Blake Field simulator to seismic modelling study

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Summary

Simulator to seismic modelling (sim2seis) was applied to the Blake Field to understand the controlling parameters of the 4D signal in a three phase system. This was necessary as it is a significant challenge to distinguish simultaneous uneven movement of the GOC and OWC around horizontal producers based on 4D seismic. Here, 4D amplitude and time-shift maps were produced via sim2seis to illustrate the effect of 1) reservoir structure, 2) relative movement of the contacts during production, 3) immediate overburden properties, and 4) seismic wavelet on the 4D signature. The outcome was an improved comprehension of the reservoir for future management.

Keywords: Blake Field, simulator to seismic modelling (sim2seis), three-phase system, oil-water contact (OWC), gas-oil contact (GOC),4D (time-lapse) seismic.

Introduction

The Blake Field is located in the North Sea about 100 kilometres from Aberdeen in the Outer Moray Firth Basin. It comprises oil with a gas cap contained in Lower Cretaceous Captain (Blake Channel) and Coracle Sandstones (Blake Flank). Both the Captain and Coracle Sands are deep-water turbidite facies. This study is focussed on the Blake Channel sands which are thick enough to be imaged on seismic data. Production from the Blake (Channel) field began in 2001 from six wells, five of which were completed in the central crest of the field. To maintain pressure support during production, two injectors were completed in the aquifer in the North and South of the field, and have been injecting since the beginning of production. This water injection has been effective in maintaining reservoir pressure and so the main cause of 4D seismic response is changes in fluid saturation. Using 4D seismic to map the movement of the oil-water contact (OWC) and gas-oil contact (GOC) around horizontal wells poses a significant challenge, due to the lack of vertical seismic resolution and the modest contrast between oil and water. The thickness of the gas cap and oil leg varies around (below and above) tuning thickness, which adds to the complexities of analysis. In order to understand the observed 4D seismic response due to fluid contact movements, and to evaluate the dynamic response of the simulation model from a 4D seismic perspective, a simulator to seismic (sim2seis) modelling study was performed.

Complications of 4D seismic data analysis in Blake

The pre-production seismic survey was acquired in 1992. The monitor seismic survey was acquired in 2007 after six years of production. Both vintages were reprocessed using a 4D processing workflow, in 2008. The average NRMS (Kragh and Christie 2002) value of 30% represents a moderate repeatability of the 4D seismic data by present-day standards but is nevertheless a significant achievement given the following challenges. The baseline survey is old (1992) and has not had the benefit of dedicated 4D surveying technologies. Although the seismic acquisition in the Moray Firth area suffers from strong tides, which cause high feather in the streamers, the monitor survey in Blake was the world's first use of Western Geco's fully-automated vessel with source and streamer steering (Brown and Paulsen 2011). The Blake Field was also the first attempt to acquire a 4D seismic survey for a North Sea Cretaceous oil field beneath such a thick chalk layer. Seismic imaging is made challenging not only by the chalk layer but also by overburden complexities associated with the eroded debris from the adjacent Halibut Horst, which stream south west in the overburden above the reservoir. Finally the 4D seismic response is a combination of movements of both the GOC and the OWC.

Sim2seis modelling

The two-way-time (TWT) horizon corresponding to the GOC is mapped in both synthetic and real seismic data. The 4D time-shift map is generated by subtracting the TWT map for the baseline GOC from the TWT map for the monitor GOC. Figure 1 shows the observed and synthetic time-shift maps for the GOC. The area in the south of the observed time-shift maps with a chaotic response, and the areas with positive time-shift values, are not reliable and are therefore excluded from the analysis. The area of interest in the central crest is highlighted in the maps, where a negative coherent time-shift is observed, which is related to the downward movement of the GOC. The results show that the synthetic time-shift (and hence the downward movement of the GOC in the simulation model) is overestimated compared to the observed map. Based on this analysis, it is suggested to update the simulation model to have less downward movement of the GOC in the central crest of the reservoir.

Figure 2 (a,b) shows the observed and synthetic 4D amplitude maps respectively. The 4D amplitude map is generated by subtracting the RMS map of the baseline seismic from the RMS map of the monitor seismic. RMS maps are calculated between horizons corresponding to the reservoir top and the palaeo-OWC. One of the areas of mismatch between the observed and synthetic responses is highlighted. Unlike the time-shift, which was mainly derived by GOC movements, there are different features that affect the 4D amplitude; therefore, a comprehensive evaluation is needed to capture the causes of the discrepancies. As discussed below, apart from fluid contact movements, other less obvious parameters, such as the wavelet and the initial gas cap thickness prior to production can also change the synthetic 4D response.

Gas cap thickness prior to production can change the 4D response. Figure 3 shows two models with different initial gas cap thicknesses. It is shown that a thinner initial gas-cap can fix the mismatch (Figure

2c). However, it should be noted that the GOC in the reservoir model in this area is tied to the GOC in the appraisal well A6. Nevertheless a thin (3 ft) tight sand zone exists beneath the reservoir top, which can potentially explain a thinner gas cap. The wavelet can also change the synthetic 4D response. Three different wavelets are tested in this study (Figure 4). Wavelet A is extracted statistically from the baseline seismic cube over the whole trace, wavelet B is extracted statistically from the baseline seismic data over a limited time interval around the reservoir (1100-1350 msec), and wavelet C is extracted from a deterministic well-tie on well A6. Figure 6 (a,b,c) shows that a wavelet with a wider bandwidth (wavelets B and C) can improve the match between the synthetic and the observed 4D signal in the mismatch area. The effects of fluid contact movements are also evaluated in this area. Figure 5 shows two scenarios for fluid contacts after production. The first scenario (Figure 5a) is the prediction of the simulation model, and the second scenario (Figure 5b) assumes a model with higher oil-water contact movement and less downward movement of the gas-oil contact, compared to the predictions of the simulation model. The latter model is suggested based on the 4D response cubes analysis in order to create a positive 4D amplitude response in the mismatch area. The 4D amplitude maps (Figure 6 (d,e,f)) show that the second scenario can improve the match in the area. However, higher movement of OWC in this scenario increases the risk of water-flooding in the production wells in the middle of the reservoir, the evidence of which is not yet observed in the production data. Figure 6 shows how the combined effects of wavelet and fluid contact movements improve the match between the synthetic and the observed 4D response.

Conclusions

The 4D seismic signature of the Blake field results from the interplay of movements in the gas-oil contact and oil-water contact on a scale near to seismic resolution. Simulator to seismic (sim2seis) modelling of different scenarios aids understanding, identification and interpretation of different aspects of the 4D seismic signature in order to arrive at an overall interpretation of how the reservoir model can be updated to better match the observed seismic.

Sim2seis results show that the synthetic time-shift (and hence the downward movement of the GOC in the simulation model) is overestimated compared to the observed map. For the 4D amplitude map, a combination of different features can improve the agreement between the observed and synthetic 4D amplitudes. These include a thinner gas cap prior to production, less downward movement of the GOC and higher movement of the OWC compared to predictions of the simulation model, and a wavelet with a wider bandwidth. Having less downward movement of the GOC was also supported by 4D time-shift analysis. It is very likely that a model combining these factors is the best solution. It should be noted that uncertainties associated with the seismic imaging, time to depth conversion and reservoir structure are part of the complexity in the model-based 4D seismic interpretation in the Blake Field. Quantitative 3D seismic reservoir characterisation approaches such as seismic inversion can be used to clarify some of these ambiguities.

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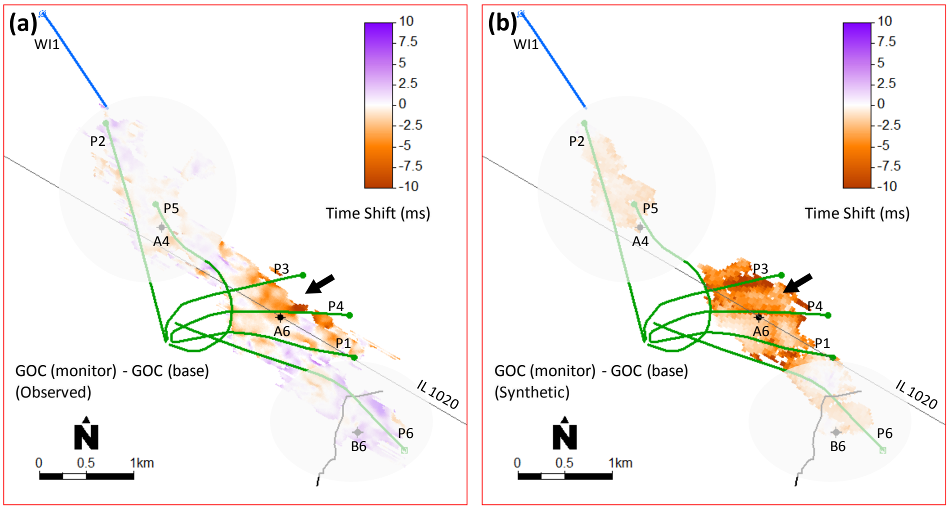

Figure 1 GOC 4D time-shift; **(a)** the observed map; **(b)** the synthetic map.

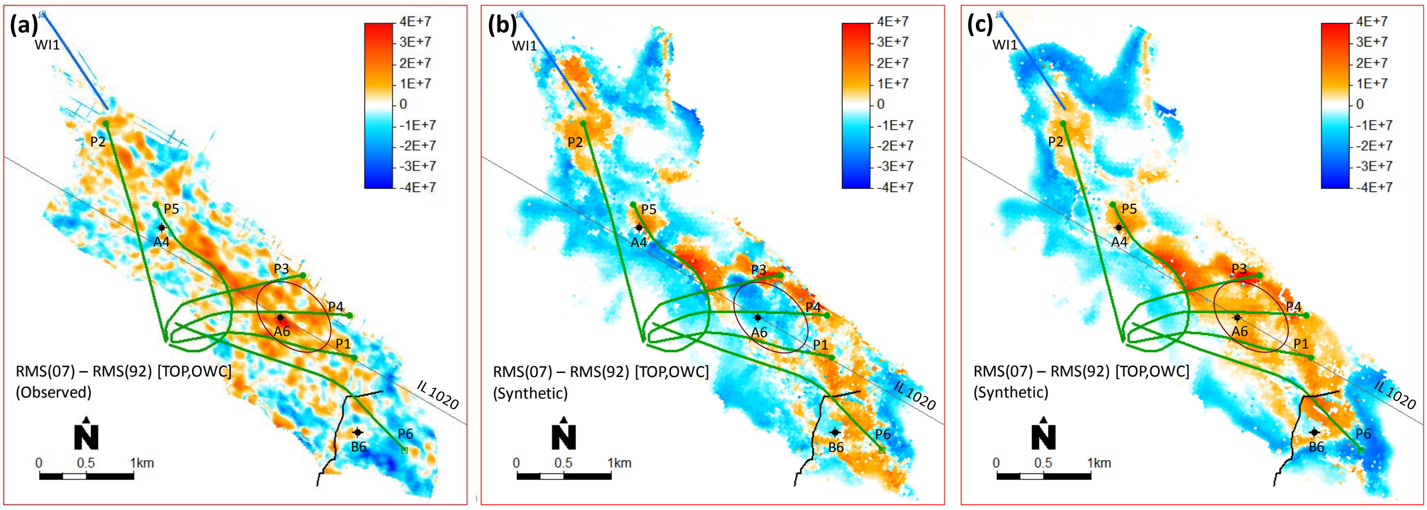

Figure 2 4D amplitude map; **(a)** the observed map; **(b)** the synthetic response from simulation model (Figure 4a); **(c)** the synthetic response using a thinner initial gas-cap (Figure 4b).

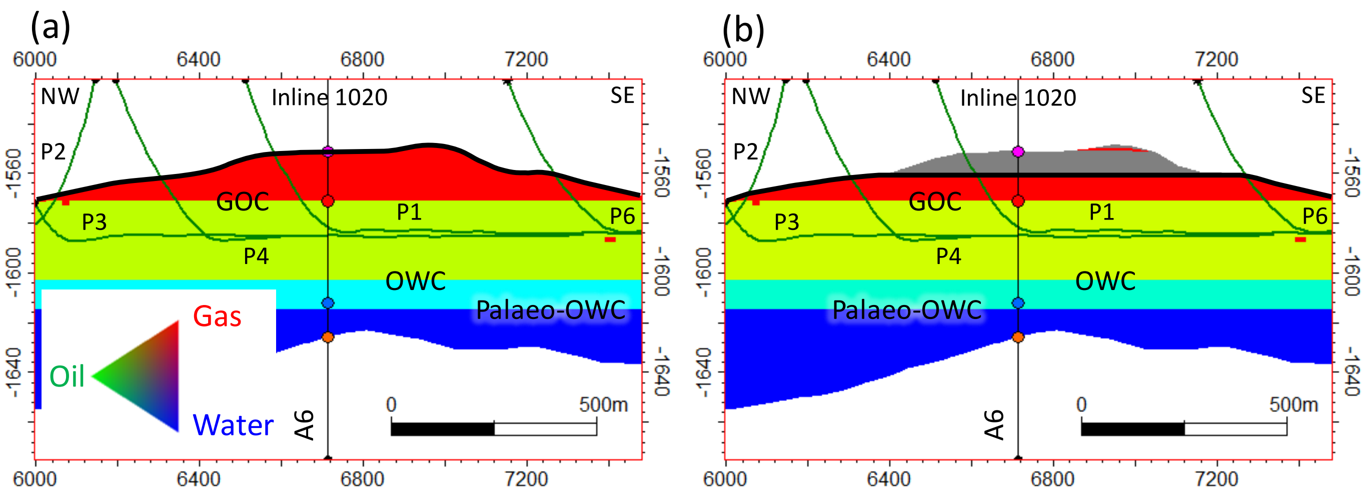

Figure 3 **(a)** The fluid phases thicknesses prior to production from the geomodel; **(b)** a model with a thinner (decrease about 6 m) gas-cap prior to production. The upper part of the gas-cap (grey) is a part of the overburden.

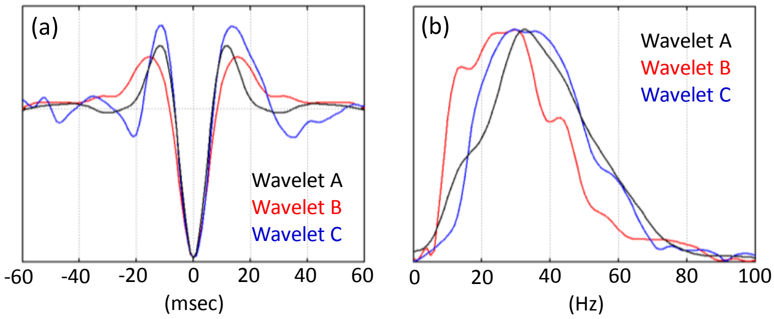

Figure 4 (a) Three wavelets used for sim2seis modelling, **(b)** the amplitude spectra of the wavelets.

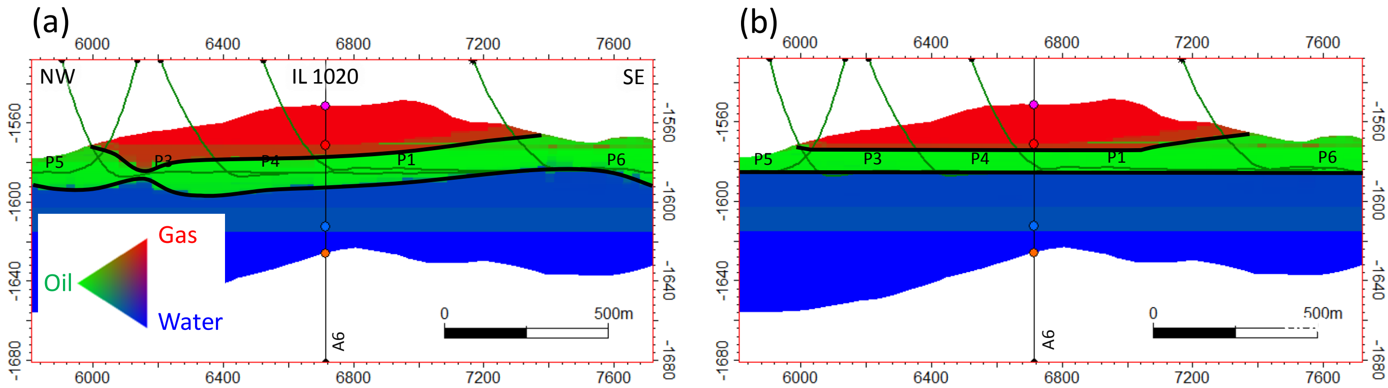

Figure 5 Saturation profile after production at time of monitor survey; **(a)** the contact movement prediction from simulation model; **(b)** a proposed scenario with less downward shift of the GOC and higher movement of the OWC.

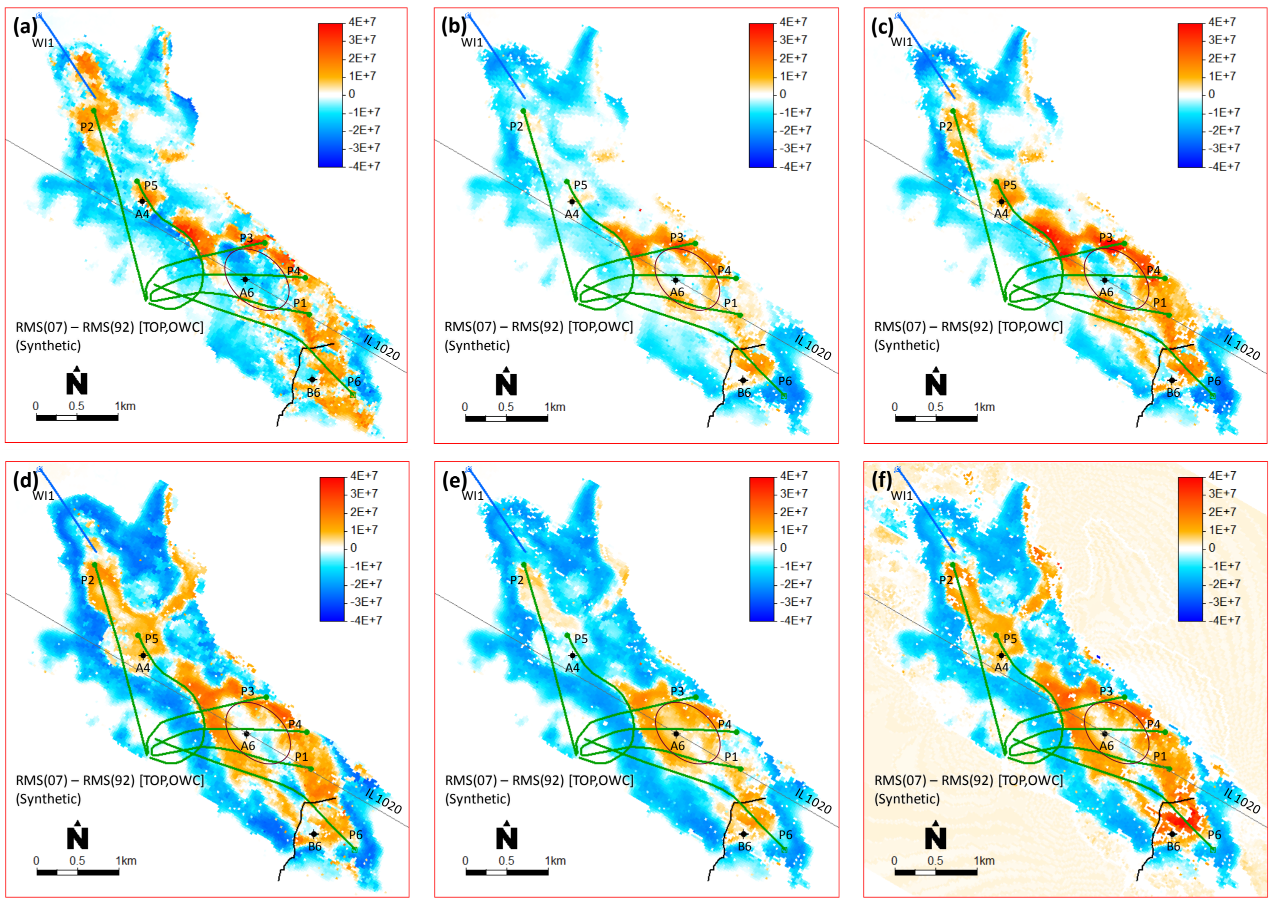

Figure 6 The synthetic 4D response using a combination of different fluid contact movements (Figure 5) and wavelets (Figure 4); **(a)** fluid contacts from the simulation model (Figure 5a) and wavelet A; **(b)** fluid contacts from the simulation model (Figure 5a) and wavelet B; **(c)** fluid contacts from the simulation model (Figure 5a) and wavelet C; **(d)** modified fluid contacts (Figure 5b) and wavelet A; **(e)** modified fluid contacts (Figure 5b) and wavelet B; **(f)** modified fluid contacts (Figure 5b) and wavelet C. The combination of the effect of the wavelet and fluid contact movements (e) and (f) can improve the mismatch area.