# Fullband imaging

by
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## ABSTRACT

Recent advances in broadband acquisition and processing are a significant step towards meeting the industry's drive for better bandwidth and resolution in seismic imaging. Conventional marine seismic acquisition and processing typically exhibits a usable bandwidth of about 8 to 80 Hertz (Hz) due to the phenomenon of ghost and the absorption effect of an anelastic earth. The ghost effect is the result of reflections from the surface of the ocean. These reflections interfere constructively or destructively with the primary reflections, generating notches in frequency spectrum, thereby limiting the usable bandwidth. The anelasticity of the Earth causes energy dissipation, the effects of which can be commonly described by the quality factor (Q), resulting in more energy loss for high-frequency signal that further degrades the resolution of the seismic image as seismic wave propagates deeper.

Acquisition solutions addressing the ghost issue have been implemented and can be broadly classified into two categories: (a) using variable-depth sources and/or cables to create ghost diversity; (b) using multi-component sensors to attenuate ghost by combining the opposite polarity signals, that bounce off the sea surface, received by pressure and velocity sensors. To complement these acquisition configurations, various processing solutions have been put forward to handle the ghost, a process that is called deghosting. This offers only a partial solution for full broadband imaging because the absorption effect of the Earth needs to be taken into account as well. This can be done in processing through the estimation and application of Q factor in imaging.

In this article, we focus on variable-depth streamer acquisition and propose a full broadband processing solution that involves three important components: (a) 3D deghosting; (b) Q estimation using Q-Tomography; (c) Q application via Q pre-stack depth migration (Q-PSDM).

## INTRODUCTION

Extending the usable frequency through broadband acquisition and processing has proven to be beneficial in areas such as advanced seismic velocity model building and Full Waveform Inversion (FWI) (Ratcliffe et al., 2013), the enhancement of imaging (Zhou et al., 2014), and inversion studies (Soubaras et al., 2012). In the area of broadband processing, one of the key steps is deghosting. In recent years, active research has been conducted into both pre-migration and post-migration deghosting algorithms, as well as application of deghosting to different marine acquisition configurations, e.g. conventional shallow cable, variable-depth cable, multi-component cable, etc. (Amundsen and Landrø, 2013). In particular, it has been pointed out that the 3D nature of the Earth must be considered in the deghosting process (Wang et al., 2014). For full broadband processing, however, the attenuation effects of the Earth's subsurface also need to be taken into account. To this end, the intrinsic anelastic nature of the Earth must be considered in the processing workflow. Moreover, in the presence of gas, both as shallow pockets and as commercial reservoirs (not an uncommon geological setting in many parts of the world), localized strong absorption from these gas bodies will cause amplitude dimming and frequency-dependent dissipation, and this degradation in signal needs to be recovered.

By quantifying the attenuation of seismic energy due to the Earth's anelasticity as background Q (Qb) and gas bodies as anomalous Q (Qa), we have proposed two tomography methods for estimating Qb (Xin et al., 2014) and Qa (Xin and Hung, 2011). However, the combination of Qa and Qb models has not been discussed and the application of total Q (Qt = Qa + Qb) has not been shown. Furthermore, the combined effects of deghosting and compensation using Qt have not been explored in the industry.

In this article, we propose a full broadband solution (fullband). This solution combines proprietary advanced technology with a unique workflow that is purely data-driven and applicable to both conventional and variable-depth towed-streamer data. Three important ingredients of our workflow are highlighted: (1) 3D deghosting; (2) Q Tomography for estimating Qt; (3) Q-PSDM. We illustrate the effectiveness of our fullband imaging flow with a field data example from offshore Malaysia, acquired using CGG's BroadSeis™ technology, which exhibits severe absorption resulting from gas pockets, in order to show how our workflow can provide high-resolution delineation of the target structures.





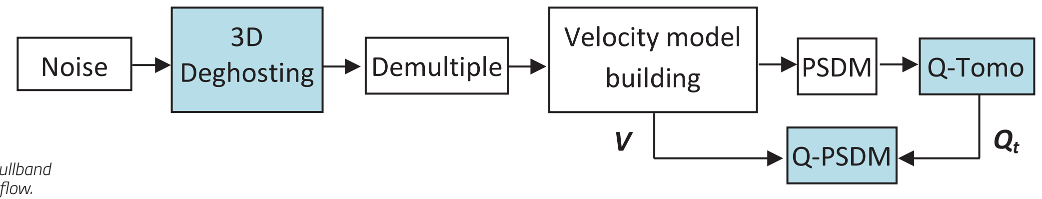


*Figure 1: Fullband imaging workflow.*

## FULLBAND IMAGING

Figure 1 shows our simplified proposed workflow for full broadband processing in the presence of gas, with only the key steps specified. Since the topic of broadband processing includes a wide range of practices, we limit the scope of this paper by focusing on the highlighted boxes in the figure. In practice, iterations may be needed in updating Q fields and velocity consecutively; here we depict a linear approach for the sake of simplicity.

We applied the workflow shown in Figure 1 on CGG's BroadSeis marine data acquired offshore Malaysia. Figure 2 shows a 3D pre-stack time migration (PSTM) seismic volume which indicates an area characterized by an extensive complexity of Miocene reef carbonate rocks formed during a period of maximum transgression. The extended carbonate structures, highlighted by red arrows, act as significant absorptive layers which degrade the resolution of events underneath, making them difficult to delineate and interpret. Moreover, the carbonate pinnacles exhibit strong 3D effects which present a challenge to deghosting. In addition, the gas pockets, indicated by the dashed ellipse, distort the signals near the top of the carbonates in such a way that the events underneath become discontinuous as a result of amplitude dimming and phase distortion within the affected zones. Hence, the processing objectives are to enhance the image resolution through deghosting and recover the signal by Q compensation.

### 3D deghosting

Figure 3 demonstrates the advantage of 3D deghosting (Wang et al., 2014) over a bootstrap approach (Wang and Peng, 2012) in the presence of complex structures. While the bootstrap deghosting works well in most parts of the data, for instance, the ghost associated with the seafloor is

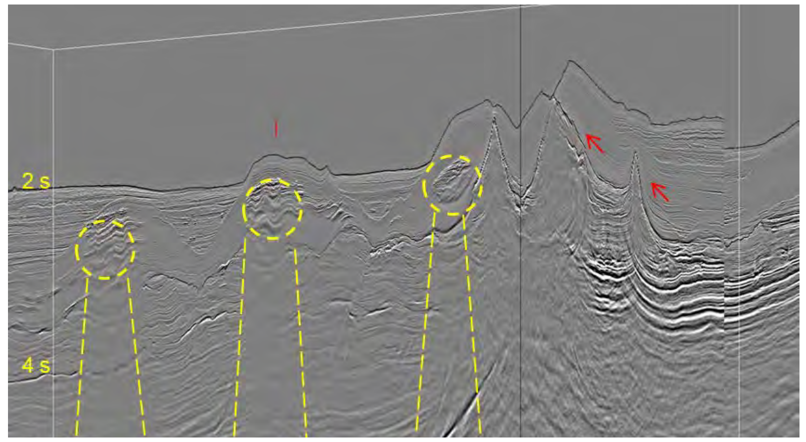


*Figure 2: A 3D PSTM image volume showing the presence of complex carbonate structures (red arrows) and gas pockets (yellow circles) which lead to signal degradation.*

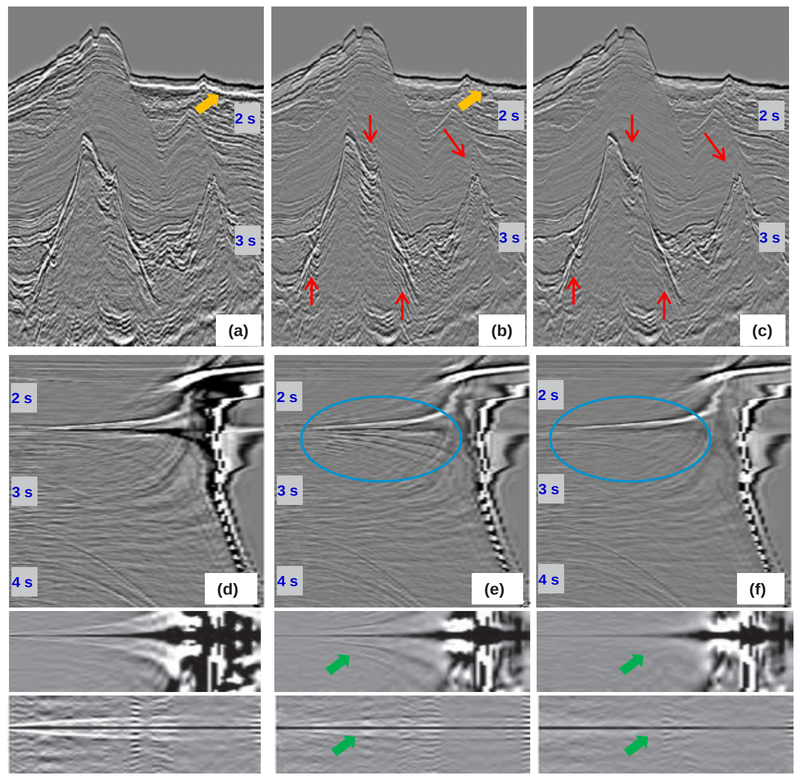


*Figure 3: Comparison of bootstrap deghosting and 3D deghosting results. (a) Common channel before deghosting; (b) after bootstrap deghosting, and (c) after 3D deghosting; (d) NMO-corrected CMP gathers before deghosting; (e) after bootstrap deghosting, and (f) after 3D deghosting. The plots at the bottom show the corresponding autocorrelations for data in shallow and deep areas.*

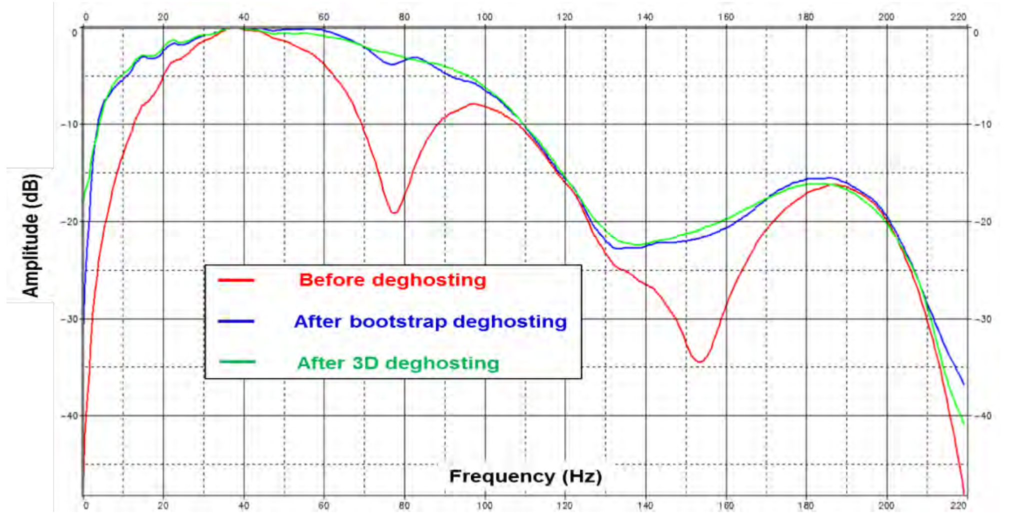


*Figure 4: Comparison of amplitude spectrum using different deghosting methods.*

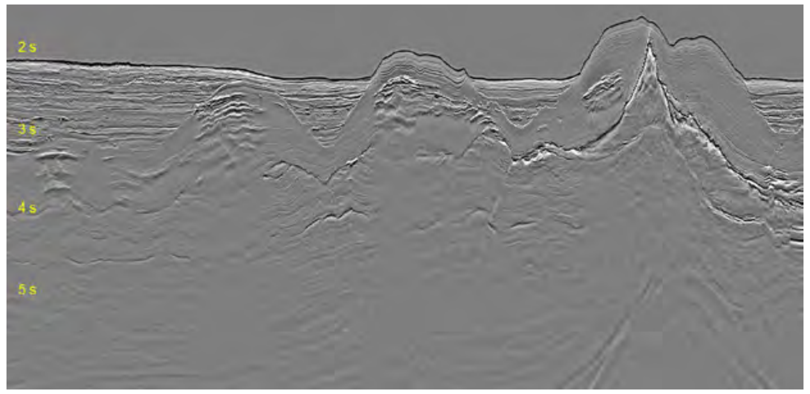

*Figure 5: PSDM result with deghosting shown in time domain.*

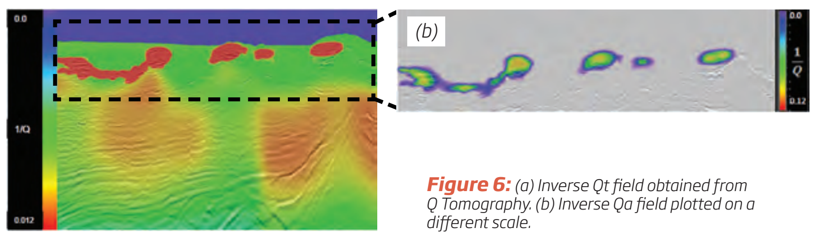


*Figure 6: (a) Inverse Qt field obtained from Q Tomography. (b) Inverse Qa field plotted on a different scale.*

effectively removed as shown by the orange arrow in Figures 3(a) and (b), it struggles with out-of-plane diffraction energy corresponding to the complex reef carbonate pinnacles giving rise to artifacts after deghosting. On the other hand, our advanced 3D receiver deghosting technology effectively attenuated the ghost wavefield related to complex geology as displayed in Figures 3(c) and (f). Consequently, as depicted in Figure 4, the notches due to the ghost are filled up in the amplitude spectrum, resulting in more low-frequency and widely usable bandwidth. Nevertheless, even with deghosting, the decay of the spectrum towards the high frequencies is obvious. This is the effect of the Earth's natural attenuation. To address this issue and further enhance the bandwidth, Q compensation is needed.

## Q Tomography and Q-PSDM

After performing multiple attenuation and PSDM on the deghosted data, a migrated seismic section was obtained as shown in Figure 5. The enhanced low-frequency response allows the deeper part of the data to be imaged with higher signal-to-noise ratio. The next step was to handle the absorption effects caused by the gas pockets and the Earth in general. By applying Q Tomography on the common image gathers (CIGs) in two separate steps to obtain Qa and Qb, we generated an inverse Qt (1/ Qt) field as shown in Figure 6. The boundaries of the gas pockets, displayed in red, were constrained by the FWI inversion results which ensure meaningful correspondence in a geological sense (Zhou et al., 2014). It can also be observed that the distribution of Qb is fairly consistent with the geological structures. Due to the difference in dynamic range of the scale, the inverse Q values associated with the gas pockets are plotted on a different scale as shown in Figure 6(b).

Applying Q-PSDM (Xie et al., 2009) using this Q field, we generated a seismic section as displayed in Figure 7. Compared with the migrated result without Q compensation shown in Figure 5, it can be seen that the distortion in amplitude and phase of the events in the affected area has been nicely compensated. The continuity and the resolution of the carbonate structures are significantly enhanced. Moreover, the faults in the deeper area are now much more clearly defined. Overall, the target structures are better delineated, making inversion work easier. The uplift is further confirmed by the comparison of amplitude spectra in Figure 8. The stepwise widening of the frequency bandwidth is evident from the application of 3D deghosting and total Q compensation. This validates the effectiveness of our fullband imaging workflow.

## CONCLUSIONS

We have presented a broadband processing workflow that incorporates 3D deghosting with Q tomography and Q-PSDM to compensate for the loss of signal due to ghosts and the Earth's absorption. We have shown the interplay between deghosting and Q tomography in enhancing the estimation of background Q and anomalous Q. We have successfully demonstrated the first application in Asia Pacific of combining the two Q models in a data-driven manner to compensate for the frequency-dependent absorption on a variable-depth streamer survey. We suggest that the proposed fullband workflow is necessary to meet the drive for better bandwidth and resolution in seismic imaging.

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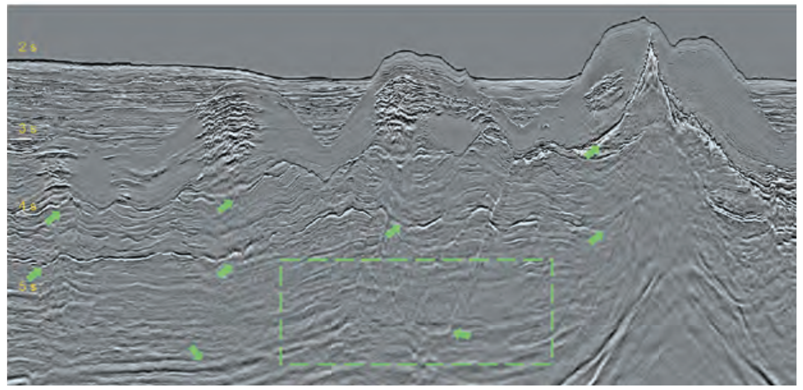

*Figure 7: Q-PSDM result with deghosting (both source and receiver) and Q-Tomography shown in time domain. Amplitude dimming and pull-down effects caused by gas pockets have been compensated (illustrated by green arrows); whereas signal-to-noise ratio and fault imaging in the deeper part of the data (green box) have been enhanced.*

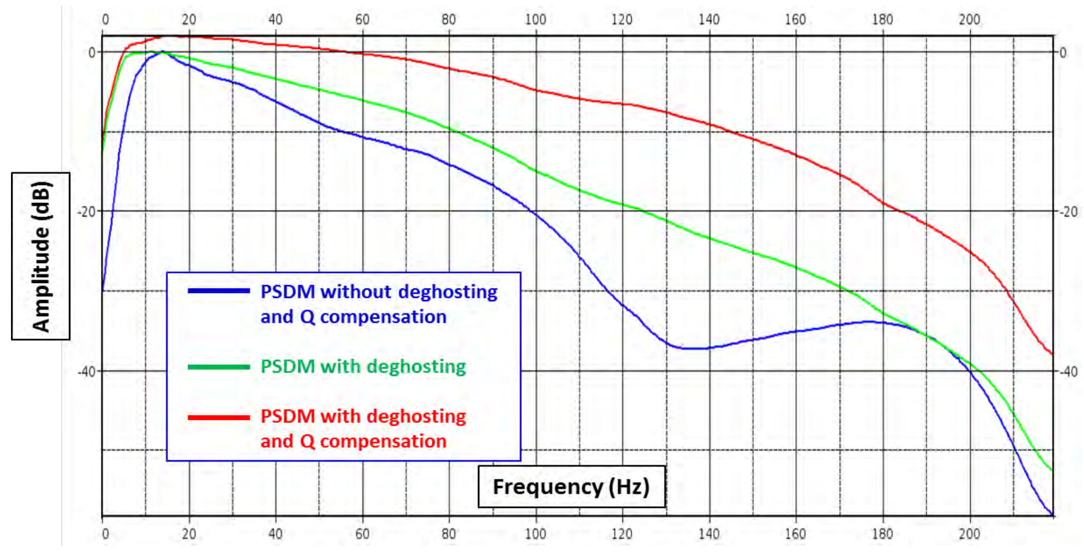


*Figure 8: Amplitude Spectra. Stepwise extension of frequency bandwidth is observed with the application of deghosting and total Q compensation via Q-PSDM.*



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