Model-Controlled quantitative interpretation of 4D signatures in turbidite reservoirs

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Abstract

Modelling of the Foinaven reservoir architecture illustrates how geological heterogeneity affects the interference of the seismic wavelet and allows the fluid saturations to be quantified in the inter-well region. Synthetic modelling based on geological modelling demonstrates the dependence of seismic interference on the model geometry, frequency content of the seismic wavelet and the prevailing fluid saturations. Attenuation of seismic energy as the wavelet passes through a gas bearing–bearing unit causes amplitude dimming. It is found that applying a frequency filter, specific to each of the repeat seismic surveys, can eliminate this anomalous interference " dimming".

Introduction

4D seismic is an emerging imaging technology that has a great impact on reservoir management. It has the potential to image fluid movement in the inter-well region as it is identified by their associated amplitude anomalies. There is, however, not a unique relationship between the compositions of the reservoir pore fluid and seismic amplitude. Therefore there is an element of uncertainty when interpreting the time-lapse signature as a spurious artefact of the prevailing geological environment may be confused with a fluid effect. This project focus is to resolve a geological modelling problem of this nature involving a particular area of the field where it is believed that thin bed tuning precludes an accurate assessment of fluid saturations being made.

The Foinaven field was the first field to be developed in the Atlantic Frontier Province West of Shetland Islands. It is split into five panels, which are defined aerially by extensional faulting and stratigraphic boundaries. The reservoir exits in structural and stratigraphic traps sealed beneath thick mudstones, sourced from Middle and Late Jurassic rocks (Lames and Carmichael, 1999). The field is divided vertically into three layers, referred to as T34, T32 and T31.These layers were formed in a proximal submarine fan depositional system, each layer comprising a highly channelized arrangement of stacked and amalgamated sands, with continued structural activity further complicating their temporal distribution. Reservoir details are given in Table 1.

Turbidite Sands 26% average porosity 60-90% net-to-gross Sk = 0.56,Sμ = 0.56 Pk = 904.3 psia Pμ = 604.3 psia Khigh = 9.94GPa μhigh = 7.75GPa	**Fluids** API=26º Pb =3050 psia Pint = 3225 psia GOR (int)=350 scf/stb Temperature = 60º C
Reservoir Top Res: 6979.5' TVDSS 115' oil column OWC 7260' TVDSS	**Seismic** 25Hz peak frequency Surveys: 1993,1999, 2000 Towed streamer data

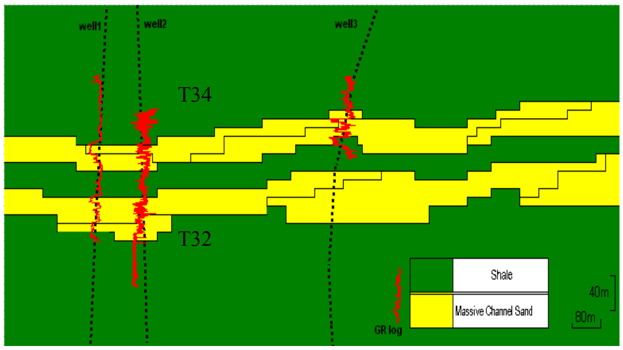
Table 1 - Reservoir and fluid properties for the Foinaven field. Stress sensitivity parameters Sk, Sμ, Pk, Pμ, K_∞ μ_∞ are averages of fits to laboratory core measurements (MacBeth, 2002).

Geological Modelling

To identify and then quantify the changing saturations it was first necessary to develop a cross sectional model which accurately represented the key geological features responsible for the seismic character of the reservoir. A full wire-line log suite, acquired pre-production, was available for wells well 1, well 2 and well 3. The location of the wells and the cross section to be modelled corresponds to a seismic line was chosen because of its location relative to the shadowing anomaly identified in each repeat survey. The gamma tool response was used to discriminate between sand and shale, and using a simple linear model, to calculate a shale volume curve. This allowed the channel sands to be isolated from the surrounding non-reservoir facies and, based on their character, to be correlated between the wells.

Correlation panel derived from the three wells formed the framework for the 2-D cross-sectional model, showing the general lobate form of the turbidite channel complexes at the inter-well scale. The model is aligned perpendicular to the direction of the regional structural trend of Foinaven field channels (S-E/N-W palaeocurrent direction (Cooper *et al*, 1999)) to ensure that the cross-section shows the true width of the channel. The correlated sand packages were then arbitrarily populated with a genetic channel unit until the model satisfied limiting parameters, such as net: gross, well and seismic data. Once the sedimentological framework was built it was digitised spatially to create x-z grid. The dimensions of the grid were selected to conform to the spacing of the real seismic data while minimising the computational power that was required. The grid therefore comprised rectangular cells with the x-dimension equal to 12.5m (seismic trace separation) and the z-dimension set to 5m.The model was then populated with appropriate P and S-wave and bulk density values derived from the wire-line log data. Figure 2(a) and (b) shows the architecture of the geological model and the seismic line (1993 data).

a)



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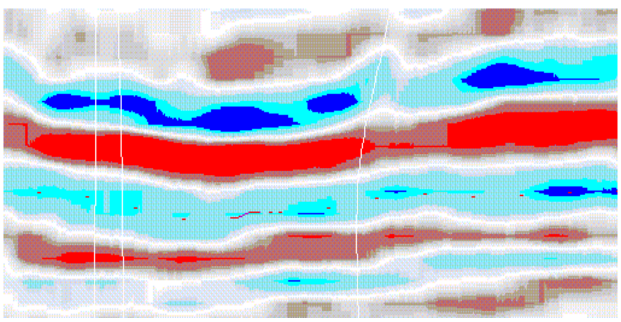
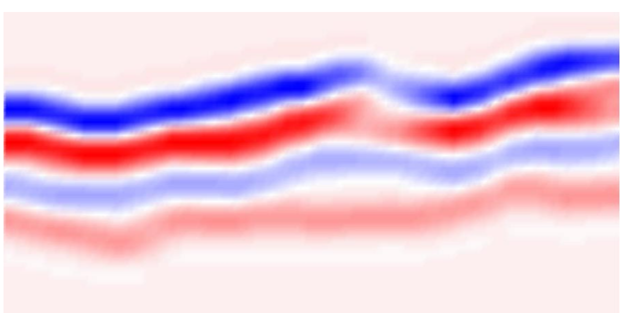


c)



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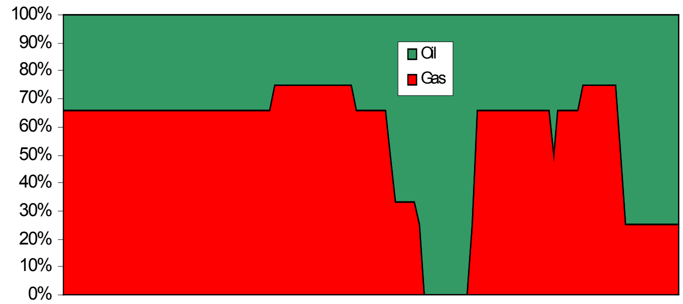

Figure 2 - a) Synthetic geological model displayed with the corresponding b) Real seismic section (1993 vintage) c) Synthetic seismic model with inhomogenous gas saturation in the upper sand. d) Non-uniform gas saturation of upper T34 sand.

Forward seismic modelling

By building a geological model it was possible to develop an array of 1D vertical pseudo-logs through the cross-section, which could be amended to reflect the migration of fluids through the reservoir. The synthetic seismic is calculated using the reflectivity method where near off-offset stacks are computed (MacBeth *et al*, 2002).
To create a synthetic seismic data that represent a model depicting the transient reservoir behaviour and adequately recreate the shadowing of the lower T32 sand. The code modelled the near offset stack to a range of 1000m, as observed in the near portion of the towed streamer data. Figure 2(c) shows a synthetic seismic section generated from the geological model presented in Figure 2(a) .The upper sand is created with a non-uniform gas-saturated upper sand and the lower sand saturated with uniform oil as seen in Figure 2(d). Comparing it with real data shows a strong agreement.

Thin Layer Tuning

The tuning characteristics of a modified wedge model displays the relationship between frequency and temporal thickness and its manifestation as a complex interference pattern as it is explained in (Barens, 2001). By constructing a synthetic wedge model, comprising an array of sand bodies of similar thickness and acoustic properties to the Foinaven Field, the character of the interference observed in the real data is recreated. Figure 3 shows a model with a gas saturated upper sand body. It shows an obvious dimming of the lower sand at approximate separation of 15m, believed to be the result of a complex interaction of seismic interference . The tuning thickness of the model is a function of the wavelet frequency; with a higher peak frequency displaying a different tuning response. This suggests that if the real data were filtered above a certain frequency then the dimming, resulting from the reservoir. architecture would no longer inhibit an assessment of the real time-lapse signature.

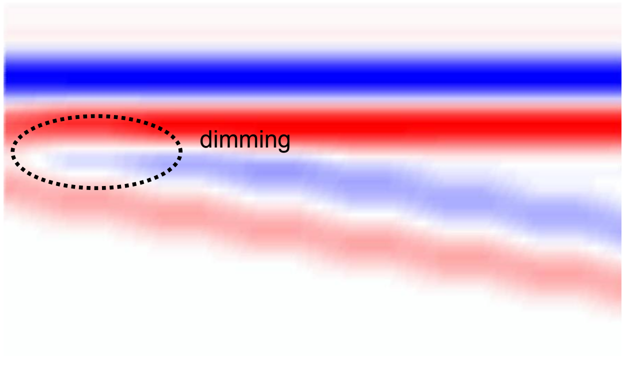

Figure 3 - Tuning phenomena of simple wedge model with gas saturated upper layer.

The appropriate filter to use is unique to each survey vintage and has been established experimentally by examining how the average amplitude ratio for the T34 and T32 events vary according to the dominant data frequency. Figure 4 shows RMS amplitude maps of T34 and T32 horizons of panel 3 before and after application of frequency filtering. This results in extraction of the true time-lapse amplitude which is due to reservoir fluid movement and not to the tuning, geological architecture, and thickness artefacts.

Attenuation Effect

So far, the effect of interference effect has been identified adopting purely an elastic model. The code used has been improved to adapt for the attenuation of the seismic wavelet as it propagates through a gas–bearing unit. It widely reported this has an effect on the reduction of observed amplitudes (Thomsen *et al*, 1997).

T34 sand unit is highly charged with gas. This gas attenuates the P-wave velocity, combined with tuning, thickness and fluid saturations induces dimming of amplitude of the lower layer. The presence of gas usually

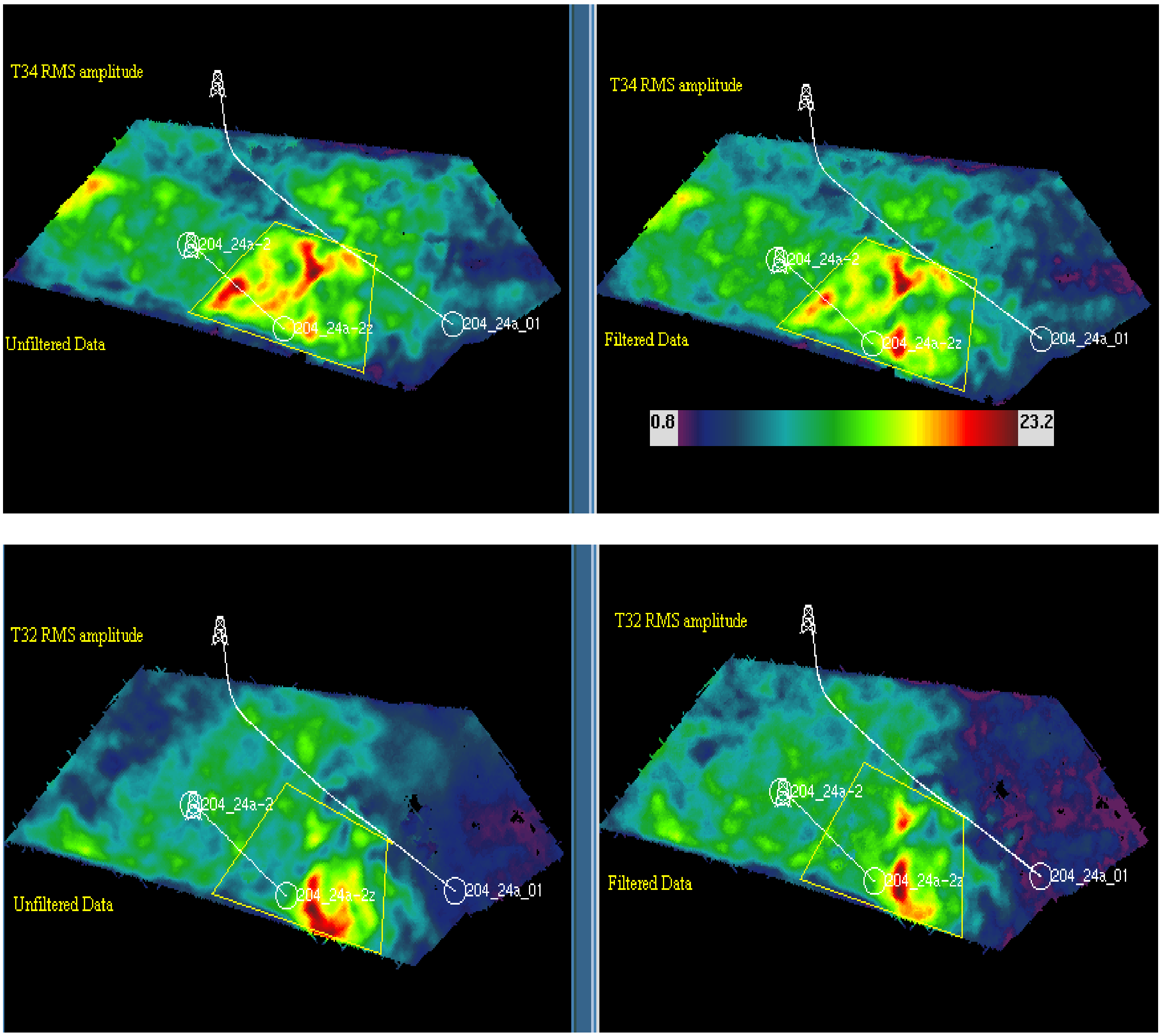

Figure 4 - RMS amplitude maps of T34 and T32 showing the seismic dimming effect of T32 to be removed in the 1993 data.

has a small effect on the shear modulus. Hence, S-waves are much less affected by gas than P-waves. The more attenuated the wavelet i.e., bigger values Q^{-1}_P and Q^{-1}_s the dimmer the amplitude (Klimentos, 1995). Figure 5 shows a synthetic section with non-uniform gas saturated upper layer including attenuation of P and S wave. Attenuation values $Q^{-1}_P = 0.2$ and $Q^{-1}_s = 0.2$ are used in this figure .Comparison with Figure 3(b) and (c) it shows that the amplitude of lower layer T32 has reduced significantly. However, this scenario is much closer to the real seismic section. Figure 6 confirms this result as it shows amplitude comparison between the non-attenuated (Figure 2(c)) and attenuated scenario (Figure 5). This proves the theory that attenuation of seismic wavelets has a great impact with other factors on the dimming effect. It is therefore proposed that geological architecture represented here within the limitations of the modelling technique, is a true representation of the real formation and the fluid saturation indicative of initial reservoir conditions.

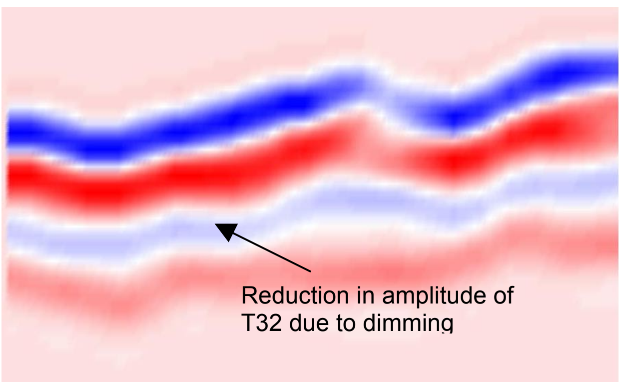

Figure 5 - Synthetic seismic section shows nonuniform gas saturated upper layer with dimmer T32 amplitude due to attenuation compared to Figure3 (c).

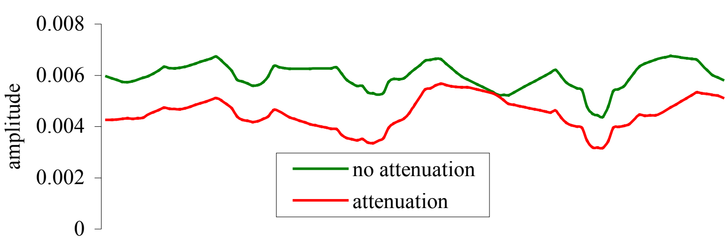

Figure 6 - Shows the amplitudes of non-attenuated scenario (Figure 3(c)) and attenuated scenario (Figure 5).

Conclusion

- Analysis of RMS amplitudes of T32 and T34 horizons revealed a seismic dimming to exist in each survey 1993,1999 and 2000 precluding an interpretation of the underlying T32 sand. Applying frequency filters specific for each survey has revealed the true seismic character.

- Forward modelling has demonstrated the sensitivity of synthetic and real seismic amplitudes to fluid saturations, bed thickness and peak frequency. It is possible to recreate the dimming of the T32 similar to real seismic dimming observed in each 3D seismic survey.

- A theoretical analysis of thin bed tuning using wedge models has highlighted that an approximate separation of 15m, coupled with a gas saturated upper sand unit, represent the geometric physical conditions necessary to recreate the seismic dimming observed in the real data.

- Attenuation of the seismic wavelet when propagating through a gas-saturated unit, contributed to the reduction of amplitude observed.

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