# Q compensation imaging in the local angle domain

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### Summary

We introduce an efficient inverse Q-filter implementation in the full-azimuth angle domain depth migration, referred as the EarthStudy 360 migration, to compensate for seismic wave attenuation and dispersion effects. The filter is realized using Futterman's model, in which these two phenomena are linked by the causality principle. Two implementations are presented and compared: The conventional approach, in which the filter is applied during the migration to the input seismic events; and a novel approach, in which the filter is applied on the seismic events of the multi-dimensional (5D) migrated gathers. Synthetic data results show spectrum enhancement and improved image recovery.

#### Introduction

One of the more important challenges in seismic imaging is revealing reflective and diffractive events that have been obscured by viscoelastic wave effects, namely attenuation and dispersion. These two physical phenomena, which cause amplitude decay and phase distortion, are coupled by the causality principle and are both characterized by a dimensionless parameter called the quality factor (Q) (Aki and Richards, 1980). These effects are normally considered and corrected in the imaging process by use of frequency domain compensation filters that are applied on time gathers, either in the pre-processing stage or in the course of migration (Wang, 2008, Foss et al., 2014).

In this paper we introduce a Q compensation operation, accounting for both phase and amplitude correction, which is incorporated into the EarthStudy 360 imaging system (Koren and Ravve, 2011). In this depth migration, the seismic data is mapped into the subsurface coordinates, comprising the spatial location as well as the scattering angles at each image point. The scattering angles are defined by the opening angle and azimuth and the directivity dip and azimuth. Each surface coordinate seismic event is therefore characterized in the prestack depth domain by a 5-dimensional event, namely by depth and the four angle components. In this process, the full recorded seismic data is mapped into common image depth-angle gathers which are five-dimensional per inline/crossline location. These gathers, also referred to as local angle domain (LAD) gathers, serve as input to an advanced 5D processing and imaging system (Chase and Koren, 2015), for which the Q compensation described in this abstract is an attractive option.

Applying the Q compensation filter results in Q-corrected 5D angle depth gathers. Two methods are implemented, the first on the input seismic data during the mapping process, and the second on the 5D gathers post-mapping. The former uses a variation of the standard approach, in which the correction is applied on the input time data, but during the migration process. The latter is a 5D gather processing operation, where the correction is executed on the 5D migrated data. This method introduces a tremendous advantage in terms of performance, with the ability to perform corrections with different parameters in a post-migration processing option.



Figure 1 The local angle domain decomposition, showing the incident and scattered rays and their LAD components.

#### Theory

The Futterman filter (Futterman, 1962) accounting both for dispersion (phase) and attenuation (global amplitude) correction, and obeying causality, reads

$$D(Ray Pair, \omega) = e^{-\frac{i\omega T^*}{\pi} ln(\frac{\omega}{\omega_r})} e^{\frac{\omega T^*}{2}}$$

where  $\omega$  is the frequency component,  $\omega_r$  is the reference frequency, and T\* is the time delay due to subsurface absorption, which is computed along the ray pair path connecting the imaging point with the surface shot receiver coordinates, and equals

$$T^* = \int \frac{dl}{v(x,y,z) \cdot Q(x,y,z)}$$

Here Q (x,y,z) is the interval quality factor and v(x,y,z) is the interval velocity. The Futterman filter operates on a gate extracted from the time seismic trace, the size of which is chosen according to the values of the time delay T\* and the reference frequency. The standard method used here performs the gate corrections during the migration onthe-fly using the T\* derived from the ray tracing.

In the 5D processing method the filter is applied for each LAD bin, so that

$$D(v_1, v_2, \gamma_1, \gamma_2, \omega) = e^{-\frac{i\omega T_{AVG}^*(v_1, v_2, \gamma_1, \gamma_2)}{\pi} \ln\left(\frac{\omega}{\omega_r}\right)} e^{\frac{\omega T_A^*}{2}}$$

Here the Futterman filter operates on a gate extracted from the LAD binned trace transformed back to time. The LAD bin is defined by the shooting directivity angle and azimuth  $v_1$  and  $v_2$ , and the opening angle and azimuth  $\gamma_1$  and  $\gamma_2$  (see Figure 1). T<sup>\*</sup><sub>AVG</sub> is the averaged global absorption time delays within a given LAD bin.

In order to avoid gain explosion for high frequencies and T\* values, a stabilizing term was added to the filter, so that in practice the filter amplitude part reads

$$D_{Amp} = \frac{e^{-\frac{\omega T^*}{2} + \sigma}}{e^{-\omega T^* + \sigma}}$$

where  $\sigma$  is a "stabilization factor", a small fraction that leads to saturation at a desired gain value.

### Examples

Presented below are synthetic data results in which Qaffected time gathers were modelled using given Q and velocity volumes. In this synthetic data, North-West Poland, Permian and sub-Permian seismic waves were simulated. The Q compensation filter was then applied in the EarthStudy 360 migration. The correction was applied in the standard approach, i.e., on the input time data, and also in our novel approach on the 5D migrated angle gathers. Figure 2 shows the images (inline sector) obtained from imaging and correcting with a reference frequency of 20 Hz, in which good reproduction of the reference unaffected image is observed. Figure 3 features results for reference frequency of 1 HZ in which dispersion causes an entire shift upwards, making this case more challenging for the compensation filter. Here, too, good image recovery is observed for both the standard and the 5D processing methods. Figure 4 shows the spectrum (wave-number) recovery for a shallow (1500m) and for a deeper (3000m) event. The stabilization factor is 10<sup>-4</sup>, for which significant recovery is detected for both regions.



**Figure 2** A section of the image obtained from migrating a) reference (Q-unaffected) gathers, b) Q-affected gathers, c) Q corrected gathers – 5D processing method (operating on 5D depth gathers), stabilization factor  $10^{-3}$ , d) Q-corrected gathers – standard method (operating on input time data), stabilization factor  $10^{-3}$ . The reference frequency of the modelling and the correction was taken as 20 Hz. Velocity and Q sectors are both seen in the top lefthand figure, with Q values scaled by the left color bar and velocity values by the right color bar.



**Figure 3** A section of the image obtained from migrating a) reference (Q-unaffected) gathers, b) Q-affected gathers, c) Q corrected gathers – 5D processing method (operating on 5D depth gathers), stabilization factor  $10^{-3}$ , d) Q-corrected gathers – standard method (operating on input time data), stabilization factor  $10^{-3}$ . The reference frequency of the modelling and the correction was taken as 1 Hz. Velocity and Q sectors are as in Figure 2.





**Figure 3** Normalized spectrum recovery for a shallow event (upper figure) and a deeper event (lower figure). The red line is the reference gathers spectrum, the green line is the Q-affected gathers spectrum, the purple line is the Q-corrected gathers spectrum in the standard method, and the light blue line is the Q-corrected gathers spectrum with the 5D processing method. Stabilization factor in both corrections is  $10^{-4}$ .

#### Conclusions

A novel Q-Compensation technique operating on 5D migrated angle gathers was introduced and discussed. The results of the filter correction in the EarthStudy 360 migration were presented. Corrected depth images and spectra of Q-affected synthetic data were shown to exhibit good reproduction of the unaffected data.

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# EDITED REFERENCES

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