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Is depth-variable streamer data AVO friendly? A study using both synthetic and real data

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SUMMARY

Variable-depth streamer acquisition has become a popular solution for marine seismic acquisition to obtain broad bandwidth data: the curved cable profile produces notch diversity that minimizes residual ghost and the deep towing segment provides high S/N at low frequencies. However, there have been discussions in the industry regarding the fidelity of AVO response from variable-depth streamer data due to the obvious changes in frequency and wavelet with offset. To answer this question, we need to focus on these key questions: can we remove the ghost successfully? Can we compensate the earth absorption effect to balance the spectrum from near to far offset?

Based on the de-ghosting algorithm that is termed Ghost Wavefield Elimination (GWE) which inversion in the tau-p domain (Wang et al. 2013, Poole 2013), we analyse the influence of GWE on the AVO response by using 2D synthetic datasets which were modelled by visco-elastic wave equation (Kjstansson, 1979) with two streamer towing configurations - conventional flat tow (8m) and depth-variable way (7~50m). GWE was applied on both datasets and the results show that it is very effective in attenuating the ghost energy. Furthermore, the AVO responses obtained in GWE results are almost identical. However, both AVO curves still decay rapidly in far offsets. To compensate this, pre-stack depth migration that incorporates the synthetic Q model (Q-PSDM) was applied. The resulting AVO curves then match well with the Aki Richards synthetic.

Our approach was then applied on a recent BroadSeis survey offshore Vietnam with source/receiver de-ghosting, shallow water de-multiple, advanced depth imaging and proper Q compensation. The high resolution common image gathers (CIGs) were then compared with the well synthetic gathers: AVO trends were picked along the top of sand layers and a good match was found within a frequency band of 5-60 Hz.

To summarise, we have demonstrated through both synthetic and real data examples that AVO fidelity is preserved for depth-variable streamer data with GWE pre-migration de-ghosting technology and ray path honouring pre-stack absorption compensation through Q-PSDM.

Introduction

Variable-depth streamer acquisition has become a popular solution for marine seismic acquisition to obtain broad bandwidth data: the curved cable profile produces notch diversity that minimizes the residual ghost, and the deep towing segment provides high S/N at low frequencies. However, there have been discussions in the industry regarding the fidelity of the AVO response from variable-depth streamer data due to the obvious changes in frequency and wavelet with offset. To answer this question, we need to focus on two key questions: Can we remove the ghost successfully? Can we compensate the earth absorption effect to balance the spectrum from near to far offset?

We have demonstrated through both synthetic and real data examples that AVO fidelity is preserved for variable-depth streamer data with GWE pre-migration de-ghosting technology.

Method

As a standard practice for pre-migration de-ghosting in broadband processing, we are using a suite of deghosting algorithms termed Ghost Wavefield Elimination (GWE) based on inversion in the tau-p domain (Wang *et al*., 2013). We analyse the influence of GWE on the AVO response by using 2D synthetic datasets which were modelled by the visco-elastic wave equation (Kjstansson, 1979) with two streamer towing configurations: conventional flat tow (8 m) and variable-depth tow (7-50 m). GWE was applied on both datasets and the results show that it is very effective in attenuating the ghost energy. Furthermore, the AVO responses obtained in GWE results for both towing configurations are almost the same. However, both AVO curves still decay rapidly in far offsets. To compensate this, pre-stack depth migration that incorporates the synthetic Q model (Q-PSDM) was applied. The resulting AVO curves then match well with the Aki-Richards (Aki and Richards,2009) synthetic.

Our approach was then applied on a recent variable-depth streamer survey offshore Vietnam with source/receiver de-ghosting, shallow water de-multiple, advanced depth imaging and Q compensation. The high resolution common image gathers (CIGs) were then compared with the well synthetic gathers: AVO trends were picked along the top of sand layers and a good match was found within a frequency band of 5-60 Hz.

Synthetic example

We start with analyzing the influence caused by GWE on AVO response with a synthetic dataset. The datasets were properly modeled by visco-elastic wave equation which describes the attenuation and dispersion mechanism of wave propagation (Kjstansson, 1979), both in conventional and DVS tow way. Figure 1 shows a comparison of typical shot gather between conventional and DVS, from which different ghost delay time caused by streamer configuration can be observed.

The first issue we need to address is the influence of earth absorption effect on AVO. Figure 2 shows three gathers, gather A is modelled by the Aki-Richards equation (Aki and Richards,2009) which contains little absorption effect from near to far offset. We can use it as a ground truth reference for comparison. Gathers B and C are the gathers with and without Q compensation after GWE process. Here the Q compensation was conducted by the QPSDM using the exact Q field. We output the AVO response respectively in the same window. It is observed that from figure 2(B) the AVO curve drops faster than the reference while figure 2(C) has very similar AVO trend compared to the reference. That means proper de-ghosting plus Q compensation make a more compliant AVO response.

The second problem we would like to discuss is whether the GWE process is AVO friendly. Conventionally the effect of the receiver ghost on AVO has not been realized to be handled properly. In broadband processing (conventional and DVS tow), the ghost energy is attenuated in the GWE process. In figure 3,(a) and (b) are CRP gathers of conventional and DVS without GWE respectively. (c) and (d) are the corresponding CRP gathers with GWE. From the AVO curve extracted from the data according to different time windows it is obvious that the main difference is coming from the receiver ghost on (b). However after GWE the AVO curve extracted from each data are very similar so that data (c) and (d) are very close in terms of its amplitude, phase and AVO variations. The AVO trend after GWE is also very close to the conventional data without GWE. This analysis shows that AVO trend of the broadband processing is not affected by GWE process.

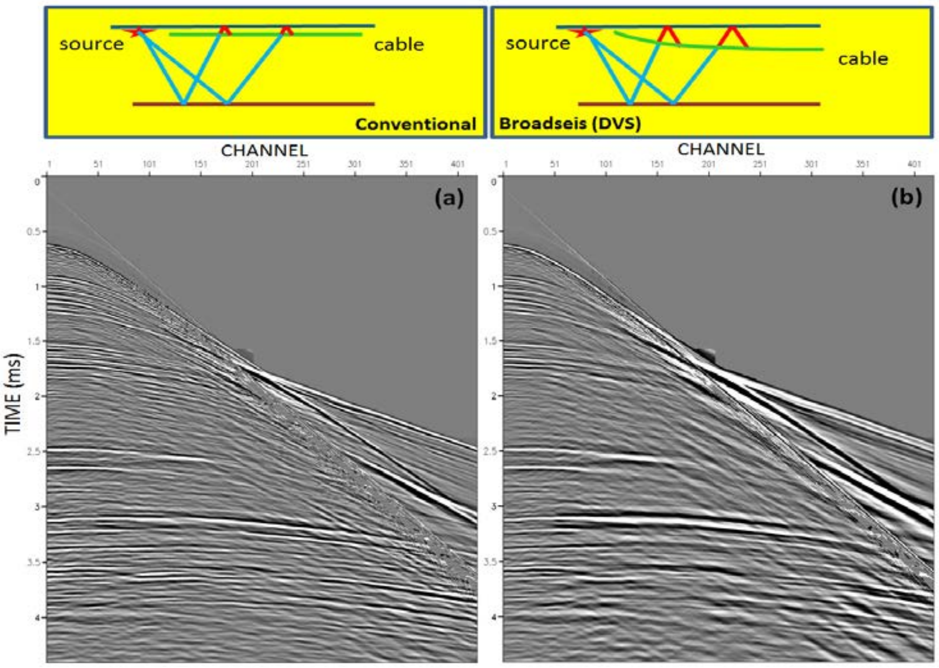

Figure 1 *Typical shot gather of (a) conventional flat tow data and (b) variable depth streamer data.*

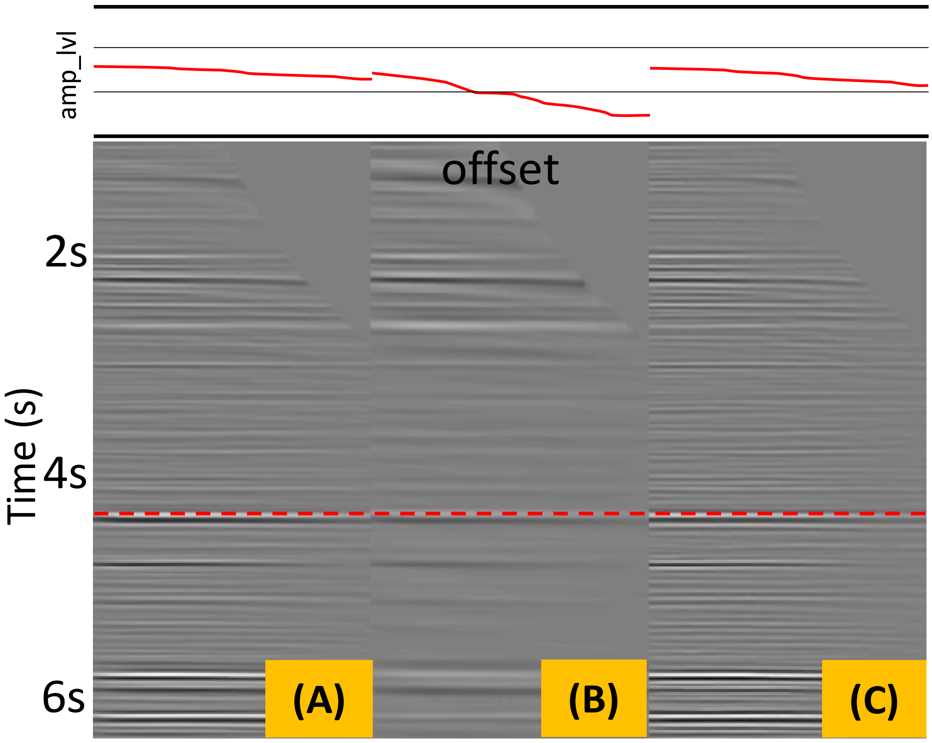

Figure 2 *CRP gathers and AVO response: (a) gathers modelled by Aki-Richard equation (b) gathers after deghosting with normal PSDM (c) gathers after deghosting with Q PSDM.*

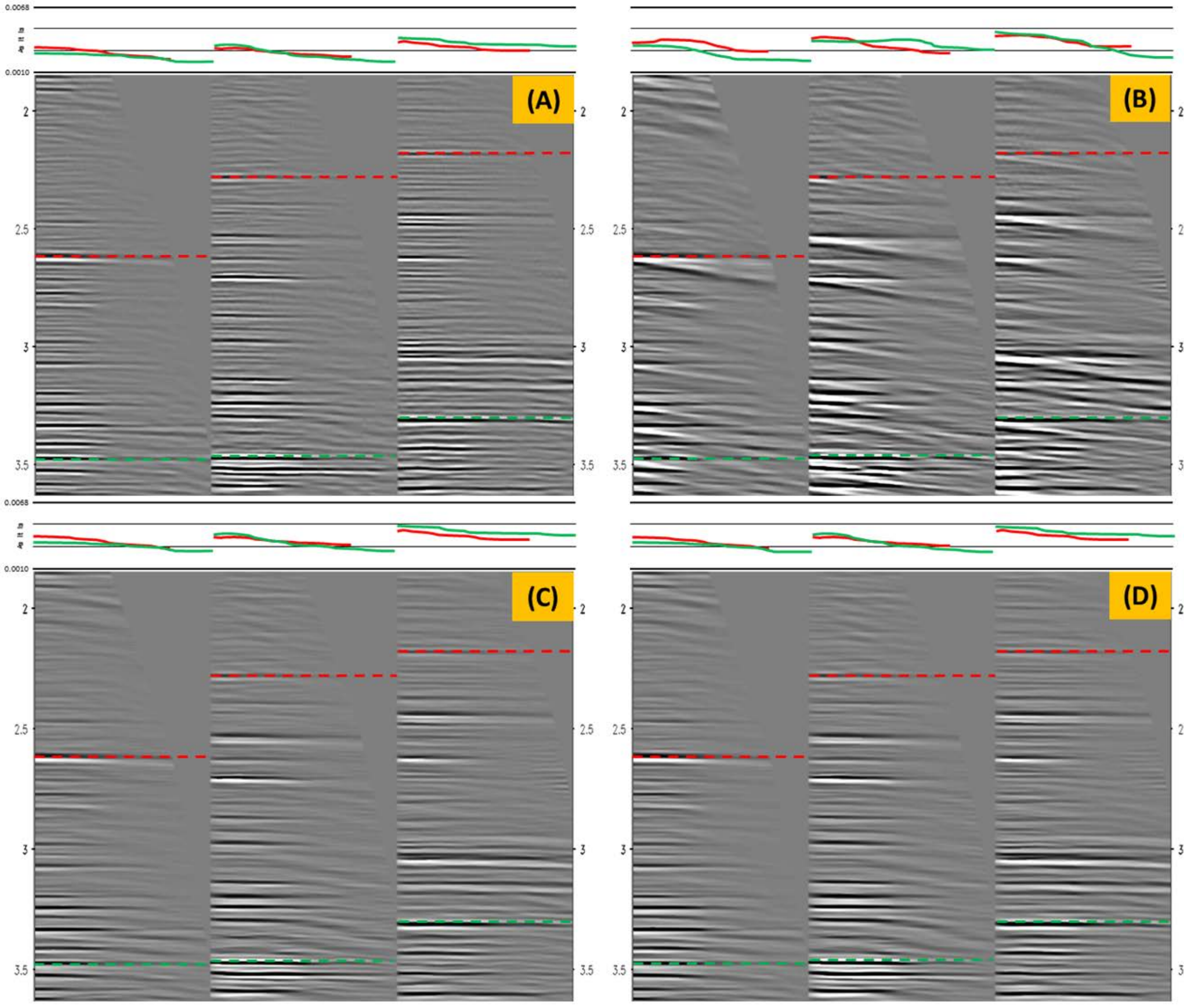

Figure 3 Selected CRP gathers after migration: (a) conventional data before GWE and its AVO response (b) DVS data before GWE and its AVO response,(c) conventional data after GWE and its AVO response, (d) DVS data after GWE and its AVO response.

Real data example

The real data example is from the Nam Con Son basin, offshore of southern Vietnam. In real data processing, preservation of relative amplitude information is critical for reservoir characterization studies such as AVO and Inversion analysis. Latest trend in the industry is moving forward with broadband solutions. It is well know that broadband data are rich in low frequency content which is intern minimises the dependency on low frequency model in Inversion studies. Generally all broadband solutions are associated with Pre-stack de-ghosting process; however it is critical to cross check that de-ghosting process for broadband seismic is AVO compliant.

The figure 4 illustrates an example of AVO compliant processed broadband seismic data at well location. The leftmost pane in figure 4 shows the well logs panel including the impedance, porosity, volumetric (Vclay) logs and water saturation. The interval with low Vclay values corresponds to sand zones. Figure 4A shows the processed seismic gather and figure 4B shows the modelled synthetic gather. To verify the AVO behaviour of reservoir sands, we pick the horizon along the seismic event that corresponds to sand top. Bottom curves map shows graphs of amplitude variation with offset which shows that AVO trend of model synthetic gather is similar to that processed gather AVO response. This confirms that we have done AVO compliant processing for broadband solutions.

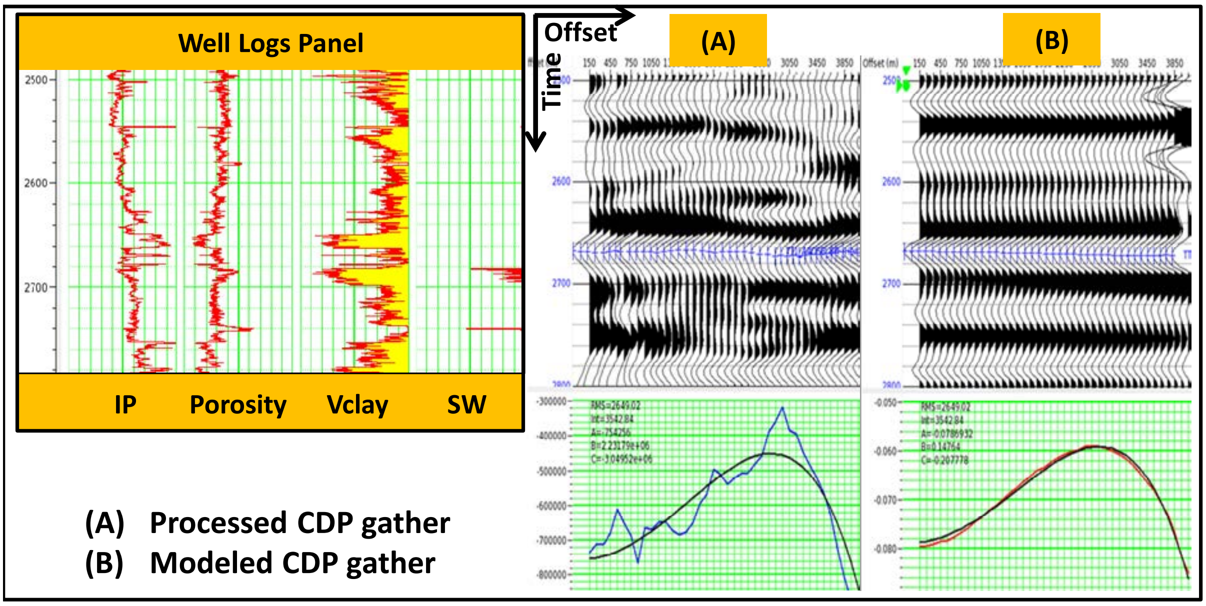

Figure 4 *AVO analysis and comparison on processed and model CDP gather with well logs panel.*

Conclusions

In order to prove the GWE process is AVO friendly, we demonstrate this process with AVO response analysis both using synthetic data and real data example along with the inversion analysis on real data. Q compensation through QPSDM for broadband data can help to make broadband result with compliant AVO response. Also GWE process is AVO friendly. The extra-wide bandwidth and image with higher resolution was obtained after GWE without changing the AVO trend. The QI analysis of real data example also proves the same conclusion. Therefore, we can confirm that the depth-variable streamer acquisition coupled with advanced processing techniques (GWE) is AVO compliant and trustworthy.

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