Depth imaging with amplitude correction for localized absorption anomalies. A case study from the North-West Australian shelf.

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SUMMARY

Seismic amplitudes within target intervals are often affected by localized absorption anomalies in the overburden. In the North-West Australian shelf and in many other regions, the majority of such anomalies are caused by gas trapped in shallow sediments.
We apply amplitude tomography to build a high resolution 3D absorption model and to take this effect into account in geological settings typical for the North-West Australian shelf. Two approaches have been developed recently to correct for absorption in depth imaging – the first uses frequency independent models and the second based on Q- compensation with the linear frequency dependent assumption. We show how both techniques correct seismic amplitudes but their results are not frequency balanced. In order to achieve a better fit with the real seismic data, we propose and apply a mixed absorption model that combines frequency independent amplitude correction with the linear Q-compensation and reflects the presence of different effects responsible for seismic energy attenuation in real geological media. Pre-stack depth migration with this model corrects for the overburden effects and produces seismic data with spatially balanced amplitude and spectral characteristics.

Key words: seismic imaging, absorption, amplitudes, North-West Australian shelf

INTRODUCTION

In recent years we observe increasing demand for seismic imaging with correct (true) amplitudes. Unfortunately, seismic amplitudes within target intervals are often affected by localized absorption anomalies in the overburden. In the North-West Australian shelf and in many other regions, the majority of such anomalies are caused by gas trapped in relatively shallow sediments. They create severe distortion on seismic images below and require special attention during data processing. We can observe the following effects associated with these anomalies:
A. Low interval velocities that lead to sags on seismic horizons below (figure 1.a).
B. Dimmed seismic amplitudes underneath due to anomalous absorption, transmission effects and possible other effects (figures 2.b and 4.b).
C. Wavelet changes below anomalous zones with relative decay in high frequencies. In general, both amplitude and phase spectra are distorted in comparison with data recorded away from the anomalies. Changes in the amplitude spectrum can be seen as a result of frequency dependent absorption that we have mentioned in "B". Frequency dependent changes in velocities ("A" above) lead to dispersion and distortions in the phase spectrum.
D. Diffractions at the edges of the anomalies.

We discuss these effects using data from a recent 3D pre-stack depth migration (PSDM) project from the deep water Carnarvon Basin, North-West Australian shelf. The dataset exhibited strong localized low velocity and high absorption anomalies. We used a standard iterative seismic tomography workflow and built a detailed velocity model that included different types of velocity variations (figures 1.c and 2.a) and was typical for the Carnarvon Basin. The strong low velocity anomalies (marked by arrows on the figures 1.c and 2.b) were interpreted to be caused by gas trapped within shallow sediments. Depth migration created a structurally correct seismic image and fixed some amplitude anomalies that were caused by velocity variations in the overburden leading to focusing and defocusing of the seismic rays. Some of these low velocity zones (but not all of them) also had anomalous absorption resulting in dimmed seismic amplitudes underneath (figure 2.b). To address this, we applied amplitude tomography and PSDM with amplitude correction (Hung et al., 2008).

CORRECTION FOR THE FREQUENCY INDEPENDENT ABSORPTION

We started with a model that describes seismic amplitude loses due to the absorption as:

$$\ln\left(\frac{Ao}{A}\right) = L * \beta , \qquad (1)$$

where A is the amplitude of a seismic event that has travelled the distance L in a media with absorption β, Ao is the reference amplitude observed in case there is no absorption (figure 3). We are interested in a spatially variable absorption function $\beta(x,y,z)$ that creates a complex pattern of amplitude anomalies on seismic data depending on the geometry of seismic rays travelling in the subsurface and affected by the absorption. Amplitude tomography analyses amplitude variations on pre-stack depth migrated seismic data and uses backward projection along the seismic rays to estimate the absorption volume $\beta(x,y,z)$. This takes into account relative lateral amplitude variations and does not include long-wavelength trends.

The 3D absorption function that we built for a small sub-volume with few distinct typical anomalies is shown on figure 4. In general, the absorption anomalies coincide with the low velocity zones. Subsequent PSDM with absorption (Hung at al., 2008) produces a seismic image with recovered amplitudes (figure 4.c). Figure 4.d illustrates the difference between PSDM sections migrated with and without correction for the absorption. It can be seen as additional seismic energy generated by PSDM for seismic rays crossing the absorption anomalies to compensate for real losses caused by the anomalies. The amplitude correction in PSDM is applied to pre-stack data according to the ray geometry. It takes into account and removes diffractions at the edges of the anomalies and cannot be fully substituted by any pre- or post-migration amplitude corrections.

Figure 5 shows seismic amplitude maps measured within a target depth interval below 2700m (all absorption anomalies located with the depth range 1200-1800m). Blue colour corresponds to relatively weaker and green-yellow colours represent relatively stronger amplitudes. The first column shows the results obtained on raw migrated data without any frequency discrimination (like data shown on the figures 4.b and 4.c). The second column demonstrates amplitude maps for the low frequency part of the spectrum, the third column shows central (dominant) frequencies and the forth column shows high frequency components. The first row illustrates the initial data migrated without any amplitude correction. A low amplitude anomaly (blue colour) can be clearly seen within all frequency ranges. The second row was calculated using the data after migration with frequency independent amplitude correction; as we expected, it removed the low amplitude anomaly from the full bandwidth data and the dominant central frequencies (figures 5.e and 5.g). We know that absorption anomalies always have stronger effect on higher frequencies, so it is not a surprise that the spectrum after frequency independent amplitude recovery is not balanced with the higher frequencies being undercorrected (figure 5.h) and the low frequencies being overcorrected (figure 5.f).

ABSORPTION WITH LINEAR FREQUENCY DEPENDENCY (LINEAR Q)

Then we tested another popular model that assumes linear relationship between amplitude absorption β and frequency (Xin at al., 2010):

$$\beta = \frac{\pi f}{QV}, \tag{2}$$

where Q is the frequency independent quality factor, V is the velocity and f is the frequency. If we know the dominant frequency f_0, we can tie the frequency independent absorption volume $\beta(x,y,z)$ created by the amplitude tomography with $Q(x,y,z)$ volume:

$$Q(x,y,z) = \frac{\pi f_0}{\beta(x,y,z)V(x,y,z)}. \tag{3}$$

In Q-PSDM (Xie at al., 2009), the frequency dependent absorption $\beta_f(x,y,z,f)$ determines amplitude changes for each individual frequency based on absorption $\beta(x,y,z)$measured on real seismic data with dominant frequency f_0:

$$\beta_f(x,y,z,f) = \frac{f}{f_0}\beta(x,y,z). \tag{4}$$

Figures 5.i-l (row three) display the amplitude maps obtained after Q-PSDM. Full spectrum signals after Q-PSDM (figure 5.i) have the same amplitudes as the data after PSDM with frequency independent correction (figure 5.e). Higher frequencies got an additional boost at the expense of low frequencies but again the spectrum is not balanced. Now, the high frequencies are overcorrected and the low frequencies are undercorrected.

These displays show that our data do not fully fit into a simple Q-model (2). The magnitude of the misbalance is nearly the same as we had after the frequency independent amplitude correction.

MODEL WITH MIXED ABSORPTION

The results of the two initial tests show that an optimal solution lies somewhere between the linear Q-model and the model with frequency independent absorption. A better result can be achieved by a combination of these two models. We call it a mixed absorption model and it can be described as:

$$\beta_f(x,y,z,f) = R\beta(x,y,z) + (1-R)\frac{f}{f_0}\beta(x,y,z). \tag{5}$$

The first term represents the frequency independent absorption, the second terms corresponds to the frequency dependent component. The ratio R describes the relative weights of the two components. In general, the ratio R can be considered as a variable 3D function. As the simplest version, we assumed a constant R. It implies that all spatial variations within the model (5) are based on the standard result of frequency independent amplitude tomography $\beta(x,y,z)$ and such a model can be built without significant complications in the computation scheme. For our dataset, a scan showed that the value R=0.45 produced the best (most frequency balanced) result and it was used to create the final migrated dataset (figure 5.m-p). So, our final model contained 45% of frequency independent and 55% of linear frequency dependent absorption. Following Xie at al. (2009) frequency dependant component also included the phase correction.

The major benefit of the mixed absorption model is that it allows a much better fit with the real data and produces depth migrated data with corrected spatially balanced amplitude and spectral characteristics. We can assume that the linear Q component takes into account inelastic effects and that the frequency independent part is responsible for transmission and other possible effects. For the practical implementation, it is important that the mixed absorption model requires minimal additional computational efforts as it is based on the standard amplitude tomography workflow.

CONCLUSIONS

We demonstrate how the amplitude tomography builds a 3D absorption model in geological settings typical for the North-West Australian shelf and subsequent PSDM recovers seismic amplitudes.

We show that neither model with frequency independent absorption nor Q-model with linear frequency dependent absorption produced frequency balanced results for our dataset.

We proposed and applied a mixed absorption model that allowed a better fit with the real seismic data. Pre-stack depth migration with this model produced seismic data corrected for the overburden effects with spatially balanced amplitude and spectral characteristics.

The presented workflow is recommended if there is an evidence or suspicion that seismic amplitudes within target intervals are affected by localized absorption anomalies in the overburden.

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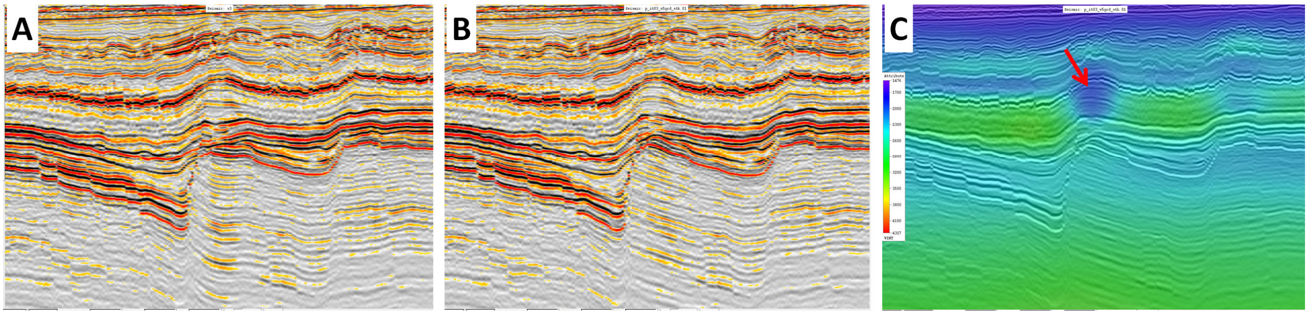

Figure 1. An example of 3D PSDM sections migrated with the initial (A) and the final (B) velocity models; C - the final 3D PSDM velocity model. All data courtesy Chevron Australia Pty Ltd and Shell Development Australia Pty Ltd

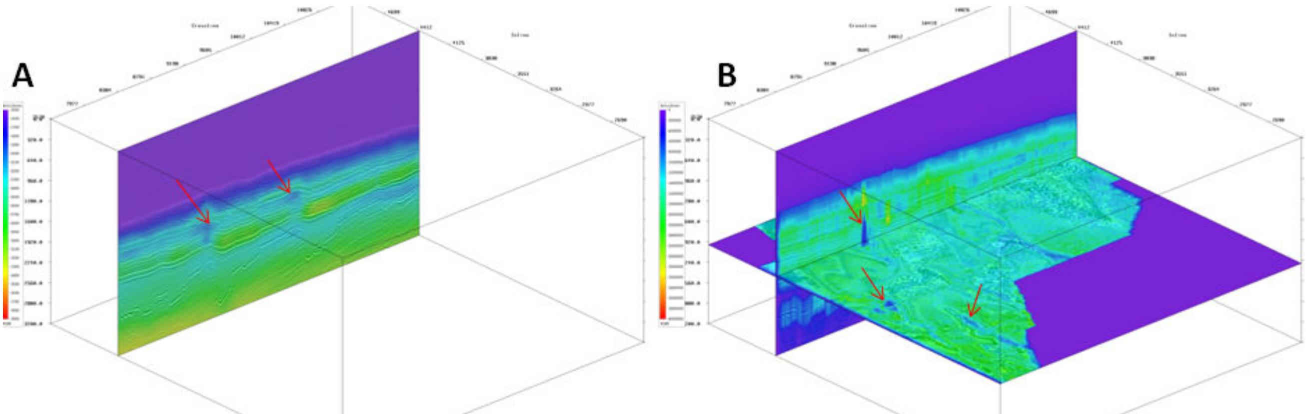

Figure 2. A - 3D PSDM velocity model; B - seismic amplitudes measured on the preliminary 3D PSDM volume in sliding 200m window (blue colour corresponds to dimed zones).

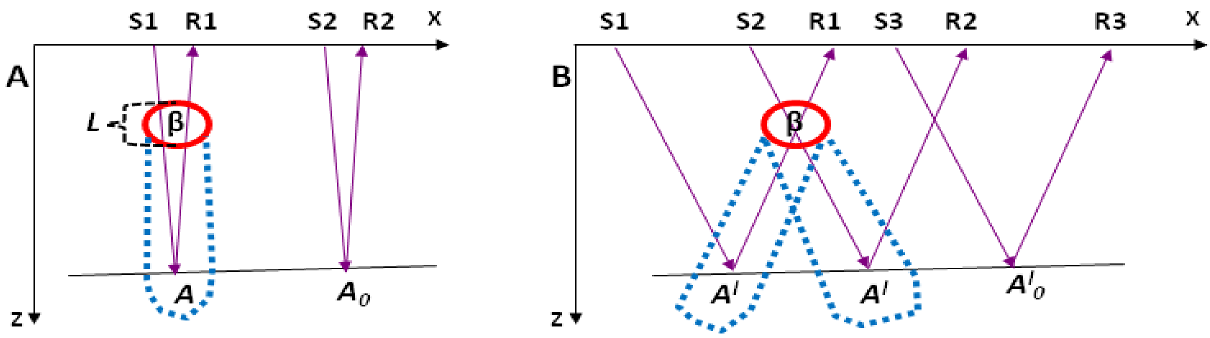

Figure 3. Examples of ray diagrams with an absorption anomaly (red) and dimmed zones (blue) for near (A) and far (B) offset data.

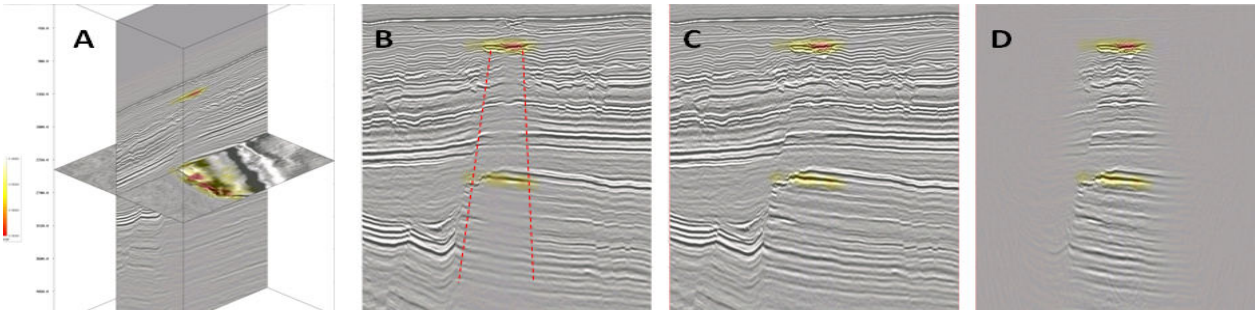

Figure 4. A - absorption volume after amplitude tomography (in colour), B and C – 3D PSDM sections before and after amplitude tomography respectively, D – the difference between C and B.

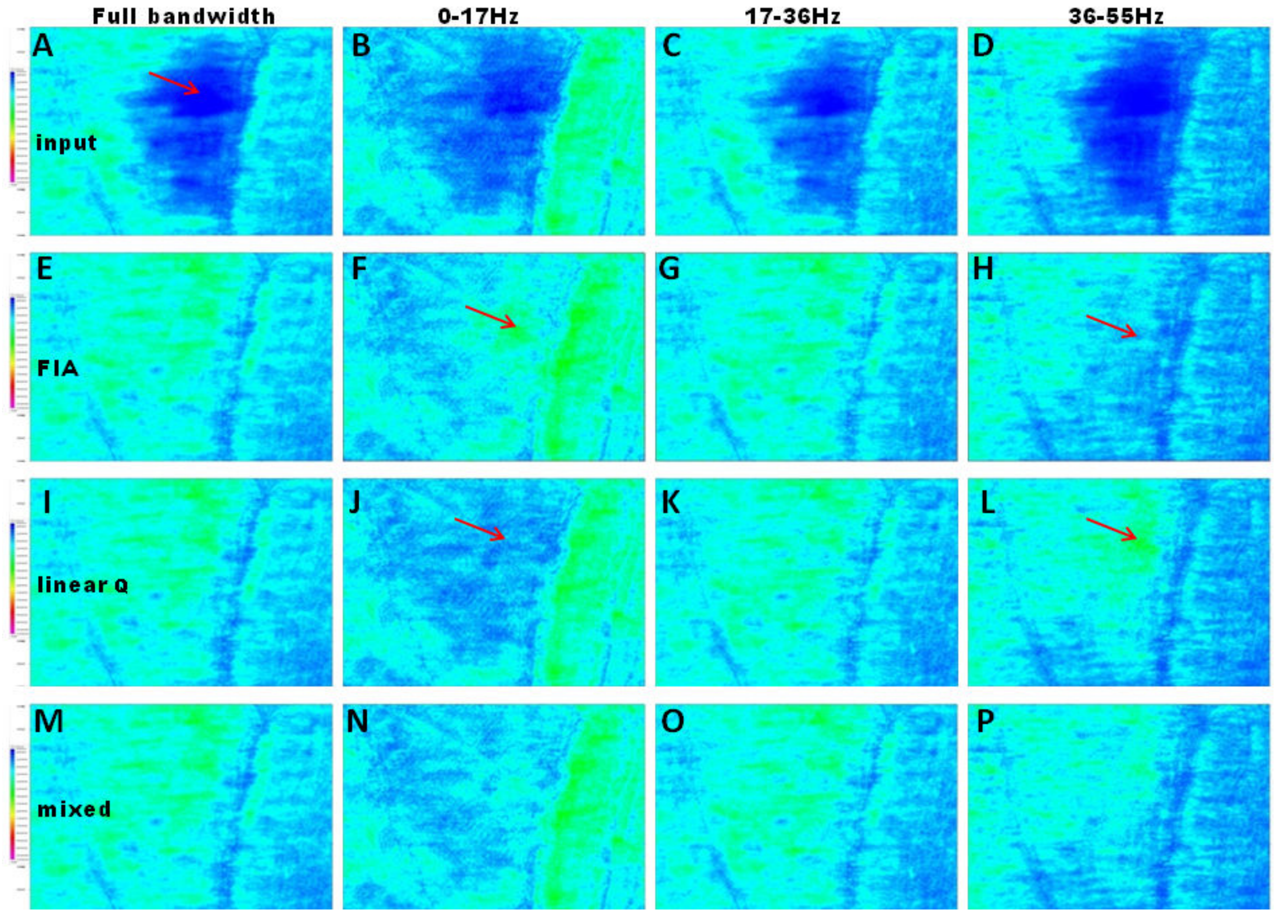

Figure 5. Amplitude maps extracted at the target depth interval. See the text for the details.