Success of high-resolution volumetric Q-tomography in the automatic detection of gas anomalies on offshore Brunei data

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Summary

Over recent years, many authors have proposed to compensate the absorption loss effects inside of the imaging process through the use of an attenuation model. This is necessary in the presence of strong attenuation anomalies. Q tomography has been developed for estimating this attenuation model but is generally limited to estimating attenuation in predefined anomaly areas. In this paper, we show how shallow gas pockets are revealed automatically by using a high-resolution volumetric Q tomography on the complex offshore Brunei dataset. A key component of our approach is the estimation of effective attenuation in pre-stack migrated domain through accurate picking of the frequency peak. Estimated Q-model is then used to compensate for absorption in the imaging process.

Introduction

The Brunei region is considered as a complex area known for its gas escaping features over folded structures, producing shallow strong absorption anomalies. These strong anomalies seriously mask the coherency of the structure beneath.

Typically, the overall effect on the signal is that higher frequencies are dimmed more rapidly as the signal propagates through these very attenuating media. This results in a loss of signal resolution. Conversely, the attenuated signal carries additional information that can be useful in locating such gas pockets.

Measured attenuation can be compensated by applying processes such as the early techniques of inverse-Q filtering (Wang, 2002). More recently, stronger compensation due to gas or mud was included directly in the imaging process (Xie et al., 2009; Fletcher et al., 2012) through an interval Q model computed by tomography (Xin et al., 2008; Cavalca et al., 2011; Xin et al., 2014, Gamar et al., 2015). Generally, effective Q quantities are then inverted to produce a 3D interval Q model. The main purpose of tomography is to de-noise effective Q measurements in a model-consistent manner. Because the tomographic inverse problem is poorly constrained due to a difficult estimation of effective attenuation, a priori information is introduced to guide the inversion.

We present a robust workflow that uses Q tomography for converting dense inhomogeneous prestack effective Q measurements into a 3D model-consistent interval Q. To compute the effective Q volume in the pre-stack domain, we have used the method proposed by Zhang and Ulrych (2002) based on the shift of the frequency peak. Since the frequency peak (frequency at maximum amplitude) is very sensitive to the noise, we increase the signal/noise ratio by using the autocorrelation of the signal rather than the signal itself. This improves the resolution of the frequency peak value and thus the accuracy of effective Q estimation. We apply the workflow on Brunei offshore dataset to localize shallow gas pockets without any a priori information on their positions. This was made possible thanks to an adaptation to Q tomography of non-linear slope tomography (Guillaume et al., 2011) using an accurate effective Q volume picked from pre-stack migrated gathers.

Volumetric Q tomography on offshore Brunei dataset

As a result of attenuation, the signal spectrum is shifted towards lower frequencies. Defining the frequency peak of a wavelet as the frequency at which the amplitude spectrum reaches its maximum, the frequency peak of a seismic pulse experiences a downshift during propagation. Our approach consists in calculating a dense effective prestack Q volume in time domain, using the shift of the frequency peak (from high to low). The effective Q volume feeds the interval Q tomography. The most important point here is that the workflow succeeds in automatically detecting interval Q anomalies like gas pockets, without any a priori information on the position of the anomaly, thanks to the quality of the effective Q estimation. After de-noising the data, the complete volumetric tomography workflow works according to the following steps:

- Dense effective Q volume (see bottom panel of Figure 1) picking in pre-stack migrated domain using the equation:

$$Q = \frac{0.5\pi t f_p f_{p_0}^2}{\left(f_{p_0}^2 - f_p^2\right)}$$

where f_{p0} and f_p are the frequency peak at time *0* and *t*, respectively. We explain below how we compute them.

- Automatic editing of effective Q outliers and filtering.
- Volumetric dip picking on image stack.
- Tomographic estimation for interval Q^{-1}.
- Q-PreStack Depth Migration (Q-PSDM) using the estimated interval Q^{-1} model.

One of the key elements in the proposed workflow is the accurate and robust estimation of the prestack effective Q volume that will be input to the tomographic inversion process. As mentioned earlier, the Q estimation is based on picking the frequency peak in the pre-stack time domain. The seismic traces are usually modeled as the convolution

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between the source wavelet and the Earth reflectivity filter. In general, the wavelet is unknown, but in some cases it can be measured or assumed as a minimum phase wavelet. Zhang and Ulrych (2002) assumed the wavelet's amplitude spectrum could be approximated by a Ricker wavelet's spectrum. This approximation works fine in many situations, but the typically low signal/noise ratio observed on real data can make fitting the data by a Ricker wavelet difficult. Here, we propose to replace the fitting by computing the autocorrelation of the signal in short time windows. This approach is easier and uses the data features. We compute amplitude spectra only on the part of the signal around the maximum peak of the autocorrelation function. This avoids including the side lobes of the autocorrelation in the amplitude spectrum, allows more accurate signal frequency peak estimation, and also makes the signal's amplitude spectrum more similar to that of a Ricker wavelet.

We illustrate the capability of effective volumetric Q tomography by applying it to an offshore Brunei dataset. The main objective of the study is to test the ability of our method to automatically detect the gas areas (see white ellipses on Figure 2, top) without any a priori information on their positions. A dedicated de-noising process was applied on 3D pre-stack depth migrated data prior to the volumetric continuous peak frequency picking and effective Q estimation. Figure 2 (bottom) shows the derived interval Q model. The alleged gas anomalies were all detected automatically by the volumetric Q inversion method despite the complexity of the geology and the presence of strong dipping events. The revealed gas pockets match quite well the high resolution tomography velocity model (Figure 2, middle) showing low velocity anomalies in those gas areas. To improve the resolution of the interval Q model, we can also use the interval velocity model as a guide for the inversion.
The 3D interval Q model was then used in a Kirchhoff Q-PSDM to compensate for dispersion and amplitude attenuation caused by the absorption (Figure 3). The resolution on the stack is improved and some events become visible on Common Image Gathers (CIGs) after Q-PSDM using an interval Q model.

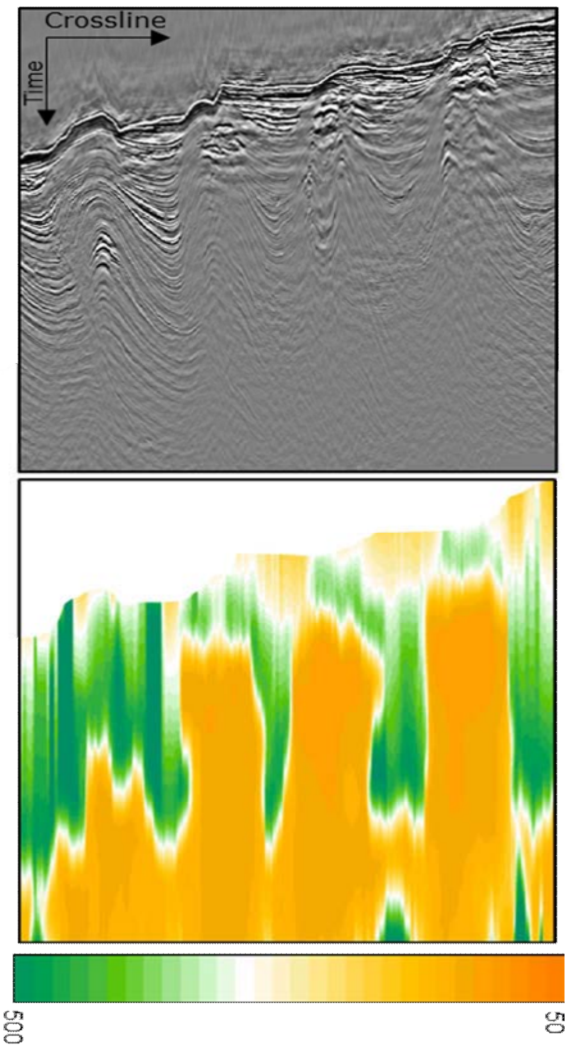

Figure 1: Near offset section (top) and the corresponding dense raw effective Q section (bottom). Low Q values (in orange) match quite well the observed attenuated zones in the data, showing that Q estimation is meaningful.

Conclusion

In this abstract, we have presented a method that can be used to derive a 3D interval Q model from raw effective Q measurements done on pre-stack data. The method is based on the continuous picking of the frequency peak estimated from local amplitude spectra. The originality of our approach resides in the use of spectra of the autocorrelation of the data to pick the frequency peak rather than the spectra of the data itself. This makes the effective Q-picking process more robust and accurate. As a result, it can be used to automatically detect absorption anomalies as shown on the 3D offshore Brunei complex field example. Application of our method on these data shows that the interval Q model obtained by Q tomography recovers most of the Q anomalies corresponding to gas pockets. The Q-PSDM nicely compensates the effect of the absorption on the data and restores amplitude and phase on both the stack and CIGs. A single iteration of velocity and Q inversions has been carried out. An improved Residual Move-Out (RMO) picking in Q compensated areas below gas pockets would serve to further improve a new velocity update performed after this first Q-PSDM.

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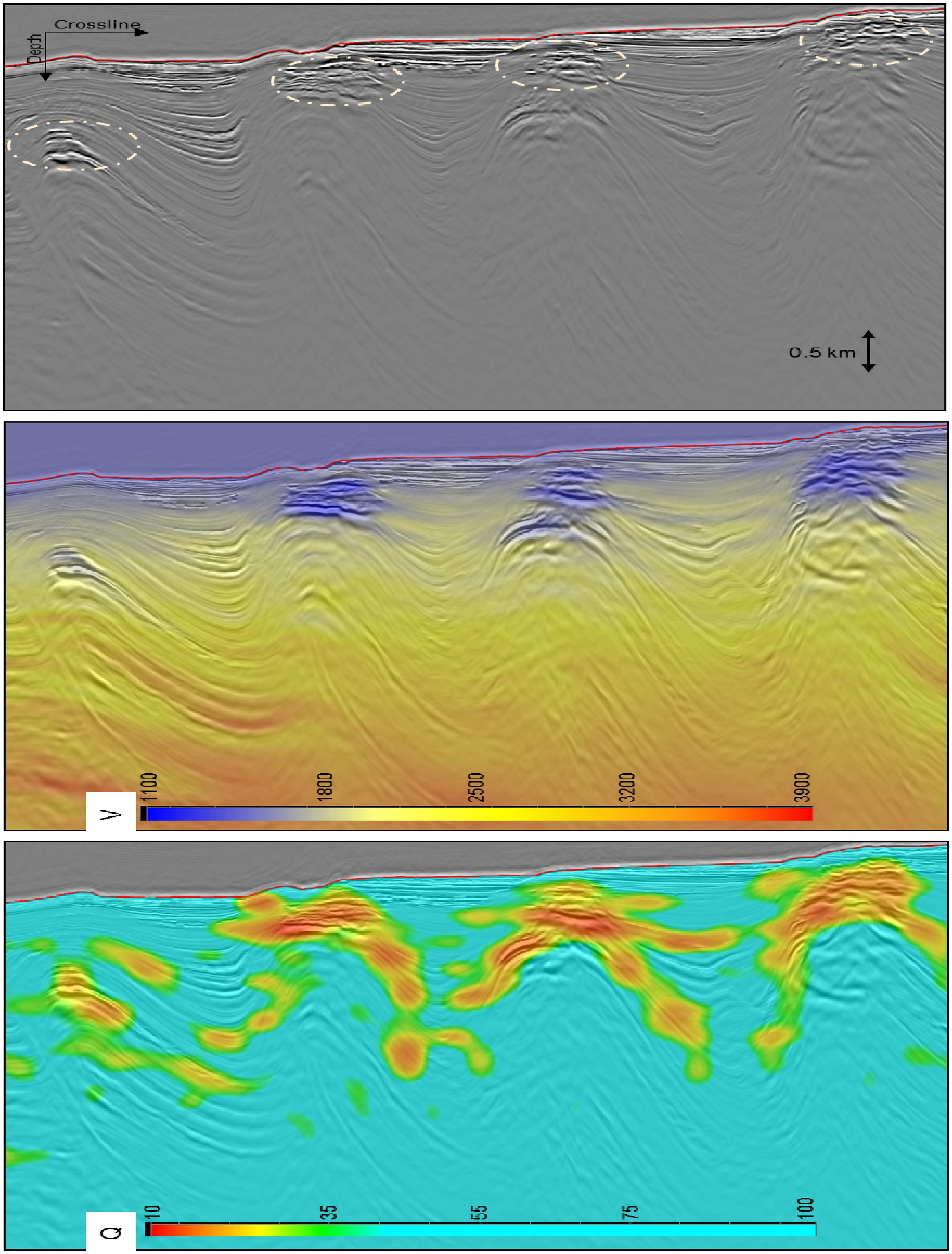

Figure 2: PSDM stack (top), high-definition interval velocity model (middle), interval Q model (bottom). Q model computed without any a priori information can be compared with high resolution tomography velocity showing low velocity anomalies due to gas pockets.

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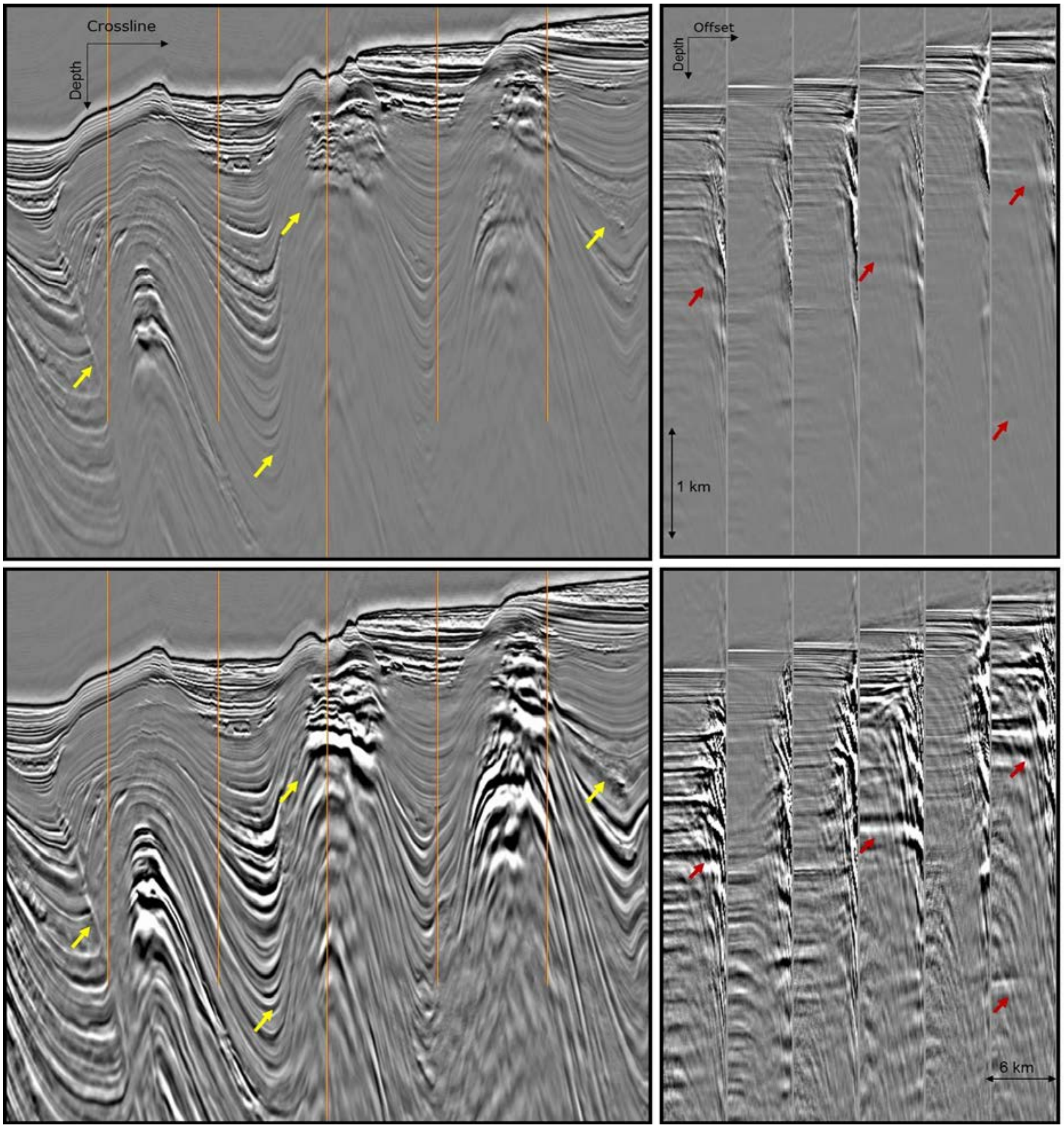

Figure 3: Comparison between Kirchhoff PSDM (top) and Q-PSDM (bottom) on stacks and CIGs (shown by orange lines on stacks). Resolution is increased by using interval Q model during the imaging process (bottom-left). On CIGs some events became visible (red arrows, right).

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EDITED REFERENCES

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REFERENCES

Cavalca, M., I. Moore, L. Zhang, S. L. Ng, R. Fletcher, and M. Bayly, 2011, Ray-based tomography for Q estimation and Q compensation in complex media: 81st Annual International Meeting, SEG, Expanded Abstracts, 3989–3993, http://dx.doi.org/10.1190/1.3628039.

Fletcher, R. P., D. Nichols, and M. Cavalca, 2012, Wavepath-consistent effective estimation for Q-compensated reverse-time migration: 74th Conference & Exhibition, EAGE, Extended Abstracts, http://dx.doi.org/10.3997/2214-4609.20148360.

Guillaume, P., G. Lambaré, S. Sioni, D. Carotti, P. Dépré, G. Culianez, J.-P. Montel, P. Mitouard, S. Depagne, S. Frehers, and H. Vosberg, 2011, Geologically consistent velocities obtained by high definition tomography: 81st Annual International Meeting, SEG, Expanded Abstracts, 4061–4065.

Wang, Y. H., 2002, A stable and efficient approach of inverse *Q* filtering: Geophysics, **67**, 657–663, http://dx.doi.org/10.1190/1.1468627.

Xie, Y., K. Xin, J. Sun, C. Notfors, A. K. Biswal, and M. K. Balasubramaniam, 2009, 3D prestack depth migration with compensation for frequency dependent absorption and dispersion: 79th Annual International Meeting, SEG, Expanded Abstracts, 2919–2923.

Xin, K., Y. He, Y. Xie, W. Xu, and M. Wang, 2014, Robust Q tomographic inversion through adaptive extraction of spectral features: 84th Annual International Meeting, SEG, Expanded Abstracts, 3726–3730.

Xin, K., B. Hung, S. Birdus, and J. Sun, 2008, 3-D tomographic amplitude inversion for compensating amplitude attenuation in the overburden: 78th Annual International Meeting, SEG, Expanded Abstracts, 3239–3243.

Zhang, C., and T. J. Ulrych, 2002, Estimation of quality factors from CMP records: Geophysics, **67**, 1542–1547, http://dx.doi.org/10.1190/1.1512799.