Submission code: 40MVG4M868

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Impact of Q Factor on Tomography: Analysis Using Synthetic Seismic Data

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Abstract Summary

This study investigates the impact of neglecting the attenuation quality factor (Q) in Iterative Tomographic Migration (ITM) by comparing velocity fields and migrated images from viscoacoustic and acoustic experiments (with and without Q anomalies). All tests used the same ITM workflow and the same initial velocity and density models for data modeling. If attenuation had no effect, the outputs would be identical, however, notable discrepancies were observed. These results demonstrate that neglecting Q can introduce distortions in both model reconstruction and seismic imaging, particularly in highly attenuative or geologically complex environments.

Introduction

Ray-based postmigration tomography has become a standard approach in seismic depth imaging, integrating reflection tomography with migration velocity analysis in the postmigrated domain (Stork, 1992). Pioneering studies (Grau and Lailly, 1993) introduced the use of depth migration for reflector positioning, followed by traveltime tomography for velocity model updates. This iterative process of migration and tomography is known as Iterative Tomographic Migration (ITM).

Despite its widespread adoption, conventional ITM often neglects the attenuation quality factor (Q), which governs seismic energy loss during wave propagation. A high Q value indicates low attenuation and preserves signal fidelity, whereas a low Q results in significant energy dissipation and degraded signal clarity. Incorporating Q effects into the tomographic process enables more geophysically accurate imaging, while its omission may lead to erroneous velocity models and misinterpretation of subsurface structures.

This study evaluates the influence of Q by comparing ITM results obtained with and without accounting for attenuation, aiming to quantify its impact on seismic image quality and model reliability.

Theory

Seismic tomography seeks to reconstruct a velocity model that minimizes the mismatch between computed and observed data. In two-dimensional settings, traveltimes are typically modeled as line integrals of the slowness $s(x,z) = 1/v(x,z)$, where $v(x,z)$ is the local wave propagation velocity. These integrals are computed along the ray path $\mathcal{C}$ connecting the source and receiver. The traveltime $t(\mathcal{C})$ along a given path is therefore expressed as:

$$t(\mathcal{C}) = \int_{\mathcal{C}} s(x,z)\,dl, \tag{1}$$

where dl denotes the differential distance along the ray path $\mathcal{C}$. Since the ray path itself depends on the velocity model, this expression is inherently nonlinear. To overcome this, a common strategy is to linearize the problem around a reference model, solving for perturbations in slowness:

$$\Delta t = D\Delta s, \tag{2}$$

where Δt is the traveltime residual, Δs is the slowness perturbation, and D contains the ray segment lengths within each model cell.

In postmigrated tomography, the data consist of depth shifts Δz of imaged reflectors, which are converted to traveltime deviations using:

$$\Delta t = 2s\Delta z \cos(\phi)\cos(\gamma), \tag{3}$$

where s is the slowness above the reflector, ϕ is the reflector dip, and γ is the angle of incidence.

In seismic surveys, each point on a reflector is illuminated by multiple shots, resulting in redundant subsurface information. During prestack migration, seismic events are repositioned to their reflection points, producing multiple partial images of the same reflector. These are subsequently stacked to generate the final migrated image. When a correct velocity model is used, the partial images align coherently, enhancing the signal-to-noise ratio upon summation. Tomography plays a central role in updating the velocity model to improve this alignment and the quality of the stacked image.

Conventional seismic imaging primarily addresses the kinematic properties of wave propagation. However, seismic waves are also subject to attenuation, described by the quality factor Q, which encompasses intrinsic absorption and scattering effects. Ignoring Q may lead to inaccurate traveltime estimates and image distortions, especially in attenuating media (Carcione, 2007). Attenuation alters both amplitude and phase, causing waveform distortions and potential imaging artifacts. To address these issues, methods such as viscoacoustic tomography (Dutta and Odé, 1979) and Q-compensated reverse time migration (Zhang and Ulrych, 2005) have been developed.

In the postmigrated domain, attenuation can asymmetrically deform the wavelet, producing apparent depth shifts (Δz) in reflectors that cannot be explained solely by velocity errors. As a result, when converting these depth shifts into time delays (Δt), an effective slowness that incorporates attenuation effects should be considered. Advanced methodologies address this by formulating coupled velocity-attenuation inversion problems, enabling the joint estimation of velocity (v) and quality factor (Q) from migrated image gathers and amplitude variations (Chevrot, 2004; Plessix and Mulder, 2001). These approaches enhance the accuracy of the velocity model and improve the reliability of geological interpretations.

Results

Three experiments were conducted to assess the impact of the quality factor Q on seismic migration and tomography, using identical velocity and density models (Figure 1a and b). Experiment 1 (Figure 1c) used a constant Q $= 2000$, representing an acoustic case. Experiment 2 (Figure 1d) introduced a horizontal Q anomaly in the central layer, while Experiment 3 (Figure 1e) featured an elliptical Q anomaly in the same region.

The velocity models obtained after five tomography iterations (Figure 2) were not significantly affected by the different Q anomalies. However, the migrated images (Figure 3) revealed clear differences. From Experiment 1 to 2, phase and amplitude changes were observed. In Experiment 3, a non-geological artifact appeared, associated with the localized elliptical Q anomaly. These results highlight the importance of accounting for attenuation in seismic imaging to avoid misinterpretation.

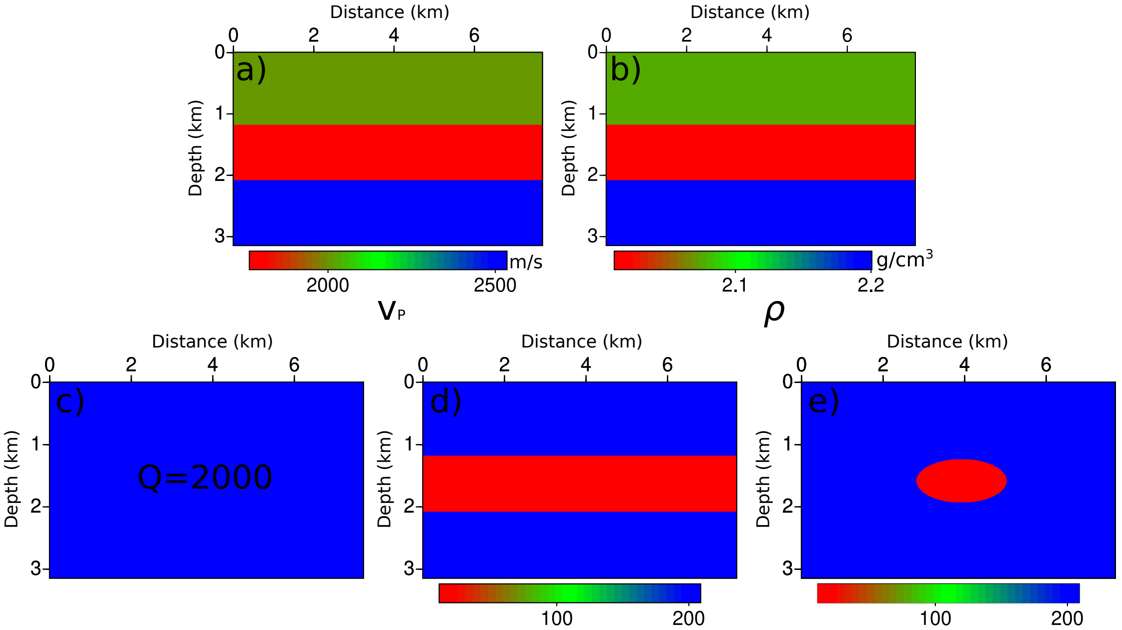
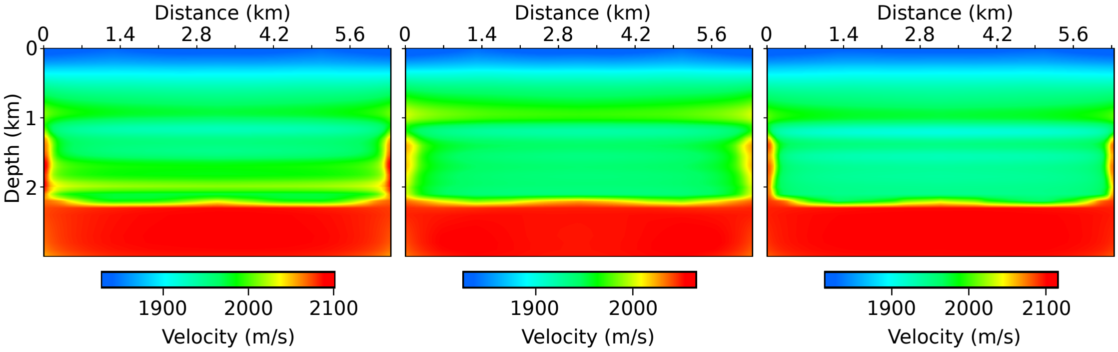


Figure 1: Experiments involving different Q-factor anomaly configurations were conducted to evaluate their impact on seismic modeling. Panels (a) and (b) respectively show the velocity and density models, which were kept constant across all experiments to isolate attenuation effects. Panel (c) corresponds to the first experiment, where a constant Q-factor simulates a conventional acoustic scenario. In the second experiment (d), a Q-factor anomaly was introduced in the central horizontally layered medium, representing a simplified viscoacoustic case. Panel (e) shows the third and most complex setup, with an elliptical Q-factor anomaly embedded in the central layer, simulating a heterogeneous viscoacoustic environment.



a) Constant Q factor   b) Layered medium Q factor   c) Elliptical Q factor

Figure 2: Comparison of velocity fields obtained using the Iterative Tomographic Migration: (a) without a Q-factor anomaly (acoustic modeling), (b) with a Q-factor anomaly in the central layer of the horizontally layered model (viscoacoustic modeling), and (c) with an elliptical Q-factor anomaly at the center of the central layer (viscoacoustic modeling).

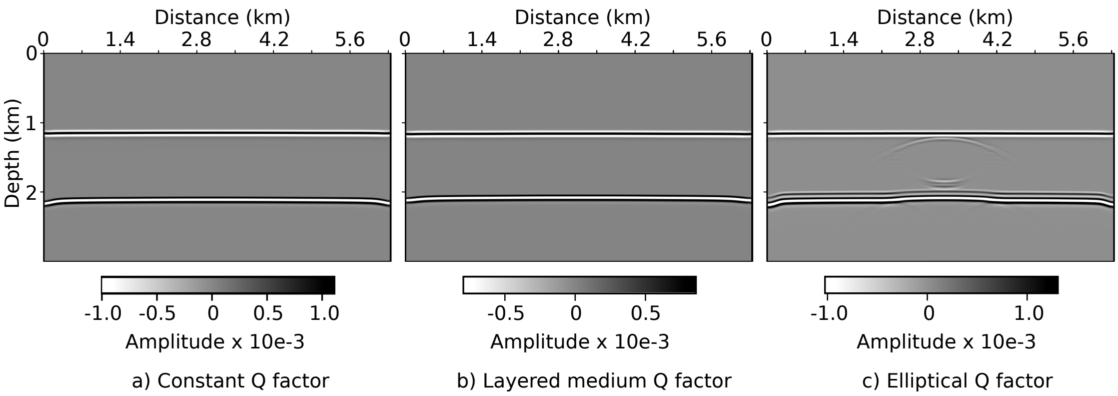


Figure 3: Comparison of migrated stacked images from offset-domain pre-stack migration using tomographic velocity fields: (a) without a Q-factor anomaly (acoustic), (b) with a central-layer Q anomaly (viscoacoustic), and (c) with an elliptical Q anomaly in the central layer (viscoacoustic).

Conclusions

This study underscores the critical importance of incorporating the attenuation quality factor Q into Iterative Tomographic Migration (ITM) workflows. The results reveal that neglecting Q can introduce significant imaging artifacts, particularly in scenarios involving localized finite Q anomalies. Such distortions may compromise interpretation by affecting reflector continuity and depth positioning. In contrast, when Q anomalies are laterally extensive and span entire horizontal layers, their impact on image quality is minimal. This indicates that the spatial distribution of attenuation is a key factor in preserving seismic image fidelity. These findings highlight the importance of including attenuation in tomography to improve the accuracy and reliability of subsurface velocity models.

Acknowledgments

The authors thank Financiadora de Estudos e Projetos (FINEP) for funding (Q-RTM Project, Ref. 0368/23), SENAI CIMATEC for execution, and both institutions for granting publication permission.

References

Carcione, J. M., 2007, Wave fields in real media: Wave propagation in anisotropic, anelastic, porous and electromagnetic media: Elsevier, **38**.
Chevrot, S., 2004, Seismic attenuation tomography from waveforms at regional distances: Geophysical Journal International, **159**, 711–728.
Dutta, N., and H. Odé, 1979, Attenuation and dispersion of compressional waves in fluid-filled porous rocks with partial gas saturation (white model); part i, biot theory: Geophysics, **44**, 1777–1788.
Grau, G., and P. Lailly, 1993, Sequential migration-aided reflection tomography: an approach to imaging complex structures: Journal of applied geophysics, **30**, 75–87.
Plessix, R. E., and W. A. Mulder, 2001, Tomographic inversion of teleseismic data with the inclusion of attenuation: Geophysical Journal International, **146**, 669–678.
Stork, C., 1992, Reflection tomography in the postmigrated domain: Geophysics, **57**, 680–692.
Zhang, Y., and T. J. Ulrych, 2005, Viscoacoustic wave-equation migration: Geophysics, **70**, E47–E53.