Y002

The Influence of Overburden on Time-lapse Saturation Interpretation

F. Domes* (Heriot-Watt University), C. MacBeth (Heriot-Watt University) & J. Brain (Shell UK Ltd)

SUMMARY

This paper studies the effect of overburden channels on saturation changes estimated from 4D seismic data. It considers the impact of source and receiver positioning in combination with a realistic overburden and reservoir structure on the ability to interpret production induced changes. The study is based on data from the Nelson field where Quaternary and Miocene age channels above the reservoir are known to cause problems when interpreting the 4D signal. Synthetic pre-stack seismic gathers are generated and processed to limited offset stacks. Interpretation of the saturation changes estimated using these post-stack data reveals contributions from spatially incoherent noise and an anomalous seismic response introduced by the presence of the channels. Most of the errors in the saturation change estimates are confined to areas directly below the channel location. For seismic attributes affected by amplitude changes alone, localised errors of as much as 30% occur below the steep dipping channel margins, which should be compared to the maximum saturation change of 45%. The absolute error in the saturation change predictions increases to 68% if the attributes are influenced by amplitude and time shift changes. The errors revealed cannot be readily predicted by considering only acquisition based repeatability metrics.

Introduction

A major problem in marine time-lapse seismic is the non-repeatability of source and receiver positions that arises, for example, from differences in streamer feathering or positioning uncertainties. Indeed, Kragh and Christie (2002) introduced the seismic data derived *NRMS* repeatability measure and showed that time-lapse data quality at the reservoir level is directly related to the repeatability of the acquisition geometry. A complex overburden geometry in combination with this non-repeatability will increase noise on time-lapse seismic attributes if it is not captured adequately by the migration velocity model. Several authors have reported the effects a heterogeneous overburden can have on seismic signatures in the static 3D case. For example, Hatchell (2000) and Malme et al. (2005) showed that AVO attributes can be significantly distorted by buried faults or shallow lenses in the overburden. Misaghi et al. (2007) concluded that distortions originating from a shale lense above a reservoir are not repeatable if the shot position is varying. They observed an increase of the *NRMS* repeatability error at the reservoir level with increasing shot separation in an offshore 3D VSP survey. Furthermore, Bertrand and MacBeth (2005) showed that variations in sea-water velocity could have a severe effect on time-lapse attributes if the data are not corrected for such inevitable changes.

The above studies re-affirm that time-lapse attributes can be affected not only by production changes in the reservoir but also by overburden complexity. However, time-lapse pressure and saturation inversion schemes such as the one presented by Floricich et al. (2006) depend on attributes which are assumed to represent changes driven solely by reservoir production. Thus, there is a need to explore the interaction between the acquisition and overburden, and how this ultimately affects the estimation of reservoir state. To address this, we carry out a modelling study which uses data from the Nelson field, Central North Sea where there are known to be channels sitting in the overburden reported to impact on the interpretation of time-lapse signatures. The aim of the study is an understanding of the uncertainties involved in estimating the saturation change in the presence of overburden channels when they are not adequately captured in the migration velocity model or known in detail.

Field description

The Nelson field was discovered in 1988 and is located in the Central North Sea. The reservoir consists of Palaeocene turbidite sands occurring within the Forties formation at a depth of approximately 2200m below mean sea level. The main production drive is aquifer supported, coupled with flank water injection (Boyd-Gorst et al., 2001). The Nelson field has a strong water sweep time-lapse seismic signal due to a significant impedance contrast between oil and formation water (MacBeth et al., 2005). The overburden at the Nelson field is dominated by shale and mudstone and is structurally simple. There is no major tectonic deformation and reflectors are near horizontal. However, overburden complexity does arise from sand filled incisions of three distinct ages:

- lower velocity channels of the Quaternary age immediately below the seabed
- faster velocity channels of Miocene age at around 1000ms TWT, midway to the reservoir
- faster velocity Tay sand channels just above the reservoir

Only the Quaternary and Miocene channels are considered in this study. Although the Tay sand channels do have an impact on the time-lapse attributes they are not the main focus of our work.

Modelling time-lapse seismic data at the Nelson field

Fourteen overburden, four reservoir and one underburden horizons are picked from the post-stack seismic data and imported into a 3D subsurface model. Interval velocities for the overburden are taken from a pre-stack depth migration velocity cube and densities extrapolated from one well location. Elastic parameters, V_p, V_s and ρ, for the reservoir layers are derived from the reservoir simulation model by applying a petro-elastic transformation (MacBeth et al., 2005). Simulation data are taken at two distinct time steps, pre-production and after approximately 4 years of production. Navigation data from three existing seismic surveys are used to provide two acquisition cases: a poor repeat where no attempt was made to repeat baseline shot and receiver positions and a dedicated (good) repeat where the towing configuration was repeated and baseline source locations were replicated. Positioning repeatability is measured as the distance between base and monitor source positions plus the distance between base and monitor receiver positions ($\Delta S+\Delta R$). The average $\Delta S+\Delta R$ for the poor repeat case versus legacy is 180m, while the dedicated repeat case is 65m. The NORSAR-3D modelling package is chosen to implement the 3D pre-stack seismic modelling. In the next step, a seismic processing sequence including CMP binning, NMO correction, post-stack migration and post-stack rebinning is executed with the ProMAX software suite. In order to quantify the impact of the channels in the overburden, models with and without channels are used. Thus, a comparison can be made with a relatively simple reference case. Initial studies on extracted amplitude maps show significant distortion of time-lapse amplitude changes below the channels, with local distortions exceeding production induced changes.

Saturation estimation

A multi-attribute time-lapse inversion approach is used to determine simulated saturation changes in the reservoir (Floricich et al., 2006). For this method, production data from three wells are used to calibrate each time-lapse attribute. *RMS* amplitudes are independently extracted in a 20ms window centred on the T80 horizon (top reservoir) for baseline and monitor survey from three angle stacks. Next, differences of these individual *RMS* maps are calculated and used as input for the saturation change estimation. These attributes are not very sensitive to time-lapse time shifts, which exist in the data due to the overburden channels and thus this allows us to focus only on the amplitude contributions.
Figure 1(a) displays the predicted oil saturation change from the simulation model. To assess the accuracy of the seismic modelling, processing and inversion process, a study using the same acquisition parameters for the base and monitor survey is firstly carried out. The results are reasonably consistent with the input from the simulator (Figure 1(b)), and thus provide assurance that sufficient accuracy is available for the proceeding studies. For the poor and dedicated repeat cases models with and without the channel in the overburden are used to calculate saturation change maps. The difference of the saturation change estimates with and without the channel is taken (Figures 1(e) to (h)) to assess the impact of the channels on the method. Figures 1(i) to (l) show the channel and the *NRMS* repeatability (as defined by Kragh and Christie (2002)) measured from full offset stack amplitudes in a 600ms window above the reservoir.

Miocene channel: The errors in the saturation change estimate are confined to the reservoir region directly underneath the channel location, and amount to 30%. For the poor repeat case the errors are mostly distributed across this region (Figure 1(e)). The saturation change errors decrease to 22% using the good repeat case and form only a few clusters of localised error (Figure 1(f)). As expected, the results are not significantly affected outside the area underneath the channel, even though there is the same degree of non-repeatability - as illustrated by the $\Delta S+\Delta R$ maps in Figures 1 (c) to (d) because the errors are duplicated. There is some degree of spatial correlation between highs in the repeatability measure introduced by the overburden channel and the error in the saturation estimation (Figures 1 (i) and (j)). In contrast however, we observe a better correlation between the errors in saturation change estimation and the repeatability measure when time shifts are taken into account by calculating the *RMS* amplitude from the time-lapse seismic difference data, In this case, the absolute error in the saturation change estimate increases to 68%.
Quaternary channel: The saturation change error, due to amplitude effects only, is 25% for the poor repeat case. However, these errors are now confined to the steep dipping channel margins (Figures 1 (g) and (h)). The good repeat case improves the former result to 21% saturation change error. The saturation change estimates are not affected in areas where the channel topography is slowly varying, e.g. in the middle of the channel. Therefore, the *NRMS* repeatability measure does not consistently coincide with the saturation change errors (Figure 1 (k) and (l)). However, if time shifts are included by taking the *RMS* amplitudes of the difference volume, good agreement between

the repeatability and the error in the saturation change prediction (up to 60%) caused by the channel in the overburden is found.

Conclusions

The impact of un-anticipated overburden channels on time-lapse saturation inversion using limited offset stacks is investigated. It is observed that non-repeatability of source and receiver positions during marine seismic data acquisition have a significant impact on the saturation change estimation. The presence of channels in the overburden adds high levels of noise to the data and increases the uncertainty of the results, making quantitative interpretation difficult and unpredictable. The error in the saturation change prediction (68%) is greater than the actual oil saturation change (45%) if *RMS* amplitude attributes are calculated from the time-lapse difference data, as they are also sensitive to acquisition induced time shifts. We suggest taking the difference of the *RMS* amplitudes, which significantly reduces the influence of time shift noise. Therefore, errors in the saturation change estimates below the Miocene channel are reduced to 30%, and 22%, for the poor and dedicated repeat survey, respectively. For a shallow Quaternary channel, the error for the poor and dedicated repeat survey is 25% and 21%, respectively.

Acknowledgements

The authors thank the Nelson Field partners: Shell, ExxonMobil, Total, Oil Exco and Summit for their support and publishing permission. Many thanks to Karl Stephen (Heriot-Watt University) for helping out with the simulation data. This work is funded by the Edinburgh Time-Lapse Project and its Phase III sponsors BG, BP, Chevron, ConocoPhilips, EnCana, ExxonMobil, Hess, Ikon Science, Landmark, Maersk, Marathon Oil, Norsar, Norsk Hydro, Petrobras, Shell, Statoil, Total and Woodside.

References

Hatchell, P. [2000] Fault whispers: Transmission distortions on prestack seismic reflection data. Geophysics, **65**, 377-389

Malme, T.; Landrø, M. & Mittet, R. [2005] Overburden distortions - implications for seismic AVO analysis and time-lapse seismic. J. Geophys. Eng., **2**, 81-89

Misaghi, A.; Landrø, M. & Petersen, S. [2007] Overburden complexity and repeatability of seismic data: Impacts of positioning errors at the Oseberg field, North Sea. Geophys. Prosp., **55**, 365-379

Bertrand, A. & MacBeth, C. [2005] Repeatability enhancement in deep-water permanent seismic installations: a dynamic correction for seawater velocity variations. Geophys. Prosp., **52**, 229-242

Boyd-Gorst, J.; Fail, P. & Pointing, L. [2001] 4-D time lapse reservoir monitoring of Nelson Field, Central North Sea: Successful use of an integrated rock physics model to predict and track reservoir production. The Leading Edge, **20**, 1336-1350

MacBeth, C.; Stephen, K. & McInally, A. [2005] The 4D seismic signature of oil-water contact movement due to natural production in a stacked turbidite reservoir. Geophys. Prosp., **53**, 183-203

Kragh, E. & Christie, P. [2001] Seismic repeatability, normalized rms, and predictability. The Leading Edge, **21**, 640-647

Floricich, M.; MacBeth, C.; Stammeijer, J.; Evans, A. & Dijksman, N. [2006] Determination of a seismic and engineering consistent petro-elastic model for time-lapse seismic studies: Application to the Schiehallion Field. 76th Ann. Internat. Mtg., Soc. of Expl. Geophys.

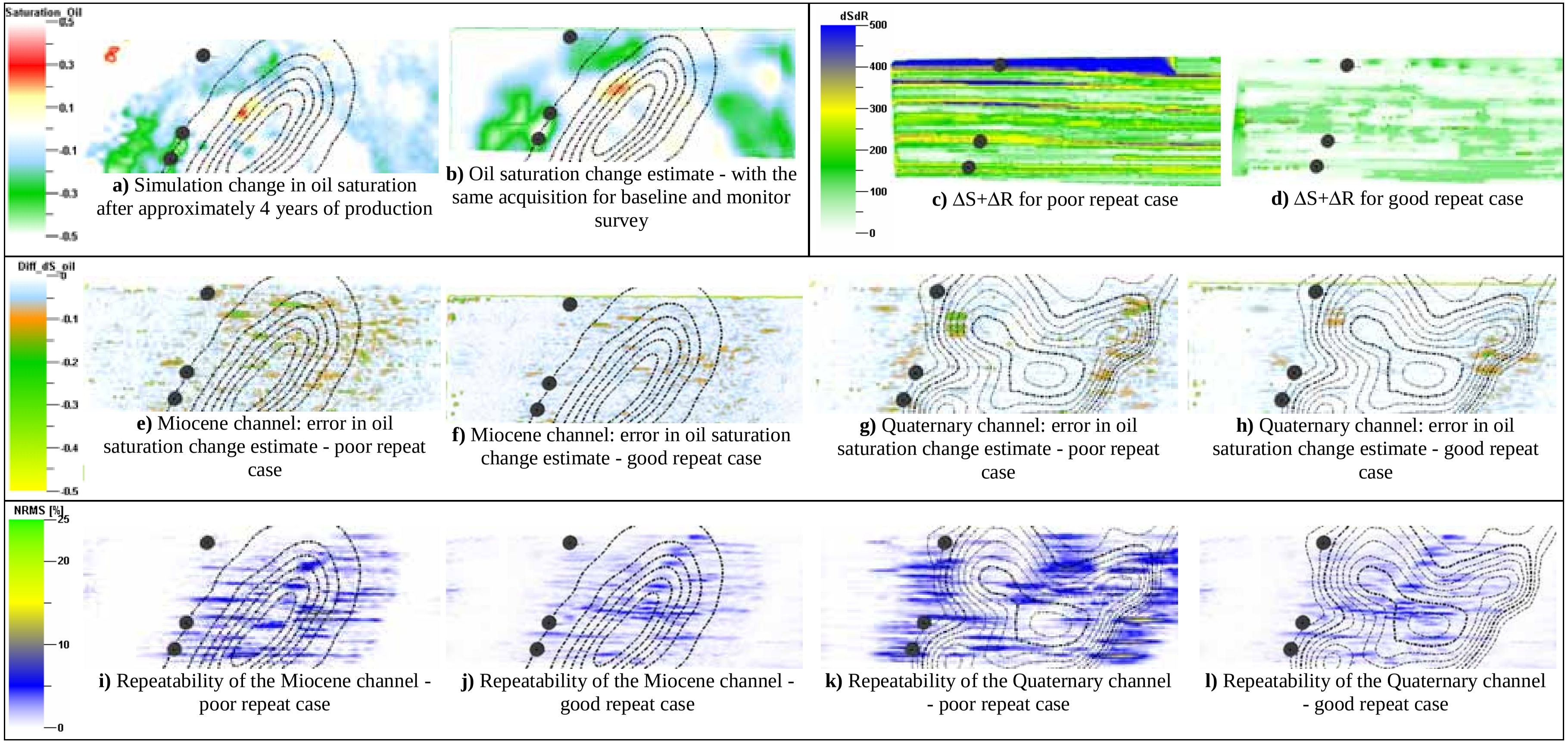

Figure 1. *(a) Simulation oil saturation change for approximately four years of production. (b) Saturation change estimate using identical navigation data for baseline and monitor survey. (c)-(d) Repeatability measure for the two survey pairs. (e)-(h) Error in saturation change prediction for Miocene channel and Quaternary channel, respectively. (i)-(j) Full stack NRMS repeatability measure for the Miocene channel and Quaternary channel, respectively. The repeatability measure is calculated in a 600ms window above the reservoir for both models, with and without the channel, then subtracted to highlight the channel impact only. Black circles mark the calibration wells used for estimating the saturation change. Dashed contour lines indicate the channel position. Line spacing is 50m for the Miocene and 15m for the Quaternary channel.*