Tomographic Q compensation during depth imaging to improve gas cloud affected zone in North Tapti

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Summary

Seismic imaging has always been poor around gas zone due to amplitude absorption and phase rotation of sound energy in gas. Hence a conventional averaged constant Q compensation process will not be able to yield a clear image of the subsurface. Even a pre and post migration variable Q application process may also fail to produce decent result. In this scenario only the application of tomography driven spatial and temporal variable 3D Q model directly during depth migration process will improve the image within and below the gas cloud zone. This process has been applied in a gas chimney affected zone in North Tapti area of Western offshore basin in India. The use of Q tomography preceded by Effective Q Estimation and followed by QKDM has dramatically improved the shallow gas cloud effected image.

Introduction

Q is the measure of the quality of a formation or rock related to absorption and attenuation of seismic energy. Whenever sound wave travel through a medium it experience absorption. This absorption is variable with respect to frequency and result in phase rotation of events. However this value of Q does not vary much within a geological province and hence a constant inverse Q application is sufficient to compensate this losses in most of the cases. But wherever gas chimney or any other high absorbing medium is present a low Q zone is formed and it effects the sound energy passing through it thereby deteriorating the final image within and below it. Although a variable Q estimation and application method before and after migration or an overburden compensation process in a surface consistent manner may help to improve the image, the best solution is to address the attenuation losses during migration after proper estimation of interval Q model.

Theory & Method

The Q tomography process starts after resolving all velocity related issue i.e. when the seismic data and final Velocity model or anisotropic model (Velocity, Epsilon, Delta, Dip & Azimuth) is ready for depth migration. A very broad sequence of the entire process is shown in figure 1.

Figure 1: Broad Processing Workflow for Q compensation

This process includes three major steps apart from other conventional processes as detailed below

a) Effective Q estimation from pre-migrated data:

It is very important to derive an effective Q volume (from the surface seismic data) prior to running Q tomography. The effective Q is a measure of the cumulative Q effect seen by an event during its whole propagation. This can be defined as below

\[
\frac{t}{Q_{eff}} = \sum_{l} \frac{t_l}{Q_i}
\]
Improving gas cloud affected zone in North Tapti

where Q are the interval Q in each spatial interval i crossed by the ray and t are the partial travel time (propagation time) in each spatial interval i crossed by the ray.

Effective Q can be computed from the amplitude decay of single or several frequencies. Q\textsubscript{eff} can also be estimated using time domain matching Q filters i.e. comparing the amplitude spectrum of the data trace with that of a wavelet which is unaffected by Q within a narrow time window and searching through a broad range of Q values to find the optimum forward Q filter.

b) Interval Inverse Q Volume preparation using Q Tomography

This step is basically reconstructing the main interval 1/Q anomalies present in the subsurface. It relies upon a (ray-based) inversion of the attenuated travel time \( t^* = t/Q_{\text{eff}} \), where Q\textsubscript{eff} is the 'effective Q' overcome by the seismic signal at various CMP, time, offsets and azimuths.

\[
\delta t^* = \sum_{(i,j,k)\in \text{ray}} t_{ijk} \delta Q_{ijk}^{-1}
\]

\[
t^* = \int_{\text{ray}} \frac{Q^{-1}(s)}{v(s)} ds
\]

The final anisotropic earth model, after resolving all kinematics was populated with a representative constant 1/Q value of the area. Then the residual attenuated travel time (TT) were picked in the pre-stack data and relations were constructed between this residual attenuated TT pick and the 1/Q model. Tomography were run to refine the interval 1/Q values (Figure 2) and an updated Earth model were prepared that support the geological knowledge of the area.

c) Model Driven Q compensation during Depth Migration

Finally Q Kirchoff depth migration was run using this final updated earth model. The interval 1/Q values being in the model will help the migration algorithm to resolve the attenuate.

Resolving Gas cloud affected zone of North Tapti

Conventionally acquired 3D seismic data of North Tapti area (Figure 3) has been used in this work. North Tapti area in the western offshore basin of India is characterized by the presence of shallow gas chimney in a doubly plunging anticlinal structure and the seismic image is heavily deteriorated below it (Figure 4).
Improving gas cloud affected zone in North Tapti

The seismic data was conditioned for migration that include Denoising, Demultiple, Regularization and other signal processing steps.

The anisotropic earth model was prepared using seismic and well data. Initial interval velocity model were converted from picked RMS velocity. Delta & Epsilon were estimated using Well marker, Horizon, VSP, seismic velocity and picked Eta field. Dip & Azimuth were calculated from PSDM Stack. Then this interval velocity was refined using tomographic iterations.

Once all kinematic related problems were resolved the next step was to enter into the Q tomography. As already explained Effective Q volume was required for Q tomography. This effective Q volume was estimated from Pre migration Stacks based on amplitude decay of combinations of frequencies (Figure 5). Several combination of frequencies were tested and many of them were taken upto depth migration stage to compare the results and a combination of 20Hz, 30Hz & 50Hz had given a better result for this dataset (Figure 6).

The final Effective Q model and its corresponding seismic section have been shown in figure 7 and a low Q zone is clearly visible in the gas white zone. This volume had to be used later to calculate attenuated travel time during tomographic differential equation preparation.

After this the final anisotropic earth model was populated with a background 1/Q value of 0.008 (Figure 8). This background Q property was updated through Q tomography i.e. picking the residual attenuated travel time, creating tomographic differentials and solving them to get an optimum result.
Improving gas cloud affected zone in North Tapti

This tomography was repeated for different effective Q volumes and the best result was chosen. Also the final earth model was updated in a geologically constrained manner (Figure 9) so that the Q update does not affect the other parts of the data. The final interval 1/Q volume is shown in figure 10 where the updated 1/Q model is following the plunging anticlinal structure. The comparison of effective Q model and final interval Q model is also shown in figure 11 and the interval Q model is indicating that the extent of the gas zone is limited to shallower part only.

Finally this interval inverse Q model was used during Kirchoff depth migration and the results are shown in figures 12 to 15. When compared to the conventional constant Q depth migration the Q tomography driven new volume is showing remarkable improvement in the gas affected shallow zone as well as the deeper reflections.

Figure 8: Background inverse Q population into the earth model

Figure 9: Modelling the zone of amplitude absorption and phase rotation

Figure 10: Tomographic updated inverse Q comparison with the initial background model

Figure 11: Comparison of Effective and Interval Q model

Figure 12: Comparison of Q tomography result with the conventional PSDM (Inline Section)

Figure 13: Comparison of Q tomography result with the conventional PSDM (Crossline Section)
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Even when compared to the pre & post migration variable Q applied seismic volume the current Q tomography volume is showing improved continuity and clarity within and below the gas chimney.

**Conclusion**

The best possible solution so far for gas cloud or any high absorbing medium is application of tomography driven spatially and vertically variable Q volume during depth migration. If the amplitude absorption and phase rotation of seismic energy is compensated in this way the subsurface image within and below such zone will greatly improve as visible in the final results of North Tapti.
Improving gas cloud affected zone in North Tapti

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