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# Automatic Gas Pockets Detection by High-resolution Volumetric Q-tomography Using Accurate Frequency Peak Estimation

F. Gamar-Sadat* (CGG), P. Guillaume (CGG), A. Pica (CGG), G. Pignot (CGG), P. Poggi (CGG), A. Henry-Baudot (CGG), A. Prescott (CGG), A. Gacha (CGG), D. Carotti (CGG) & V. Prieux (CGG)

## SUMMARY

Conventional imaging does not deal adequately with absorption, especially in the case of strong anomalies. Over recent years, many authors have proposed to compensate the absorption loss effects inside of the migration through the use of an attenuation model. Q tomography has been developed for estimating this attenuation model but is generally limited to estimating attenuation in predefined anomalies. In this paper, we explain how we developed a high-resolution volumetric Q tomography to attain an accurate volumetric estimation of the attenuation model. A key component of our workflow is the estimation of effective attenuation in the pre-stack data domain through accurate picking of the frequency peak. Finally we present a case study where our approach has been used to reveal shallow gas pockets and compensate for absorption in the migration.

## Introduction

Seismic attenuation, usually quantified by the quality factor, Q, can be caused by anelastic energy losses (Reine et al., 2009). Typically, the overall effect on the signal is that higher frequencies are dimmed more rapidly than lower frequencies as the signal propagates over greater distances or through more attenuating media like gas or mud areas. This results in a loss of signal resolution. Conversely, the attenuated signal carries additional information that can be useful in locating gas pockets and mud channels. 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). Generally, effective Q quantities are then inverted to produce a 3D interval Q model. The main purpose of tomography is to de-noise Q measurements in a model-consistent manner. When the tomographic problem is especially badly formulated, a priori information is introduced to guide the inversion.
We present a robust workflow that uses Q tomography for converting dense inhomogeneous 4D raw effective Q measurements made on pre-stack data into a 3D model-consistent Q interval. To compute the effective Q volume in the pre-stack domain, we use the method proposed by Zhang and Ulrych (2002) based on the frequency peak shift. Since the frequency peak (frequency at maximum amplitude) is very sensitive to the presence of noise, we increase the signal/noise ratio by using the autocorrelation of the signal instead of the signal itself. This improves the resolution of frequency peak values and thus the accuracy of effective Q estimation. We apply the workflow on a complex Brunei offshore dataset to localize shallow gas pockets without any a priori information on their positions. This was made possible thanks to our high resolution tomography (Guillaume et al., 2011) using an accurate effective Q volume picked from pre-stack migrated gathers using 4 dimensions.

## Volumetric Q tomography

As a result of the attenuation, the signal spectrum is shifted towards lower frequencies. Defining the frequency peak of a seismic 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 4D Q volume (time, inline, crossline, offset), 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 tries to automatically detect the interval Q anomalies like gas pockets, without any a priori information on the position of the anomaly. After de-noising the data, the complete volumetric tomographic workflow proceeds according to the following steps:
1 - Dense 4D effective Q volume estimation in pre-stack migrated domain. Migration stretch is removed prior to Q measurement.
2 - Automatic editing of Q measurement outliers and filtering using amplitude weighting.
3 - Volumetric dip picking on stack.
4 - Tomographic inversion for interval $Q^{-1}$ estimation using the objective function:

$$dt^* = \left(t^*_{calculated} - t^*_{observed}\right) \quad \text{where} \quad t^* = \int_{ray} \frac{dl}{Q_l V_l} \quad \text{is attenuated travel time}$$

$Q_l$ and $V_l$ are the interval Q and the interval velocity along the raypath, respectively.
The inversion process aims to minimize the difference ($dt^*$) between the $t^*$ calculated from an initial gridded Q (constant here) model and the $t^*$ observed (estimated) on the data from the frequency peak (first step). The inversion provides a 3D Q model consistent with attenuation observed on the data.
5 – Q-PreStack Depth Migration (Q-PSDM) using the estimated interval Q model.

One of key elements in the proposed workflow is the accurate estimation of the 4D effective Q volume that will be input to the tomographic inversion process. As mentioned earlier, the 4D Q estimation is based on picking the frequency peak in the pre-stack domain. The seismic traces are usually modeled as the convolution 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 very difficult. In this paper, we propose to replace the fitting by computing the autocorrelation of the signal in short time windows (Figure 1, right). 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 (Figure 1, blue curve). 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 $\omega$ more similar to that of Ricker wavelet's (Figure 1, green curve) expressed by:

$$\omega(f) = \frac{2}{\sqrt{\pi}} \frac{f^2}{f_{p_0}^2} e^{\left(\frac{f^2}{f_{p0}^2}\right)}$$ where $f$ is the frequency and $f_{p0}$ is the dominant frequency.

When a wavelet propagates in a medium, an amount of energy will be absorbed due to attenuation. After traveling for time $t$, the resulting wavelet will look as follows:

$$\omega(f,t) = \omega(f) e^{\left(\frac{-\pi f t}{Q}\right)}$$ where $f$ is the frequency, $t$ is the travel time, and $Q$ is the quality factor (assumed frequency-independent). The frequency peak $f_p$ value is obtained by:

$$\frac{d\omega(f,t)}{df} = 0$$ and then the dense $Q$ volume is derived from frequency peak values as:

$$Q = \frac{0.5\pi t f_p f_{p_0}^2}{\left(f_{p_0}^2 - f_p^2\right)}$$ An example of this can be seen in right-hand panel of Figure 2.

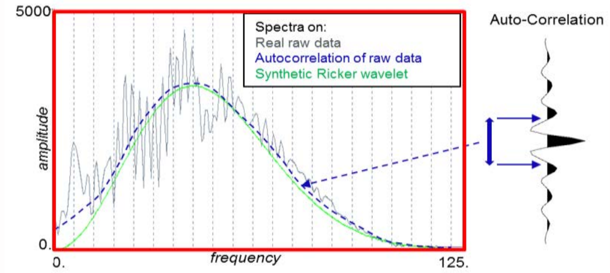


***Figure 1*** *Amplitude spectra from a short time window on real data. The amplitude spectrum, in blue, computed on the portion around the maximum peak of the autocorrelation (blue arrows on the right side) matches quite well the data spectrum allowing a more precise picking of the frequency peak value and Q attribute.*

## Brunei real data example:

We now illustrate the capability of the volumetric Q tomography by applying it to a real dataset from offshore Brunei. The data are acquired in an area that in addition to a rugose water bottom exhibits several well-developed shallow structures containing small gas pockets on top of them (see yellow ellipses on Figure 3, top). The goal of the study is to test the ability of our method to automatically detect these gas areas without any a priori information on their positions. A dedicated de-noising process was applied on 4D pre-stack depth migrated data prior to the volumetric continuous peak frequency picking and effective Q estimation. Figure 3 (middle) shows the derived interval Q model. The five alleged gas anomalies were all detected automatically by the volumetric Q inversion method despite the complexity of the geology and the strong presence of dipping events. The revealed gas pockets match quite well the high resolution tomography velocity model (Figure 3, bottom) showing low velocity anomalies in those gas areas. 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 4). The resolution on the stack is improved and some events became visible on Common Image Gathers (CIGs) after Q-PSDM using an interval Q model.

## Conclusion

In this abstract, we have presented a method that can be used to derive a 3D interval Q model from 4D 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 novelty of our method resides in the fact that spectra of the autocorrelation of the data, instead of the spectra of the data itself, are used for peak frequency picking. This makes the Q-picking process more robust and accurate. As a result, it can be used to automatically detect absorption anomalies as shown by the 3D offshore Brunei complex field example. Application of our method on this data shows that the interval Q model obtained by Q tomography recovers most 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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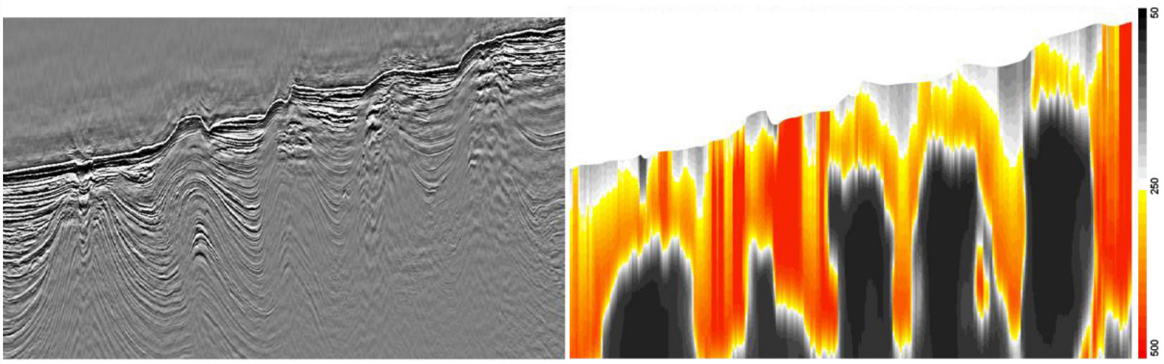


***Figure 2** Brunei dataset: Near offset section (left) and the corresponding dense raw Q section (right). Low Q values (in black) match quite well the observed attenuated zones in the data, showing that Q estimation is accurate.*

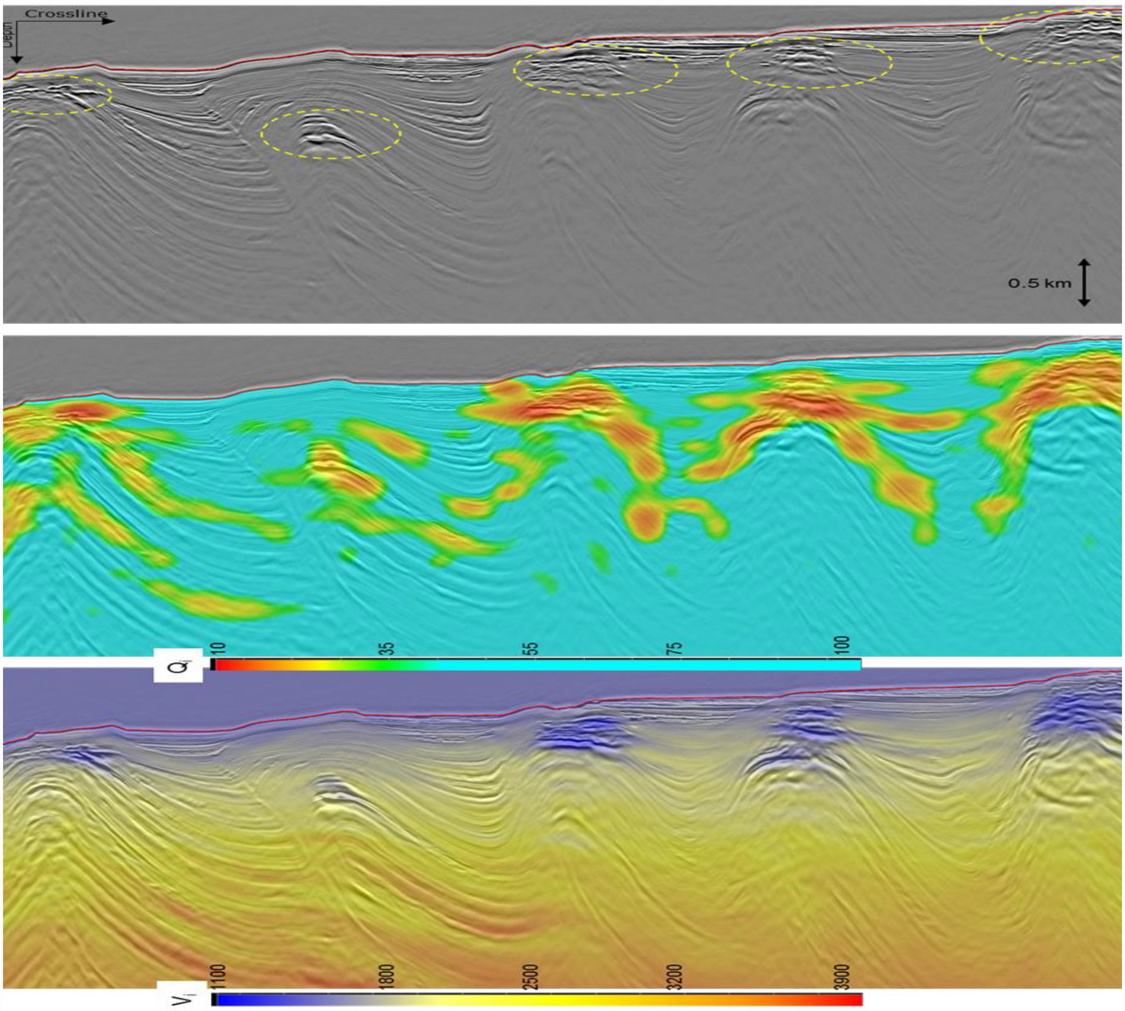


***Figure 3*** *Brunei dataset: PSDM stack (top), interval Q model (middle), high-definition interval velocity model (bottom). Q model computed without any a priori information can be compared with high resolution tomography velocity showing low velocity anomalies due to gas pockets.*

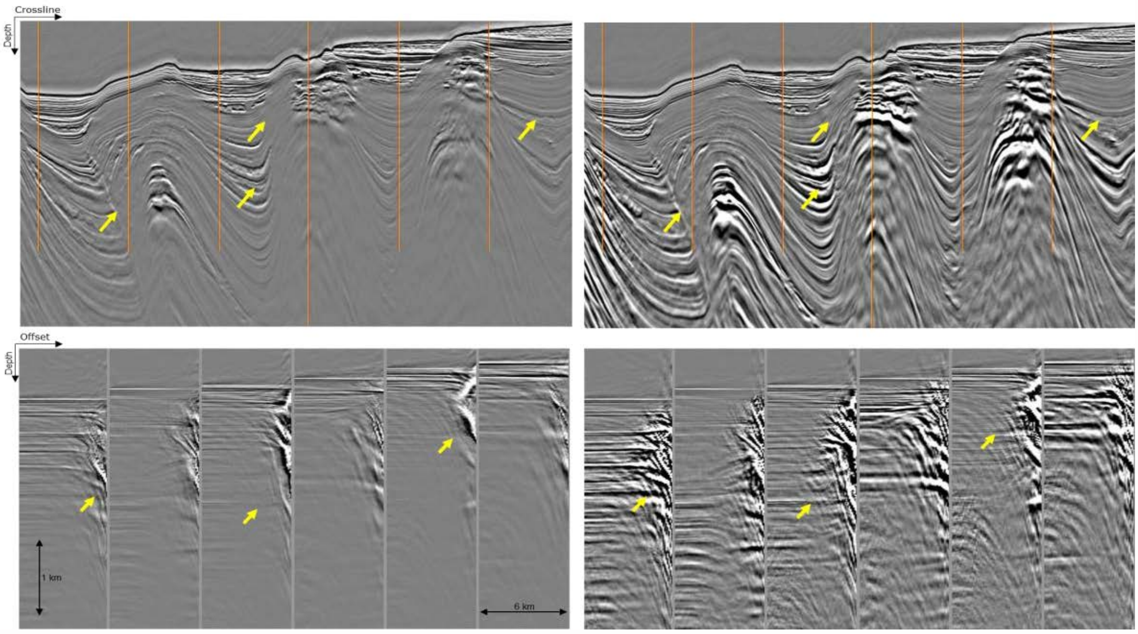


***Figure 4*** *Comparison between Kirchhoff PSDM (left) and Q-PSDM (right) on stacks and CIGs (showed by orange lines on stacks). Resolution is increased by using interval Q model during the imaging process (top-right). On CIGs some events became visible (yellow arrows, bottom).*