

Testing Q Sensitivity in WEB-AVO Inversion

Introduction

Amplitude-driven interpretation in frontier offshore basins is strongly affected by the fidelity of pre-stack amplitudes. In deep-water passive-margin settings, prospect evaluation often relies on subtle variations in amplitude, bandwidth and angle-dependent response, while local well calibration may be limited or absent. In such settings, an apparent seismic anomaly may reflect reservoir or fluid effects, but it may also be influenced by overburden attenuation, transmission losses, illumination effects, processing artefacts or residual wavelet effects. Establishing amplitude robustness is therefore a prerequisite for inversion-based prospect evaluation.

A common processing response to mitigating attenuation-related amplitude and bandwidth loss is Q compensation. In seismic processing, Q compensation is used to counteract the effects of anelastic attenuation, including frequency-dependent amplitude decay, bandwidth reduction and phase or wavelet distortion (Wang, 2008). Its practical objective is to recover resolution and improve the reliability of amplitude-versus-angle behaviour before interpretation or inversion. However, Q compensation is not risk-free and can potentially introduce undesirable effects. By boosting attenuated components of the seismic signal, it may amplify noise, alter event character, introduce ringing, or create sharper responses that are not necessarily more geologically correct.

The implications of Q compensation are particularly relevant for Wave-Equation-Based AVO (WEB-AVO) inversion. Unlike conventional reflectivity-based methods, WEB-AVO is an elastic wave-equation-based AVO inversion method, in which transmission effects within the inversion window are already represented by the modelling engine. Therefore, applying Q compensation before WEB-AVO raises a practical question: to what extent does Q treatment improve the input data by correcting attenuation-related amplitude and bandwidth effects, especially in the overburden, and to what extent does it disturb the consistency between the processed gathers and the underlying subsurface properties? In other words, Q compensation may help by improving apparent target definition and lateral continuity, but it may also increase residual mismatch or introduce ringing that influences interpretation.

The objective of this study is to test this trade-off directly. We compare a no-Q baseline with four Q-compensated inputs and evaluate how the alternative Q treatments propagate into WEB-AVO inversion attributes. The study asks a deliberately practical question: how much does Q compensation help, and how much does it harm, when the resulting data are used for WEB-AVO-based amplitude interpretations? The analysis focuses on elastic property changes, residual behaviour, lateral continuity and apparent target definition.

Method

Wave-Equation-Based AVO inversion is a 1.5D elastic Full-Waveform-Inversion (FWI) method that iteratively solves the integral representation of the wave equation (Gisolf et al., 2017). Unlike conventional linear reflectivity-based AVO inversions, WEB-AVO models the seismic response within the target interval using the elastic wave equation, accounting not only for primary reflections but also for non-primary energy that is physically described by the wave equation, such as transmission effects, internal multiples and mode conversions. The inversion solves directly for the elastic properties Compressibility and Shear Compliance, rather than for Acoustic and Shear Impedance. These attributes are used because they provide a reservoir-oriented parameterisation with enhanced sensitivity to fluid and rock-frame effects under favourable rock-physics conditions.

The seismic inputs analysed in this study were generated during a previous reprocessing project that employed a modern Pre-SDM workflow designed to improve the reliability of relative amplitudes for AVO interpretation, see Barkwith et. al, 2024. That study demonstrated that prospect-level AVO character is strongly affected by the imaging workflow, particularly by the Q model used to compensate for frequency-dependent attenuation losses during propagation. The processing sequence included high-resolution velocity-model building, FWI, Q tomography and Q-Kirchhoff PreSDM, with several Q implementations evaluated, including layered and low-Q insertion variants.

In the present study, a no-Q baseline dataset was compared with four Q-compensated angle-gather inputs derived from the same processing framework. The WEB-AVO inversion workflow is kept fixed so that changes in Compressibility, Shear Compliance, contrast volumes and residuals can be interpreted as the response of the inversion attributes to the alternative Q treatments, rather than to changes in the inversion algorithm. Furthermore, an average statistical wavelet was calculated for all four Q-compensated datasets. The five tested inputs comprise the no-Q and four Q-compensated versions: Conventional Q, Q Tomography, Layer-Q, and Layer-Q + Q30 insertion (Table 1).

Case	Short label	Input-data description	Purpose in comparison
1	No-Q	No-Q angle-gather input	Baseline response without Q-amplitude compensation
2	Conventional Q	Conventional Pre-SDM Q-amplitude angle gathers	Tests standard Q-amplitude compensation relative to the no-Q baseline
3	Q Tomography	QPreSDM Q-Tomography angle gathers	Tests Q-Tomography / QPre-SDM implementation
4	Layer-Q	QPre-SDM layer-Q angle gathers	Tests a layer-Q / QPre-SDM implementation
5	Q30 insertion	QPreSDM layer-Q angle gathers with Q30 insertion	Tests the strongest/sharpest Q-compensated variant in the current comparison

Table 1: Input datasets used for the WEB-AVO Q-sensitivity test, comprising one no-Q baseline and four Q-compensated angle-gather versions. The short labels are used throughout the text to compare how alternative Q treatments affect the resulting Compressibility, Shear Compliance and residual behaviour.

Results

The five input datasets and their corresponding WEB-AVO inversion results are compared in Figure 1, using identical crossline, target window and display convention for the seismic gathers, Compressibility and residuals. A complementary 1D comparison of the gather and Compressibility prediction at a pseudo-well location is provided in Figure 2. The no-Q seismic data have reverse polarity relative to the Q-compensated seismic data; therefore, reverse-polarity wavelets were used in the corresponding tests.

The no-Q baseline produces the most “blocky” inversion response, both within the overburden and in the target interval. In comparison, the four Q-compensated inputs yield sharper elastic property responses and a more continuous representation of the target zone. The Q-compensated results are relatively stable with respect to one another, indicating that the main WEB-AVO response is relatively insensitive to the specific Q implementation within the tested range.

Among the tested cases, the Q30 insertion variant exhibits the most prominent apparent target continuity in the upper target interval, as indicated by the white arrows in Figure 1. This improved definition is accompanied by increased vertical sharpness and visible ringing effects, indicating that the improved definition may not directly correspond to improved geological resolution.

The residual panels and the 1D comparison further demonstrate that the sharper Q-processed inputs are not necessarily better matched by the fixed WEB-AVO inversion setup. These observations can be made at the pseudo-well location displayed in Figure 2, as well, where the ringiness introduced is apparent in the shallow section. Overall, the results demonstrate a clear trade-off: Q compensation improves apparent continuity and target definition relative to the no-Q baseline, but also increases ringing and residual mismatch.

Conclusions and future work

This study highlights the importance of separating the role of Q compensation above the inversion window from its role within the inversion window. For overburden-related amplitude effects, Q compensation can be a powerful tool. It has the potential to reduce lateral amplitude variations caused by propagation through the shallow section, including effects associated with shallow gas or other attenuating overburden features. In this context, Q compensation can substantially help WEB-AVO

inversion by delivering input gathers with more laterally consistent amplitude and bandwidth behaviour, allowing the inversion to produce more laterally stable elastic-property attributes. Within the inversion window, however, the role of Q compensation is less straightforward. WEB-AVO already accounts for transmission effects through its elastic wave-equation modelling. Additional Q treatment applied within the same interval can therefore create a trade-off: it may enhance or sharpen some target-related features, but it may also introduce ringing and increase the risk of over-interpreting processing-enhanced detail.

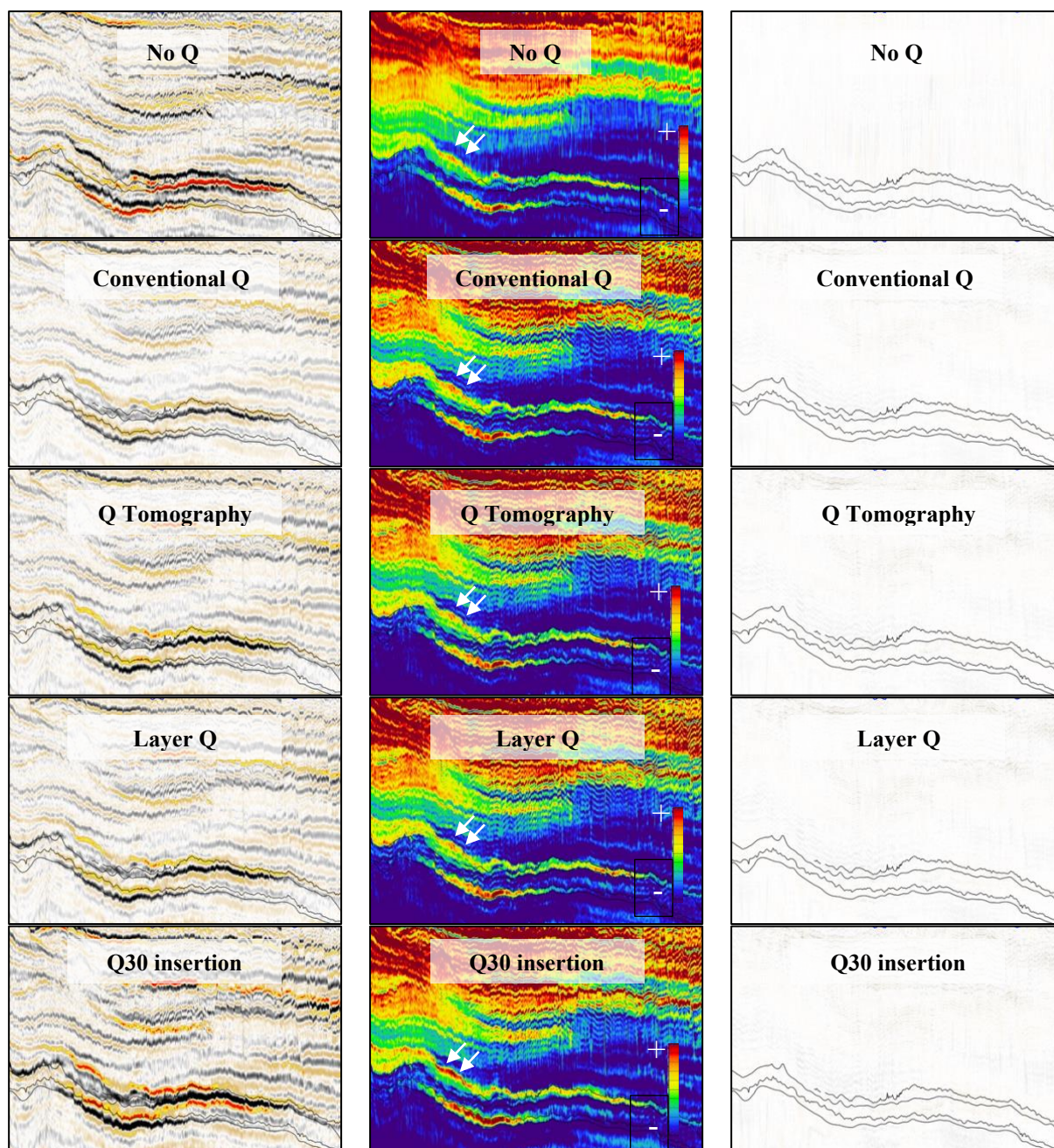


Figure 1: Comparison of the five tested input datasets and corresponding WEB-AVO outputs on the same crossline and target window. Columns show the no-Q baseline and four Q-compensated cases; rows show the seismic input, Compressibility, and residuals for each case. The comparison highlights the increased apparent sharpness and continuity of the Q-compensated results relative to the blockier no-Q baseline, together with increased ringing and residual mismatch.

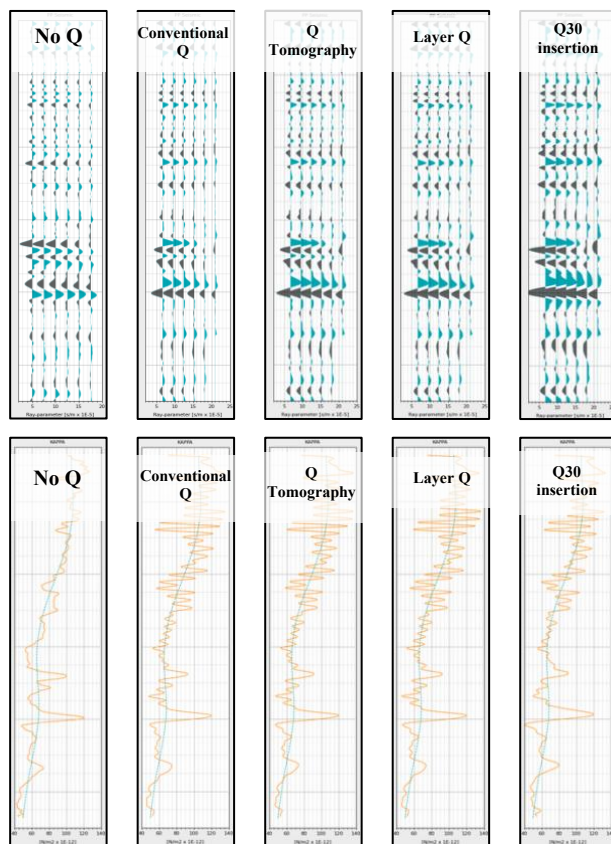


Figure 2: Seismic data and compressibility prediction at the pseudo-well location for the five datasets.

In this example, the Q-compensated results show stronger apparent definition, but the shallow part of the inversion window also displays increased ringiness. This indicates that the application of Q compensation within the inversion interval, and the interpretation of the resulting WEB-AVO attributes, must be performed with caution.

The main conclusion is therefore that Q compensation can be highly beneficial for stabilizing amplitudes affected by the overburden, but its use inside the WEB-AVO inversion window should not be treated as automatically positive. The benefit is improved apparent continuity and target definition which links to other direct hydrocarbon indicators, such as structural conformance, see Gonzalez et al, 2024. The risk is that part of this improvement may be associated with ringing or other processing-related effects rather than true geological resolution. For amplitude-driven prospect ranking, WEB-AVO results should therefore be interpreted together with Q-sensitivity diagnostics, residual behaviour and consistency checks across plausible Q scenarios.

A logical next step is to repeat this exercise on a dataset with well calibration. This would allow the observed changes in lateral stability, target definition, ringing and residual behaviour to be tested against independent geological and petrophysical constraints, and would help determine which aspects of the Q-compensated response correspond to improved subsurface resolution and which are artefacts of the processing-inversion interaction.

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