Summary

This paper continues the studies presented in this conference by Loizou et al. (2006), where we have compared the AVO analyses from four wells in the west of Shetland: Foinaven oil well (204/24A-2); Laggan gas well (206/1-2) and two prospect wells (204/17-1 and Assynt 204/18-1). In this study, we apply the spectral decomposition to the data from these four wells and provide further evidence that there are also differences in the spectral characteristics between the four wells. While Foinaven and Laggan Class III AVO anomalies are consistent theoretical predictions for frequency-dependent AVO behaviours. However, the results from the Assynt prospect 204/18-1 and another prospect 204/17-1 show rather complicated behaviour in the iso-frequency sections that cannot be fully explained. In summary, though the amplitude anomalies seen in the two prospects were originally interpreted as to be similar to the Foinaven, but our study indicated they are different in both the AVO behaviour and the spectral characteristics.
Introduction

In our companion paper by Loizou et al. (2006), we have compared AVO responses from four wells from the west of Shetland: Foinaven oil well (204/24A-2); Laggan gas well (206/1-2) and two prospect wells (204/17-1 and Assynt prospect well 204/18-1). The AVO analyses are based on intervals encountered within the Palaeo cene Vaila Formation, particularly the T31 to T36 interval. Two of the wells 204/24A-2 and 206/1-2 are hydrocarbon bearing in contrast to the other two wells 204/18-1 and 204/17-1, which are dry holes. Foinaven and Laggan both show clearly Class III AVO. Previous work suggested that amplitude anomalies from the two prospect wells were also Class III AVO. However, our re-interpretations show that these strong amplitudes anomalies seen in these two prospect wells were actually Class I as revealed by offset stacks, AVO cross-plots and decreases of amplitudes in CDP gathers. In this paper, we compare the spectral characteristics from these four wells. Our results show that spectral characteristics in Foinaven and Laggan are consistent with theoretical predictions, while the results from the other two prospects show different and rather complicated behaviours that cannot be fully explained.

Effects of dispersion and attenuation on AVO

Dispersion and attenuation of seismic waves can arise from either seismic scattering or intrinsic absorption due the presence of fluids in porous media. In a recent paper, Chapman et al. (2005) have showed how to implement ideas from squirt-flow theory to model hydrocarbon related dispersion and attenuation anomalies. One of conclusions is that P-wave reflection coefficients can become strongly frequency dependent. Synthetic modelling by Chapman et al. (2005) and field data examples by Odebeatu et al. (2006) are used to show that AVO characteristics at an interface can be strongly influenced by frequency (dispersion and attenuation).

Figure 1 shows schematically the expected variation of velocity as a function of frequency. The transition frequency related to the maximum dispersion and attenuation can occur at seismic frequency (Chapman et al. 2005).

Figures 2 and 3 show the variations of P-wave reflection coefficients with saturation and frequency for typical Classes I and III AVO, respectively. For the Class I type interface, i.e. an interface with low to high impedance contrast, high frequency will enhance the AVO effect due to the increase in impedance contrast across the interface (refer to Figure 1). So we would expect that for a Class I AVO, amplitudes would increase as frequency increases. In contrast, for the Class III type AVO, i.e. an interface with high to low impedance contrast, exactly the opposite is seen (Figure 3), i.e. amplitudes would be expected to decrease as frequency increases. The variation of AVO with frequency is also strongly dependent on saturated fluids as shown in Figures 2 and 3.

Application of spectral decompositions

The modern instantaneous spectral analysis techniques or spectral decomposition is an ideal tool to detect the effect of frequency-dependent AVO. There are several techniques that can be used, such as short-window Fourier transform, discrete wavelet transform, or Stockwell or S-transform. We use the wavelet transform with a Morlet wavelet in this paper to perform spectral decomposition.
The Foinaven oil well 204/24A-2 provides an excellent example of a soft/negative acoustic response that increases with offset angle. The Foinaven amplitude anomaly is associated with Class III type AVO (Loizou et al. 2006). Figure 4 shows the iso-frequency sections of stacked data for four different frequencies ranging from 15 to 45 Hz. Note that the maximum amplitudes in each iso-frequency section have been normalised to a constant (or reference) value so that amplitudes can be compared for different iso-frequency sections (the normalization is also applied to other data below). The marked area shows the Foinaven amplitude anomaly. From Figure 4, we can see a systematic decrease in amplitudes as frequency increases and this variation is consistent with the theoretical prediction in Figure 3 for oil-saturated reservoirs.

The Laggan gas discovery well 206/1-2 is also shown to be associated with bright spot Class III type AVO. A series of iso-frequency sections are shown in Figure 5. Again, we can see a
systematic decrease of amplitudes as frequency increases in the marked area, consistent with the theoretical prediction for Class III type AVO shown in Figure 3. Note that the corresponding gas-curves in Figure 3 are not shown, and we expect that the effect will be more dramatic for gas saturation than for brine or oil saturation. Odebeatu et al. (2006) show that for thin reservoirs, the effect of tuning can also cause changes in spectral characteristics. For the Laggan well, a net sand thickness of 62m made up of 3 separate sands equivalent to 33 ms of TWT (interval velocity of 3730m/sec) situated at a depth of 3815m TVDSS. It is almost certainly that the variation in the spectral sections in Figure 5 is due to the combination of both gas saturation and tuning effects of thin reservoirs.

Figure 5. Selected iso-frequency sections of the stacked seismic data from Laggan.

Assynt prospect well 204/18-1 was positioned on a high amplitude anomaly, located in the Foinaven Sub-basin and was largely a geophysical driven prospect. The amplitude anomaly was interpreted and seen by a number of major companies to be a direct fairway analogue to discoveries such as Foinaven. However, our work presented by Loizou et al. (2006) in this conference has indicated that the Assynt amplitude anomaly is actually associated with a Class I type AVO, rather than the expected Class III as was previously interpreted. Spectral decomposition was applied to the data to obtain iso-frequency sections between 10 and 40 Hz and reveals that the Assynt amplitude anomaly is only seen in the very low frequency ranges. Figure 6 compare the iso-frequency sections for the frequencies ranging between 10 and 25 Hz. Intriguingly, we see that the amplitudes in the marked area change dramatically from an increase with frequency between 10 and 15 Hz and then decrease with frequency between 15 to 20 Hz. This suggests that the Assynt anomaly is in indeed concentrated on the very low frequency range in a very narrow frequency band. The increases of amplitudes with frequency is consistent with the prediction in Figure 2 for Class I type AVO, but the sudden decrease thereafter cannot be fully explained.

Well 204/17-1 is another prospect well located just 8.8 km and marginally up-dip of the Assynt well 204/18-1 but was positioned on a smaller amplitude anomaly. Nevertheless, we have found that spectral characteristics (not shown here) are very similar to the Assynt results presented in Figure 6.
Figure 6. Selected iso-frequency sections of the stacked seismic data from Assynt prospect.

Conclusions

We have compared the AVO analyses from four wells in the west of Shetland. Both the 204/17-1 and 204/18-1 failed to find hydrocarbons, where our studies indicated that a Class I type AVO anomaly is present. Spectral decomposition results presented in this paper further reveal that there are also differences in the spectral characteristics between the four wells. While Foinaven and Laggan conform the theoretical predictions, the results from the Assynt prospect shows rather complicated behaviour in iso-frequency sections that cannot be fully explained. One particular highlight from the analysis was that although the Assynt amplitude anomaly was originally interpreted as analogous to Foinaven, our study firmly indicates it is different in both the AVO behaviour and the spectral characteristics.

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References