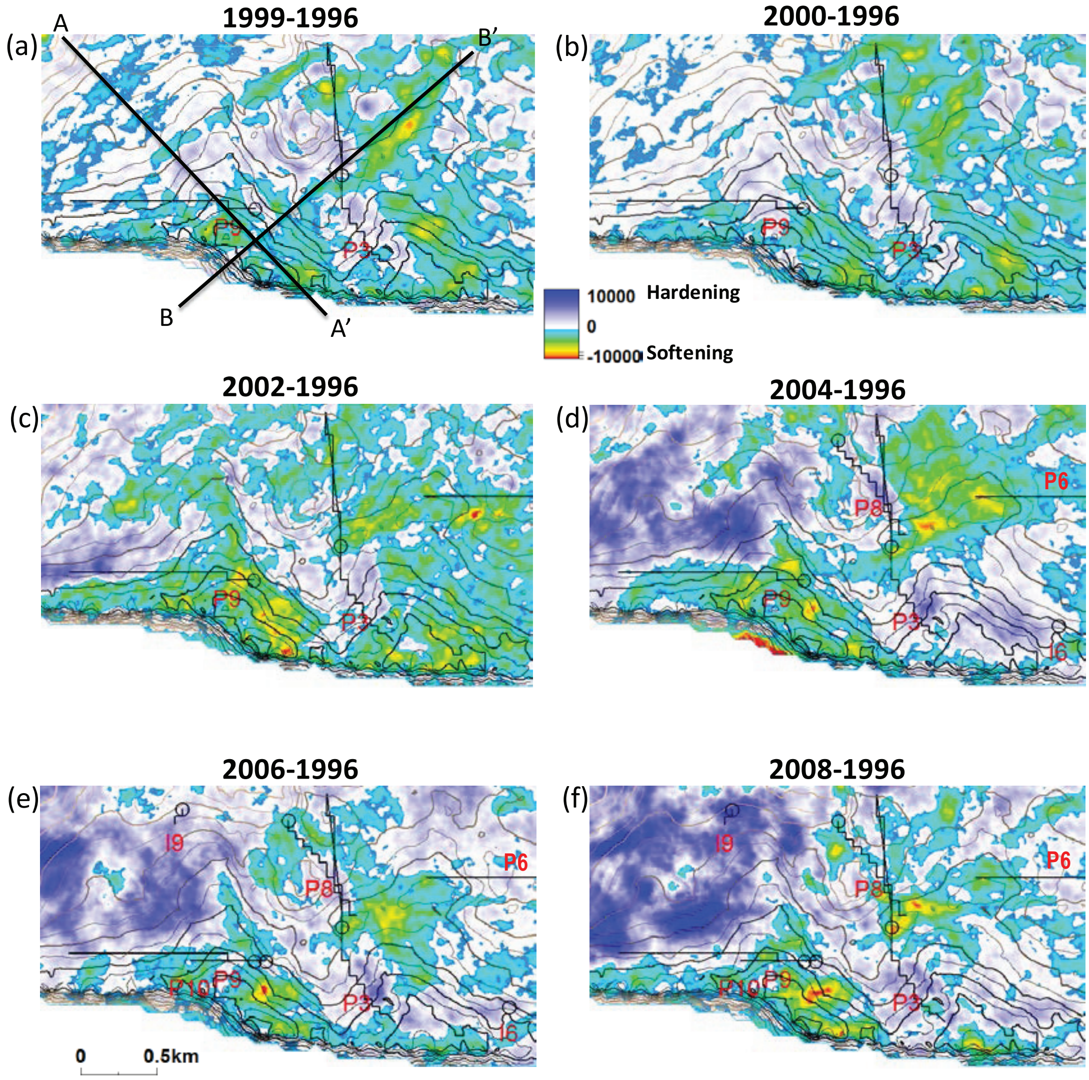

Figure 2 *Amplitude change map for the period of a) 1999-1996, b) 2000-1996, c) 2002-1996, d) 2004-1996, e) 2006-1996, and f) 2008-1996. The contour map indicates the structure of the top reservoir. All negative anomalies are related to the gas accumulations, as the region was initially entirely filled with oil. Note that the 1996 survey is a baseline taken prior to the production in 1998. After Falahat et al. (2013).*