Simultaneous Q and Velocity Model Building - Incorporating Attenuation to Enhance Model Resolution

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SUMMARY

We present a new model building workflow for simultaneous building of high resolution Q and anisotropic velocity models. The tomography algorithm uses both travel times and spectral ratios from subsurface seismic data to build the Q model together with the anisotropic velocity model. A consistent spectral analysis is achieved by computing spectral ratios in windows that follow the moveout of events in common image gathers. These simultaneous updates ensure that both the Q- and velocity-models are updated in a kinematically consistent way. The jointly derived earth models are used to perform Q anisotropic pre-stack depth migration. The performance of the new workflow is illustrated with an example from a North Sea dataset with a shallow gas cloud. The results show that QVMB generates high quality anisotropic velocity and Q models that greatly enhance imaging below the gas anomalies.

Introduction

High-resolution pre-stack depth migration (PSDM) relies on the accuracy of the velocity model. If anisotropy and attenuation effects are to be properly compensated for during migration, accurate models of anisotropy and Q are also needed. Building an accurate Q model is especially important under high viscosity structures such as gas or mud, where amplitude and phase distortions will compromise AVO/AVA, interpretation, and other post-migration processes and analyses. There are two reasons to build velocity models and Q models simultaneously for the highest quality imaging. First Q and velocity are coupled in dispersive media in which velocity is frequency dependent. Second, by including Q compensation in migration, residual moveout (RMO) analysis of common image gathers (CIGs) becomes more robust in the vicinity of Q anomalies, resulting in higher quality picks for tomography.

In this paper we present a new model building workflow (QVMB) for simultaneous building of high resolution Q and anisotropic velocity models. The same tomographic engine is used for updating velocity models and to back-project anomalies in spectral ratios. The spectral ratios are computed between a reference horizon and target horizons in order to resolve Q anomalies. A consistent spectral analysis is achieved by having the analysis windows for computing spectral ratios follow the moveout in CIGs. This enables simultaneous updates to both the Q and velocity models with consistent kinematics.

Theory

The QVMB workflow combines the essential principles from travel time and Q tomography. Through the use of ray tracing we perform joint back-projection of travel time and attenuated travel time misfits according to equations (1) and (2).

$$\int \frac{dl}{\delta v} = \delta t \approx \frac{\Delta z}{v_0} \qquad \textbf{(1)}$$

$$\int \frac{dt}{\delta Q} = \delta t^* = \frac{2}{\omega} \ln\left[\frac{A_0}{A_k}\right] - t_0^* \qquad \textbf{(2)}$$

In equation (1) dl is the length of ray segment along ray paths. An anisotropic velocity update δv is derived by minimizing the travel time residual δt, which is approximated by dividing the depth residual Δz by local velocity v_0. Equation (2) is used to update the Q model under the assumption that geometrical spreading, scattering, or other non Q-related factors have been removed from the data. The Q update δQ is computed by back-projecting the attenuated travel time misfit δt^* along all ray paths. The attenuated travel time t^* represents the logarithm of the spectral ratio between a reference spectrum A_0 and the measured spectrum A_k. The reference is measured at a horizon not affected by attenuation, for example the water bottom, while the spectrum A_k is measured at a target horizon(s). δt^* is the misfit between the normalized spectral decay and t_0^*, the reference attenuated travel time computed along ray paths in the background Q model. By assuming ray paths are unchanged in each iteration, both equations (1) and (2) can be represented as a linear system **Fm=d**, where **d** as measured residual could be either δt or δt^*, **F** is a ray path integral matrix, and m is the model update, either $1/\delta v$ or $1/\delta Q$, to be estimated. Following Zhou et al. (2011) the least squares solution is obtained from minimizing the following system:

$$\varphi = \|Fm - d\| + \lambda \|Rm\| \qquad \textbf{(3)}$$

where λ is the regularization factor and R is the regularization operator which guarantees that the tomographic updates will smoothly follow geological structures.

QVMB Workflow

The QVMB workflow is used to simultaneously build Q and anisotropic velocity models by combing equations (1) and (2). Figure 1a shows a simple flowchart of QVMB, which consists of three modules: Q-migration, Q residual moveout analysis (Q-RMO) and joint tomography, where Q-migration can be conducted by Kirchhoff, beam or reverse-time migration, etc. Figure 1b illustrates the QVMB workflow in detail. Initial seismic images are generated through Q migration using velocity model V_0 and Q model Q_0. Thereafter Q-RMO is applied to CIGs to measure travel time residuals for velocity updates and spectral ratios for Q updates. Both residuals are back-projected by a joint tomography engine in order to derive updated models V_i and Q_i, which may be used as input to subsequent iterations of QVMB.

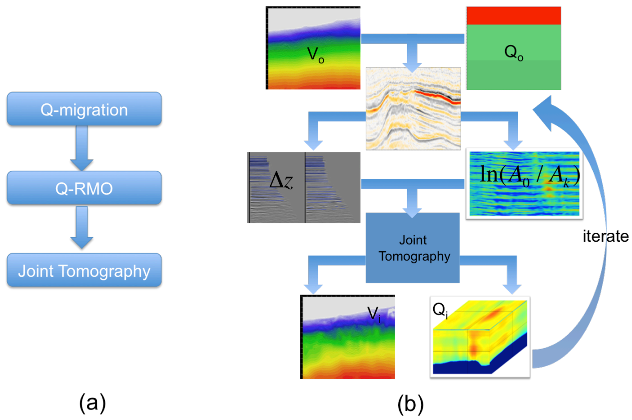

__Figure 1__ QVMB workflow

As the key module of QVMB, Q-RMO aims to measure residuals for both velocity and Q model building. As shown in Figure 2a, Q-RMO picks reflectors and measures depth residuals for velocity updates. For Q updates, shown in Figure 2b, Q-RMO picks reflectors following moveout and demigrates both CIGs and picked horizons from depth to time. Model based moveout (Liu, et. al., 2014), is applied here to efficiently perform the demigration. Spectral analysis is performed in the vicinity of each picked horizons. As such a consistent spectral analysis is performed even when gathers are not flat, thus enabling simultaneous updates to velocity and Q.

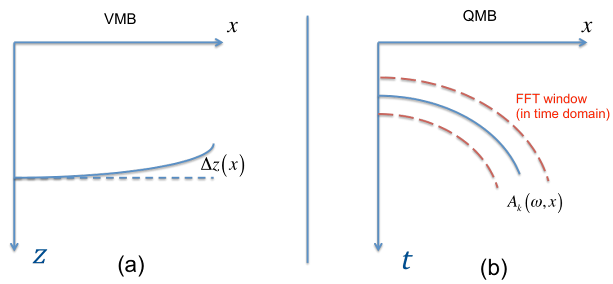

__Figure 2__ Q-RMO measures depth residuals for velocity updates (a) and spectral ratios for Q updates (b).

Examples

We applied QVMB to a 3D dataset from the North Sea. The area is characterized by a gas anomaly with strong energy decay, which hampers the imaging of reflectors at the oil reservoir level. QVMB commences with an initial anisotropic velocity model with an average misfit around 5% and a background Q model with constant Q=120. In the first step we applied QVMB in order to enhance the gathers below the gas cloud for velocity analysis. After this velocity updates and a final Q update were calculated to produce the final Q and velocity models.

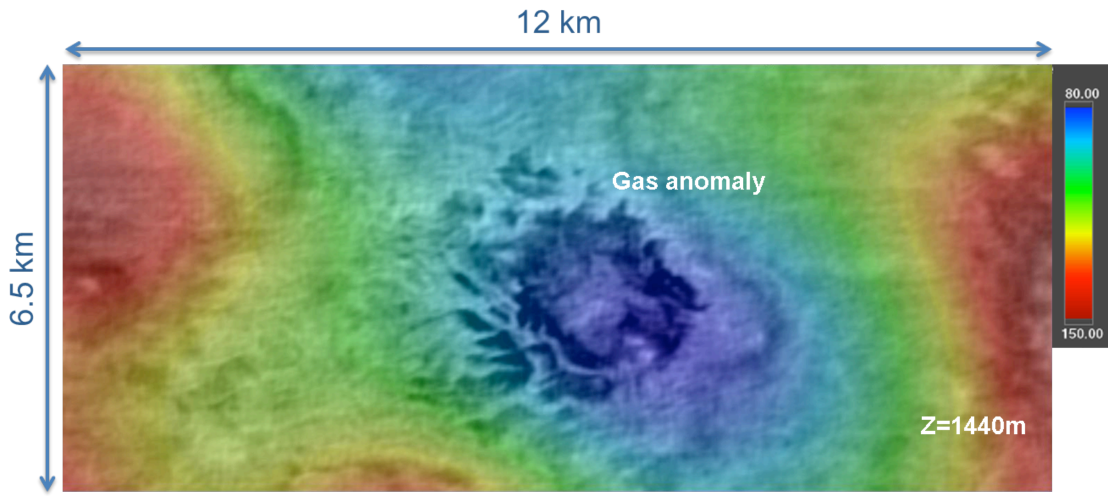

Figure 3 *Q model derived from QVMB overlaid on stack in map view at the depth of 1440 m.*

The updated Q model derived from QVMB is shown in Figure 3 by overlaid on the stack. The depth slice confirms that the major Q update is focused around the center of the gas cloud. Figure 4 displays CIGs before and after QVMB. As indicated by the rectangles, the events below the gas cloud are much better resolved after imaging with updated Q model, and are now suitable for auto-picking for further velocity updates. As shown in Figure 4c, the reflectors below the gas exhibit a broader spectrum after QVMB. Figure 5 compares the stack response in time slices from migrations with (a) the initial velocity model with no Q compensation, (b) the initial velocity model with constant Q compensation, and (c) the updated velocity and Q models after QVMB. The resolution in the post-QVMB image (c) has been considerably enhanced compared with (a) and (b).

Conclusions

We presented QVMB, a new model building workflow to simultaneously update anisotropic velocity and Q models with consistent kinematics. Using field data from the North Sea, we showed that QVMB generates high quality velocity and Q models, which greatly enhance imaging below gas anomalies.

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References

Liu, Z., Whitmore, N. D., Zhou, C. and Brown, S. [2014] A fast VTI model building method using model based moveout. *SEG Technical Program Expanded Abstracts 2014*, 4748-4752.

Valenciano, A. and Chemingui, N. [2013] Tomography and migration in viscoacoustic media. *13th International Congress of Brazilian Geophysical Society & EXPOGEF*, Rio de Janeiro, Brazil, 26-29 August 2013: 1299-1303.

Zhou, C., Jiao, J., Lin, S., Sherwood, J. and Brandsberg-Dahl, S. [2011] Multiparameter joint tomography for TTI model building. *Geophysics*, **76**(5), WB183-WB190.

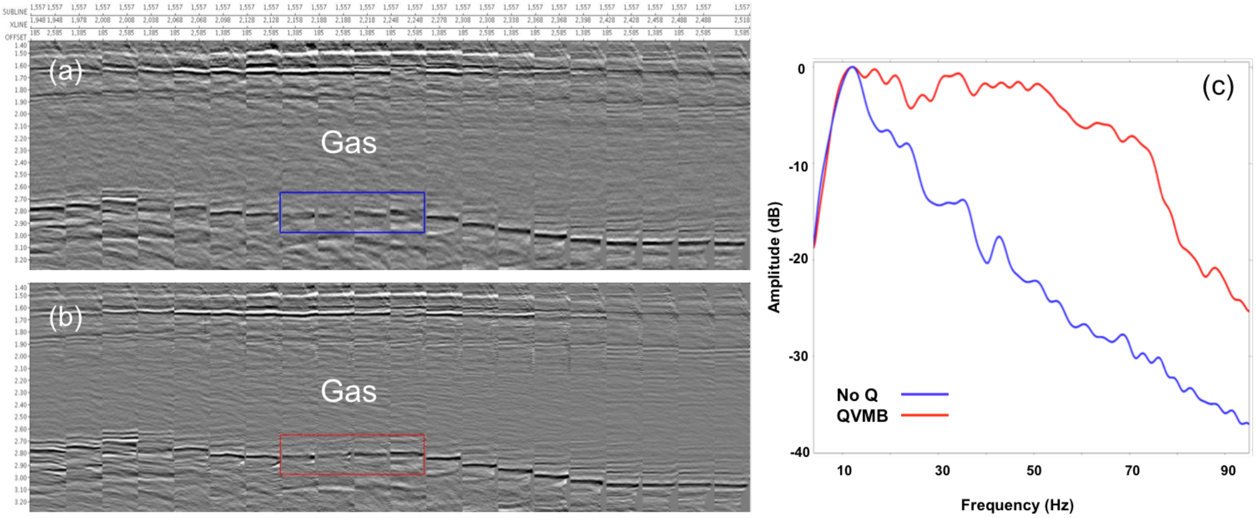

Figure 4 *(a) PSDM CIGs derived from initial velocity without Q compensation and (b) PSDM CIGs after QVMB. Both results are stretched to time for frequency analysis. (c) Spectral analysis in rectangle area of (a) and (b), which is located below the gas anomaly.*

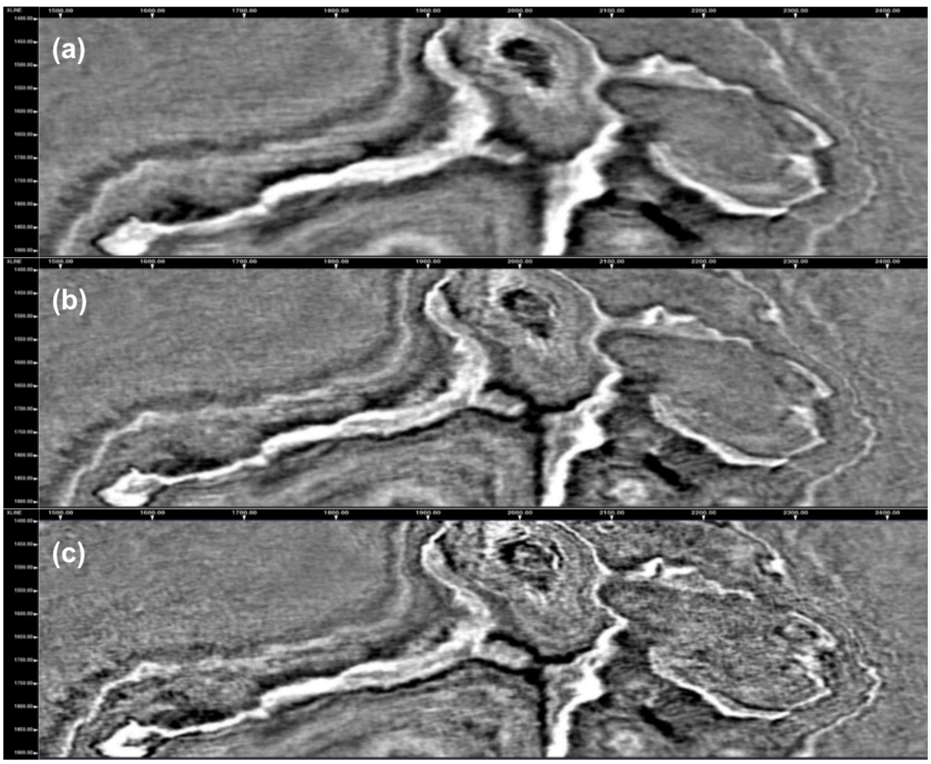

Figure 5 *Time slices at 2.8s from PSDM stacks (stretched to time) derived from (a) initial velocity model and no Q compensation; (b) initial velocity model with constant Q compensation (Q=120); (c) updated velocity and Q models from QVMB.*