Case Study on Tomographic Q Estimation & Implementation for Cambay Offshore Pre-SDM Project

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Summary

A QPSDM project for Cairn India Limited's Cambay Offshore data, Block CBOS/2 was implemented. The objective was to compensate for the masking effect caused by the shallow Babaguru gas sands on imaging quality of the deeper target horizons. Kirchhoff implementation of VTI (including full velocity model building) QPSDM was carried out, and the Q-Model was built after extensive testing and overcoming both data and operational issues. The fact that the area has sufficient number of wells penetrating the zones of interest helped in validating the final imaging results.

Introduction

Seismic waves are attenuated as they travel through the subsurface of the earth. Attenuation causes a loss of high-frequency energy, and generally distorts the wavelet's phase (dispersion effect). Seismic attenuation and dispersion are usually compensated for in conventional time domain processing using a simple attenuation model, described by the quality factor (Q). This simple assumption is not accurate if the Q model varies rapidly, both vertically and laterally. Waves arriving at different source-receiver offsets follow ray paths that can experience different attenuation profiles e.g., shallow hydrates in the Gulf of Mexico, gas chimneys in the North Sea, etc. (Chen and Huang, 2010; Yu et al., 2002). For such complex conditions, estimating the Q model using a tomographic approach (Brzostowski and McMechan, 1992) is necessary. Later at the compensation step, the tomographic Q model, combined with VTI or TTI anisotropic models, can be used to perform viscoacoustic wave-equation or Kirchhoff prestack depth migration (PSDM) that can handle the propagation complexity (Valenciano et al., 2011).
The proposed Q tomography algorithm uses spectral ratios computed from surface seismic data as the input. An integral tomographic equation relates the Q model to the measured spectral ratios. The tomography numerical implementation results in a linear inversion scheme that we solve by conjugate gradient methods with 3D regularization. The output Q model is combined with VTI anisotropic models to perform model-driven attenuation and anisotropy compensation during imaging.

Results from a VTI field dataset from the Cambay Offshore data, India demonstrate the accuracy of tomographic estimation of Q, and imaging improvement from Q-PSDM.

Theory

Assuming that geometrical spreading, scattering, or other effects affecting amplitudes non-related to attenuation have been removed from the data a tomographic equation that relates the inverse of Q with the measure spectral ratios can be derived (Brzostowski and McMechan, 1992):

$$-\frac{2}{\omega}\ln\left|\frac{A_k}{A_0}\right| = \int_{\text{ray } k} Q^{-1}(x,y,z)v^{-1}(x,y,z)ds \equiv t_k^*, \quad (1)$$

where A_k are the seismic spectra measured at a seismic horizon, A_o is a reference seismic spectra measured at a horizon not affected by anomalous attenuation, ω is the radial frequency, v is the velocity model, Q is the quality factor, and t* is defined as the attenuated travel time. Given a dataset consisting of spectral estimates at various depths, equation 1 provides a linear system in Q^{-1}.

Equation 1 can be expressed in matrix form **d = Fm** (Rickett, 2006), where **d** contains log-spectral estimates (*Ak/A0*) at interpreted seismic horizons, **F** is a chain of linear operators consisting of a diagonal matrix (containing the frequencies), and integration operator, and **m** are the parameters *Q-1(x,y,z)* to estimate. The inversion problem that looks for the model that minimizes the least-squares objective function is defined (A. A. Valenciano, and N. Chemingui) as

$$\mathbf{O = (d - Fm)^T(d - Fm)} + \varepsilon\, \mathbf{m}^T\nabla^T\nabla\mathbf{m},$$

which contains regularization with a Laplacian operator ∇, and the balancing parameter ε.

Methodology

The methodology consists of three steps. First estimate the spectral ratios from post migration gathers. Second, a tomographic approach to derive the interval Q model and third , attenuation compensation during visco-acoustic (WEM or Kirchhoff) pre-stack depth migration

The Q estimation uses spectral ratios of input seismic data. Preparation of common image gathers is important prior to spectral ratio analysis. The beam migrated (BPSDM) CIP gathers are stretched back to time using the migration velocity model. The input data gathers are prepared assuring good multiple free gathers. Selection of offset range is crucial to avoid stretch energy and noise through the main anomaly area. Spectral ratios were calculated based on the provided horizons.. The number of horizons chosen should be good enough to sample the anomaly spatially and vertically. In the present case, the first horizon starts about 200 ms above the top of the anomaly. The other horizons are about 100ms apart to capture the anomaly in the spectral ratio generation. A smoothing filter was applied in both inline and cross-line direction to remove the high frequency jitter within the spectral ratios. Frequency ranges were tested based on the data quality.
The computed spectral ratios are input into the inversion engine to produce an updated Q-model relative to a background constant Q-model. The constant background Q was taken as 300. The numerical inversion is performed using a conjugate gradient solver and Laplacian operator for regularization. The regularization factor is required to stabilize the inversion solution. The inversion is iterated until a geologically consistent Q-model is achieved.The case study is presented in Figures 1 through 5 .The inverted Q model is then combined with VTI/TTI anisotropic models to perform model-driven attenuation and anisotropy compensation during PSDM (QKirchhoff).

Conclusions

This case study demonstrates that the Q-PSDM compensates adequately for the masking effect caused by shallow Babaguru gas sands on deeper horizons. This has aided in more accurate reservoir characterization of target reservoirs.

References

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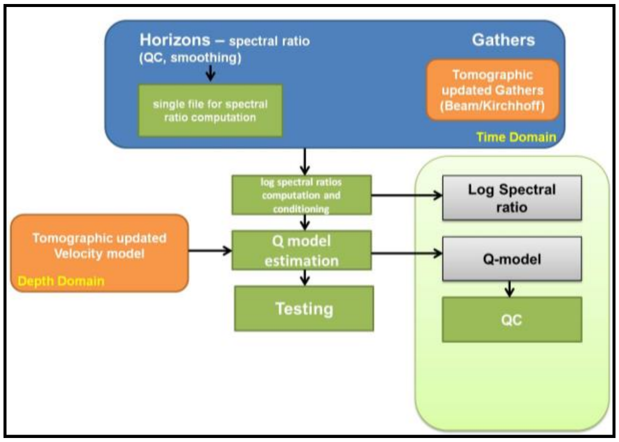

Figure 1: Work Flow for Tomographic Q Estimation

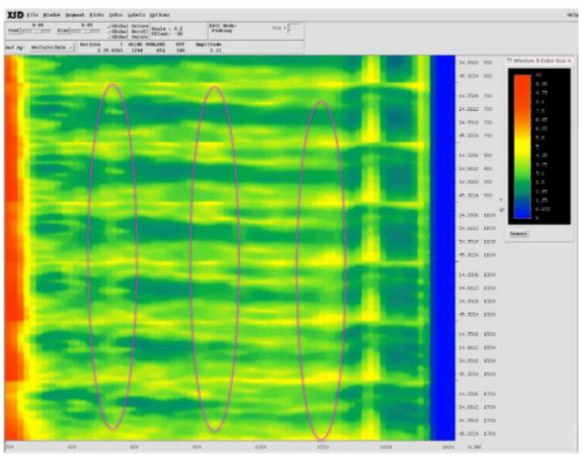

Figure 2: Spectral ratio for one horizon

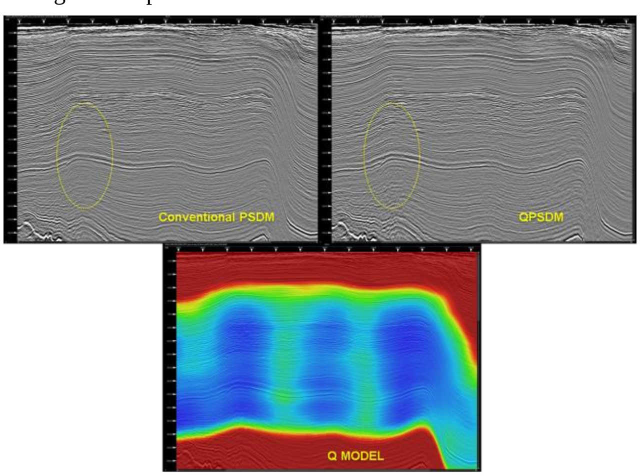

Figure 3: Comparison of Conventional PSDM vs. QPSDM

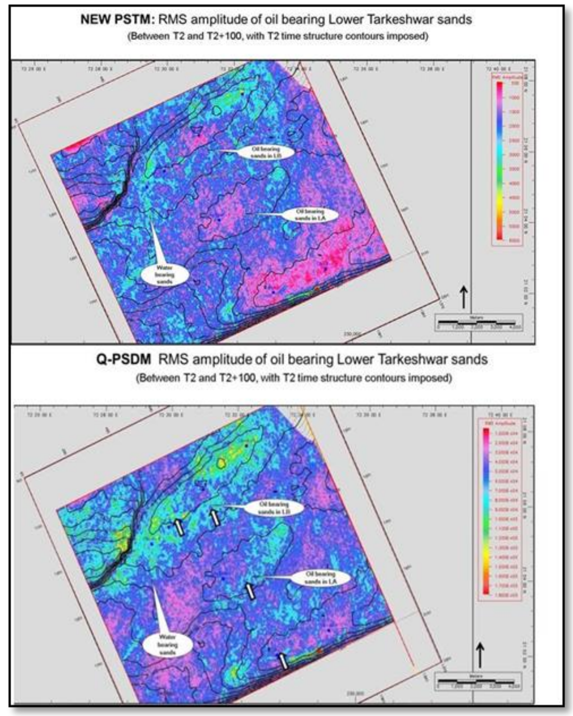

Figure4: PSTM vs. QPSDM RMS amplitude of oil bearing Lower Tarkeswar sands

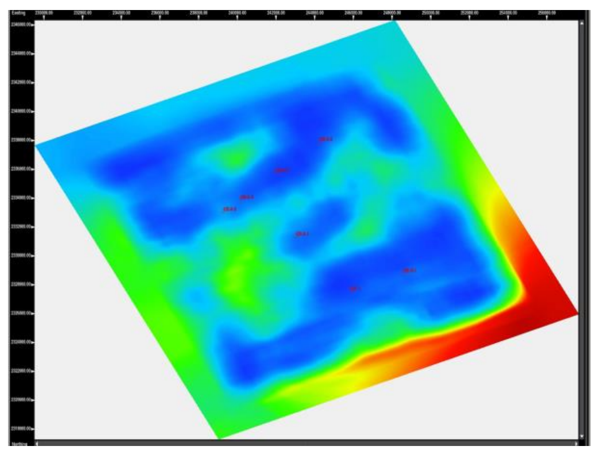

Figure 5: QMOdel confirming Low Q values covering the wells on the structures.

Acknowledgements

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