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Quantitative Integration of 4D Seismic for Field Development

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Introduction

The Nelson Field is an undersaturated oil field located in the Central Graben of the UK North Sea. The reservoir is composed principally of channelised turbidite sandstone of the Palaeocene Forties Sandstone Member. In the Nelson Field there are three principal channel complexes which run in a NW-SE direction across the structure. The Forties Sandstone Member in Nelson is subdivided into five zones, Zone 1 to Zone 5 of which Zone 5 is the youngest. Zones 3 and 4 are the pay zones, zones 5 and 2 are non-net, and zone 1 is reservoir below the fluid contact (Figure 1).

Seismic data over the field is of excellent quality and has been used both as a tool for reservoir characterisation and, through the acquisition of specific repeat 4D surveys and application of elastic inversion, to track fluid movements during production. The fluid fill of the reservoir causes a Class I to Class II AVO response. Oil filled sands have a reduced P-impedance with respect to water filled sands and demonstrate a phase reversal at far offsets. To date three 3D seismic surveys have been shot over the Nelson Field. The original seismic data was acquired in 1990. In 1997, three years after production start-up, a dedicated time-lapse monitoring survey was acquired and, in 2000, a further 4D survey was acquired.

Forward Convolutional Models of 4D Signature

Forward convolution models of 4D signature in Nelson have been carried out in order to understand and subsequently interpret fluid movement within the Nelson reservoir. The modelling has been carried out in STRATA (Hampson-Russell software). The models of the production signature have been obtained by subtracting synthetic seismic sections corresponding to an original OWC and a moved OWC. Synthetic logs were used with far offset values of Vp, Vs and Ip derived from Nelson wells. The amplitudes of the far offset difference response are greater that the amplitudes at zero offset, therefore we expect to characterise the 4D signature better in the far offset domain. Far offset products also show the fluid properties but not pressure effects (McInally et al, 2001).

Figure 2 shows the resulting seismic convolution model of Nelson using a Ricker 30 Hz wavelet, with original OWC in light blue, Top Forties in pink and Top Sele in dark green. OWC, Top Forties and Top Sele are represented by positive peaks. Top Forties shows dimming over the reservoir. The difference of the original and moved OWC's seismic convolutional models show that the original OWC corresponds with a positive peak and the moved OWC corresponds with a negative trough (Figure 3). The modelling has been repeated with other two wavelets extracted from two wells. One is a minimum phase wavelet and the other is a zero phase wavelet with a slighlty different frequency content to the Ricker 30 HZ. The results suggest that for the given Nelson reservoir model properties, different wavelets provide the same trough/peak 4D signature as long as their maximum energy is at time zero.

The experiment has been repeated using sequentially increasing steps of OWC movement from 3 ms up to 18 ms in discrete steps of 3 ms (approximately 15 ft). The wavelet used is Ricker 30Hz. For the given model parameters, the 4D signature of OWC movement cannot be detected if it is less than approximately 30 ft. From 30 to 70 ft, the amplitudes of the 4D signature increase steadily. Above 70 ft of OWC movement the amplitudes decrease, although tuning is present at the edge of the field.

Tuning has been observed in all the models above the reservoir (Top Forties) at the edge of the model due to the thin oil column. The tuning consists of trough energy above the top reservoir.

Mapping the OWC

Simple convolution forward models have provided a template for 4D seismic data interpretation. The trough/peak doublet which characterises the 4D far offset seismic signature in Nelson were mapped. Maximum amplitude of the reflectors was picked in every line. Original (peak) and moved (trough) OWCs were mapped in both 1990-1997 and 1990-2000 conventional far offset differences. Figure 4 shows the resulting mapped moved OWC in the 1990-2000 far offset conventional difference. The red line shows the extent of the field. Green dots represent production wells. The coloured area represents the extent of the 4D signature. The extent of the 4D signature is limited to areas of high oil production. The figure also shows a non-uniform rise of the oil water contact. Western and central areas show higher OWC that the eastern, south central and south areas. “Mega-cones” have been identified (warm colours indicate highs). The dimensions of these structures range from 600 to 1200 m. This coning had also been predicted from the deterministic reservoir simulator model.

Conventional 4D signal is only detected where the original oil column thickness is higher than 60 ft. In these areas OWC movement of 20-30 ft can be detected. This is in agreement with the results of the forward modelling.
Elastic inversion of far offset data is available in Nelson and OWC has also been interpreted. The 4D signature is clearer than in the conventional far offset difference.

The trough and peak of the 4D far offset conventional signature coincide respectively with a negative to positive and a positive to negative impedance change in the far offset inversion difference. This allows direct mapping of produced oil by isolating high positive amplitudes within the reservoir.

The 4D far offset inversion has allowed differential sweep between isolated reservoir zones to been observed (Figures 5 and 6). Differing aquifer drive mechanisms (basal and edge) have been inferred in different areas. Figure 5 shows the sweep in zone Z4b (upper Z4). Red dots represent wells completed in this zone. Basal drive is identified in the Western channel and South Central channel, whereas edge drive is identified in the Eastern channel where wells are located towards the edge of the production signature. Z3b shows mostly basal drive, although sweep in the South Central area might have a component of edge drive (Figure 6).

Comparison With Net to Gross

Maps of OWC movement for both Z4b and Z3b have been compared with seismically derived net to gross maps of both zones. Different cut-offs of NTG were applied in order to investigate a possible correlation between the extent of the 4D signature and the NTG value. Figure 7 show that the 4D signature for both zones Z4b is present in areas of NTG higher than 0.65. The same NTG cut-off is inferred for zone Z3b. “Mega-cones” occur in localised areas of very high NTG, 0.75 or higher.

It still remains a challenge to identify sweep in the areas of low NTG (channel margin and inter-channel facies). Forward convolution seismic modelling of thinly interbedded sequences may provide valuable insights into sweep within these heterogeneous environments.

Conclusions

Simple 4D difference signature modelling results have constrained the form and resolution limits of the 4D signature used in conventional mapping and amplitude interpretation of the OWC. In the Nelson field a trough/peak 4D signature is observed in the far offset conventional difference. The trough corresponds to the moved OWC and the peak corresponds with the original OWC. In the far offset elastic inversion difference the moved OWC becomes a negative to positive impedance contrast.

Through mapping of the moved OWC in the far offset difference volumes we have been able to constrain the spatial extent of the 4D signature as well as the resolution. Through comparison with the zonal NTG maps we have been able to determine the criteria for a 4D signature; OWC movement greater than 20-30 ft, original oil column thickness of greater than 60 ft, and reservoir NTG of greater than 0.65.

This study highlights the limitations of 4D seismic in areas of low net to gross and areas of thin oil column (<60'), where OWC movement may not be detected. Further analyses are required to resolve the low NTG areas.

OWC maps have provided a depth estimate which can be directly compared with reservoir simulator, PLT and TDT data. Ultimately we intend to produce a fully integrated seismic history match.

References

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McInally, A. et al. 2001 4D elastic inversion: stretching our understanding of the Nelson Field. PESGB Reservoir Geophysics Seminar. May 2001.

Acknowledgements

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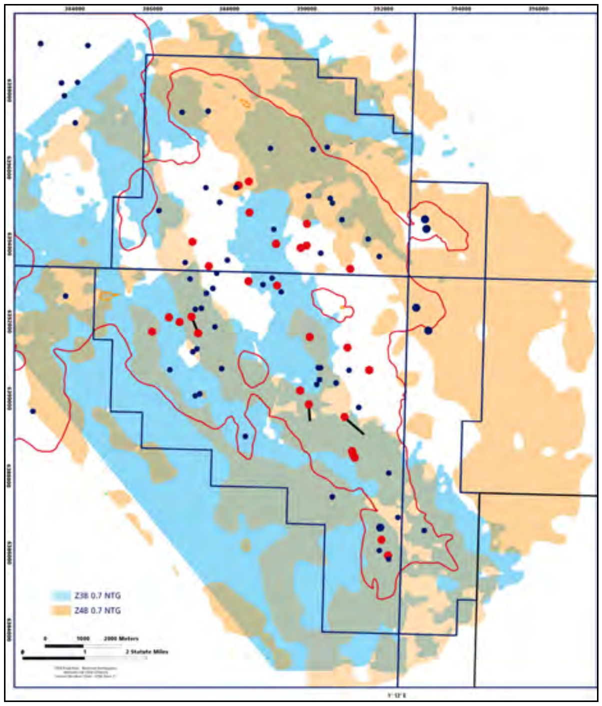

Figure 1. Schematic display of Nelson channels

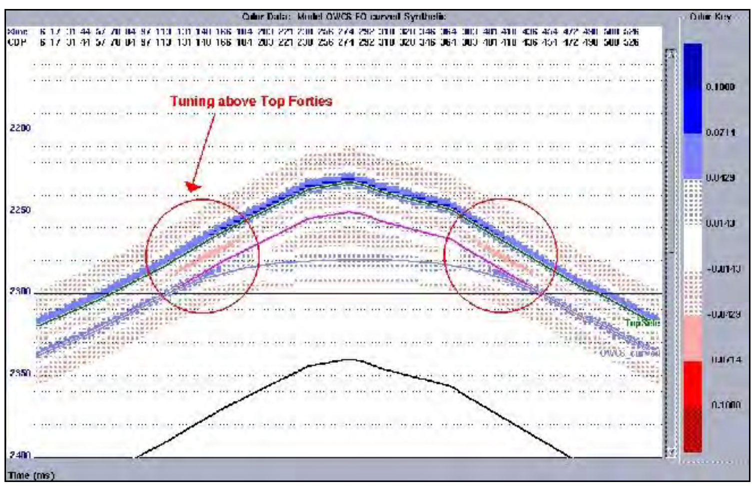

Figure 2. Forward convolutional model of moved OWC

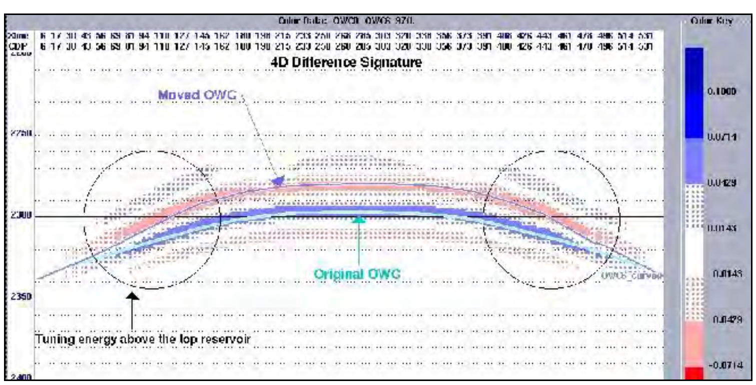

Figure 3. 4D forward convolutional model (Moved OWC – Original OWC)

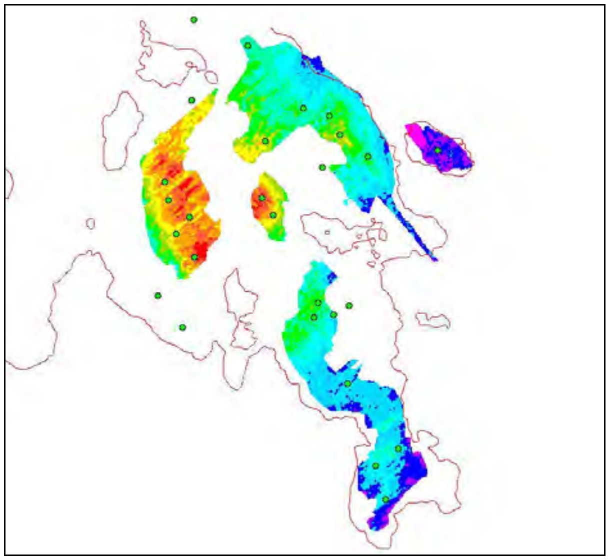

Figure 4. Moved OWC mapped in the far offset conventional difference

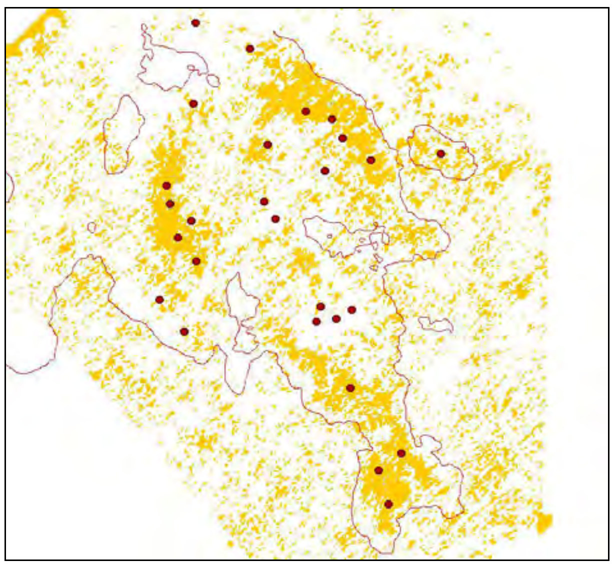

Figure 5. Sweep in the Z4b

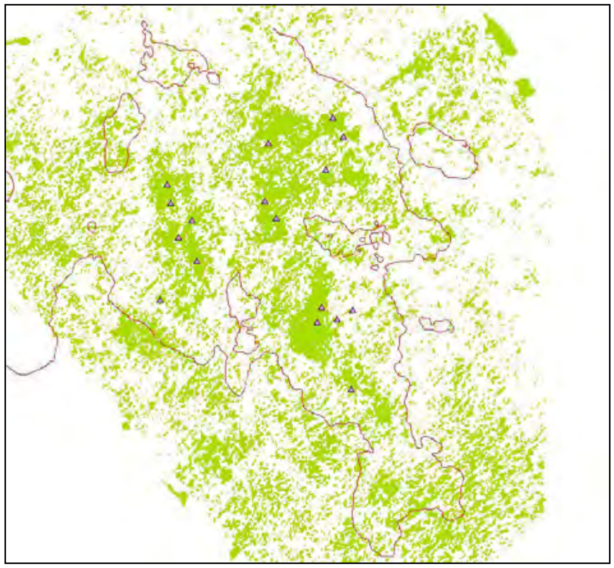

Figure 6. Sweep in the Z3b

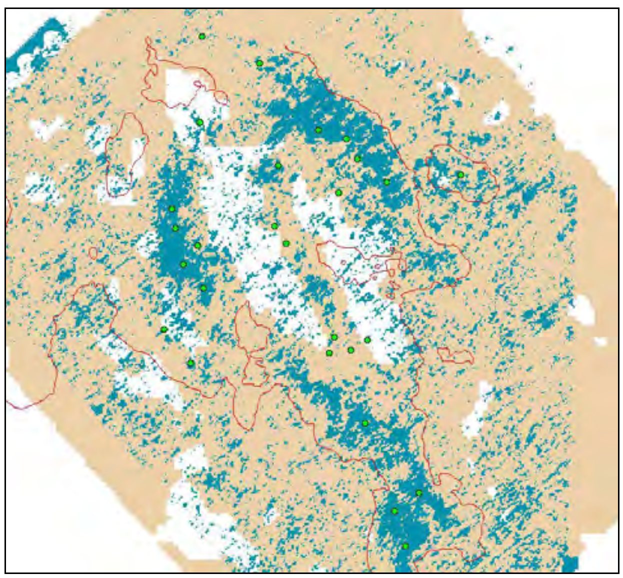

Figure 7. Z4b sweep in blue. Underneath in brown Z4b NTG>0.65