Image based Q-compensation for 4D reservoir identification and interpretation – A case study at Gulf of Mexico

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Summary

Strongly absorptive geologic bodies in the near surface, particularly from gas trapped beneath hydrates, have been a significant seismic challenge for the accurate identification and interpretation of deeper oil and gas reservoirs. In this case history, we show how the inverted Q model can compensate for the effects of amplitude loss, phase distortion and velocity dispersion seen in the recently acquired time-lapse ocean bottom node (OBN) surveys. The results of the inverted Q model are located at the same position as the low velocity anomalies derived from full waveform inversion (FWI) and align with the bright shallow structures, giving us confidence in the image compensation using this Q model. The compensation results show that the events become sharper and the structures more coherent for both Q-Kirchhoff PSDM and Q-RTM (Reverse Time Migration) imaging. We also show the impact on the 4D interpretation of the baseline and monitor 4D OBN surveys. Early interpretation results indicate the Q compensated data gives a much closer match between the 4D results and the earth model predictions.

Introduction

The propagation of seismic waves in this area is marked by significant loss in frequency and amplitude at the deeper reservoir intervals. This is primarily due to a shallow section of unconsolidated muddy gas sands, trapped by overlying hydrates, as shown in Figure 1. The amplitude map in Figure 2 shows the dimming below the gas hydrates, which covers a substantial portion of the field.

Time lapse or 4D surveys have the potential to improve reservoir recovery for these deeper reservoirs by better understanding the static and dynamic properties and allowing for better placement of producing and injector wells. Unfortunately, if the reservoir cannot be imaged or seismically resolved, the value of the 4D surveys is greatly diminished.

The interpretation of 4D amplitudes is difficult due to the visco-elastic attenuation that affects both amplitude and phase and is dependent upon acquisition offset and azimuth. This is particularly true when deriving rock properties from seismic for both static and dynamic simulation models. Building a consistent Q-compensation model that can be used to image both the baseline and monitor OBN surveys helps to alleviate these conditions. This provides a robust 4D interpretation that is more consistent with the well control and simulation model predictions.

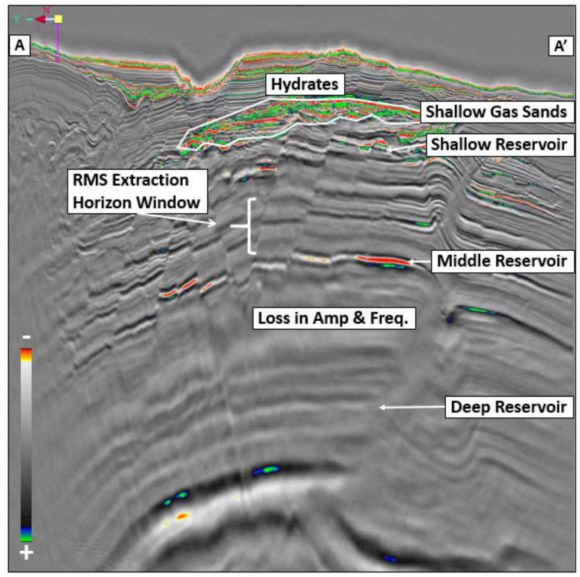

Figure 1: Amplitude and frequency loss from shallow gas trapped by hydrates

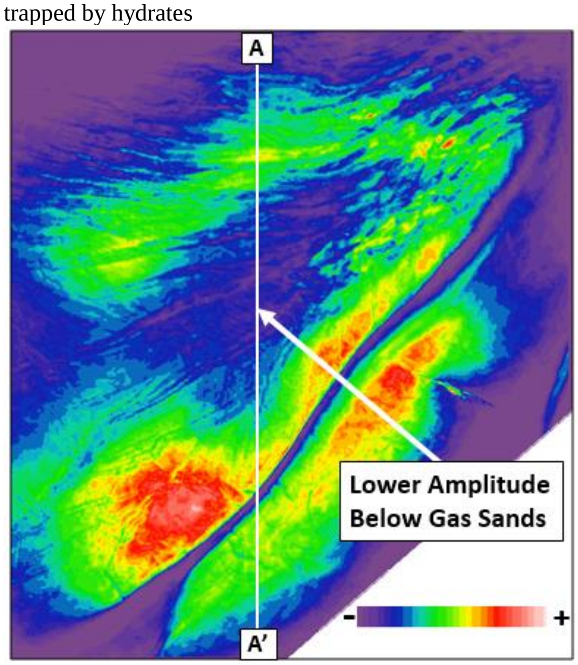

Figure 2: Amplitude map showing attenuation below gas sands trapped by hydrates

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Methodology

The workflow for this effort is shown in Figure 3 and is divided into pre-migration processing improvements for 4D repeatability, Q tomography and FWI velocity model building, and post-migration 4D residual alignment and denoise.

Pre-migration processing started with processed downgoing OBN gathers with designature, deghosting, denoise, static correction and demultiple applied. Additional pre-migration noise and multiple attenuation, node matching and statics helped to further improve the repeatability of the 4D OBN surveys. FWI utilized raw pressure data and started with existing legacy TTI models. Early iterations of FWI were used to infer the initial location of the Q attenuation anomalies. FWI iterations were interleaved with the ray based Q-tomography inversion methods. This was primarily done using frequency centroid shift Q-tomography (He et al., 2014) and later finetuned using amplitude based Q-tomography. Reflection full waveform inversion (RFWI) (Gomes et al., 2017) was used to update the deepest reservoir, after locking down the shallow and mid-depth Q model and FWI derived velocity models. Post-migration residual alignment and co-denoise methods (Peng et al., 2014) improved the final 4D repeatability. The final NRMS levels are about 4-6% at the shallow reservoir.

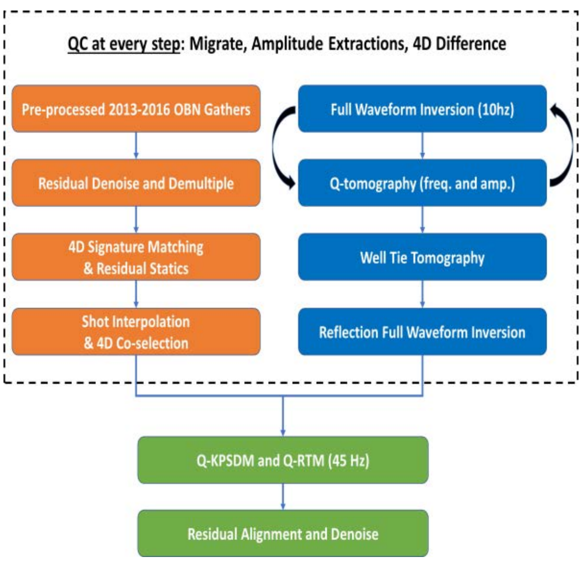

Figure 3: Workflow for 4D pre-processing, Q and velocity model building, imaging, and 4D post-migration residual alignment and denoise

Examples

Figures 4 and 5 shows the final FWI (10Hz) velocity model and the corresponding Q model derived from the frequency centroid shift Q tomography inversion, then refined with amplitude based Q tomography. The lowest Q values (~20) correspond to the gas charged sediments below the shallow hydrates. With each improvement in the Q model the FWI velocity model also improved the sharpness and resolution of the imaging. Figure 6 and 7 shows the previous constant Q model and final Q model Kirchhoff pre-stack depth migration (PSDM) results. Note the improvement in frequency stability and amplitude response.

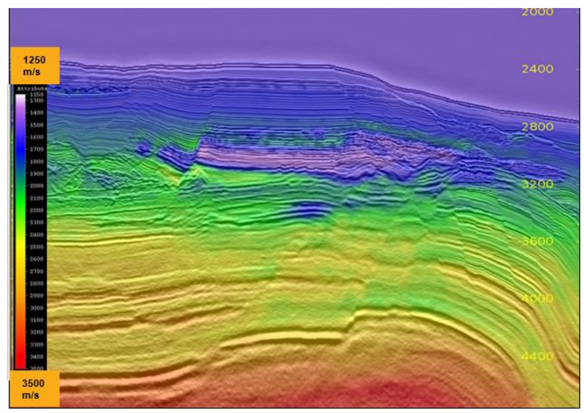

Figure 4: Full waveform inversion (10Hz) velocity model

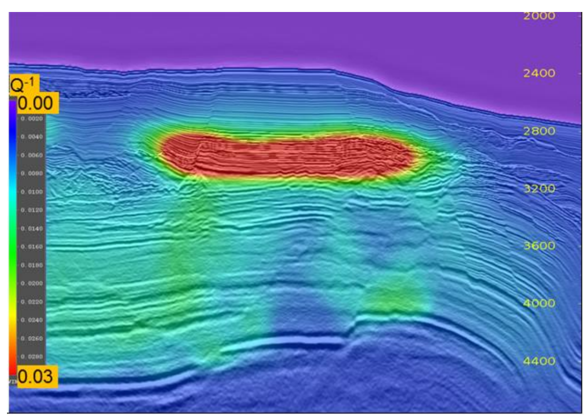

Figure 5: Q-tomography model

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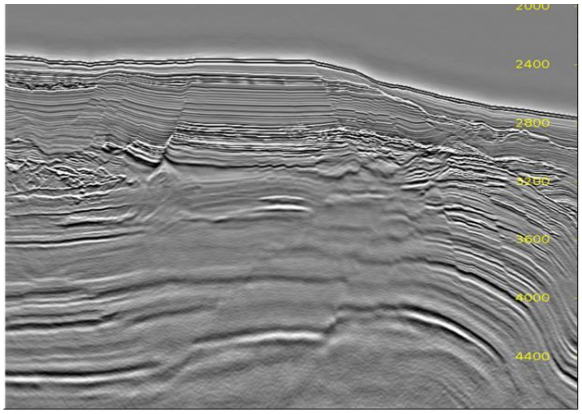

Figure 6: Constant Q Kirchhoff PSDM

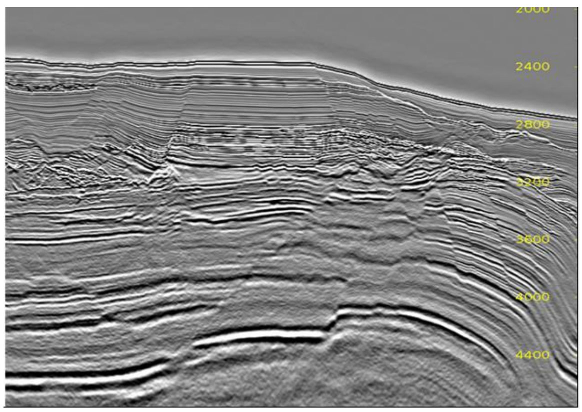

Figure 7: Q Model Kirchhoff PSDM

Figure 8 shows the uplift in imaging, comparing the initial Kirchhoff PSDM with the final Q model Q-RTM imaging. Improvements in frequency, amplitude stability and event continuity are quite evident.

Figure 9 shows the amplitude extraction for the shallowest reservoir before Q-compensation and after Q-compensation using Kirchhoff PSDM. Note the improvement in the amplitude continuity after the Q-compensation.

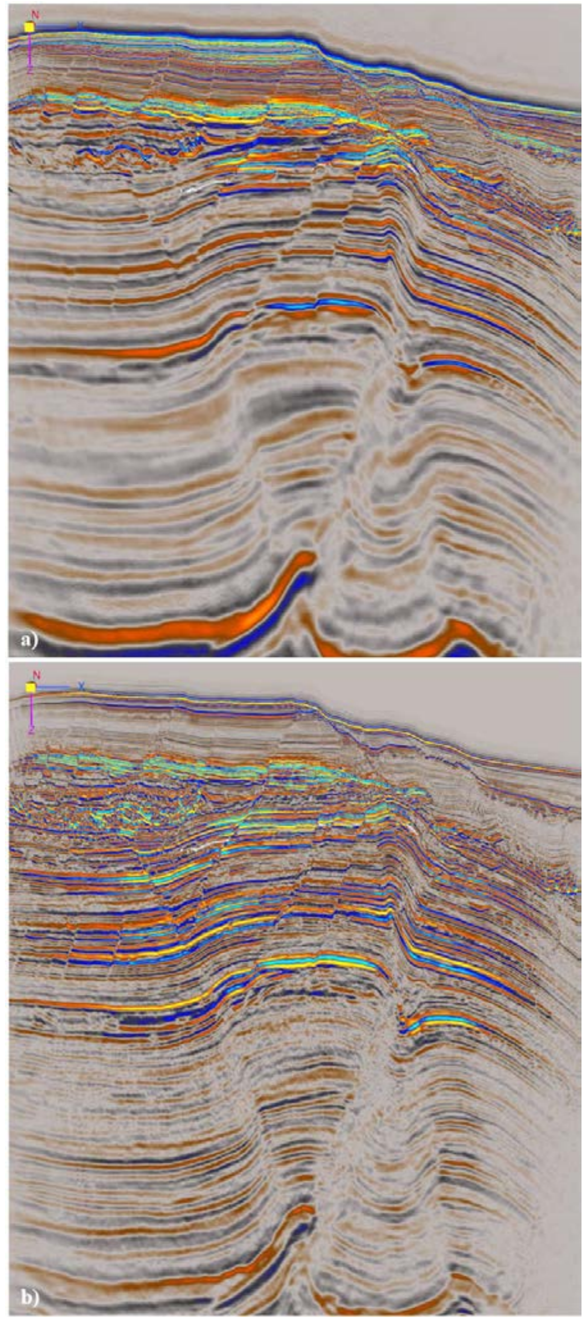

Figure 8: a) Initial Kirchhoff PSDM compared to b) Q-RTM

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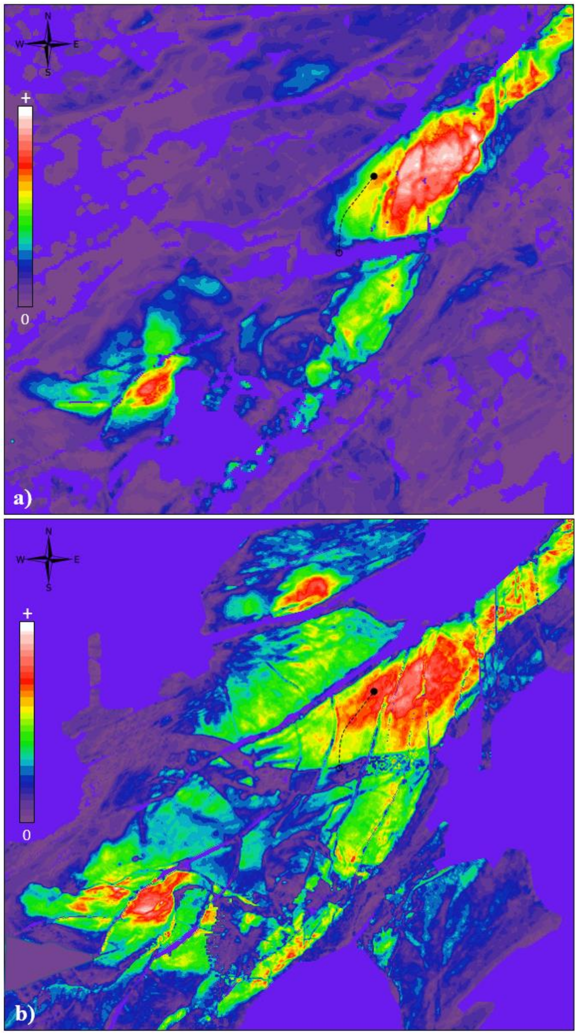

Figure 9: Shallow reservoir amplitude extraction a) before and b) after Q-compensation

Figure 10 shows the 4D difference map for the shallow reservoir from a single producing well before and after image based Q-compensation. The 4D difference map before Q-compensation shows significant softening (red) and hardening (blue) considerable distances away from the producing well. The 4D difference map with Q-compensation shows softening (red) within the fault block and shows which fault segments are in pressure communication.

Conclusions

Imaged based Q-compensation coupled with FWI can solve for significant frequency and amplitude losses below shallow overburden absorptive geologic bodies.

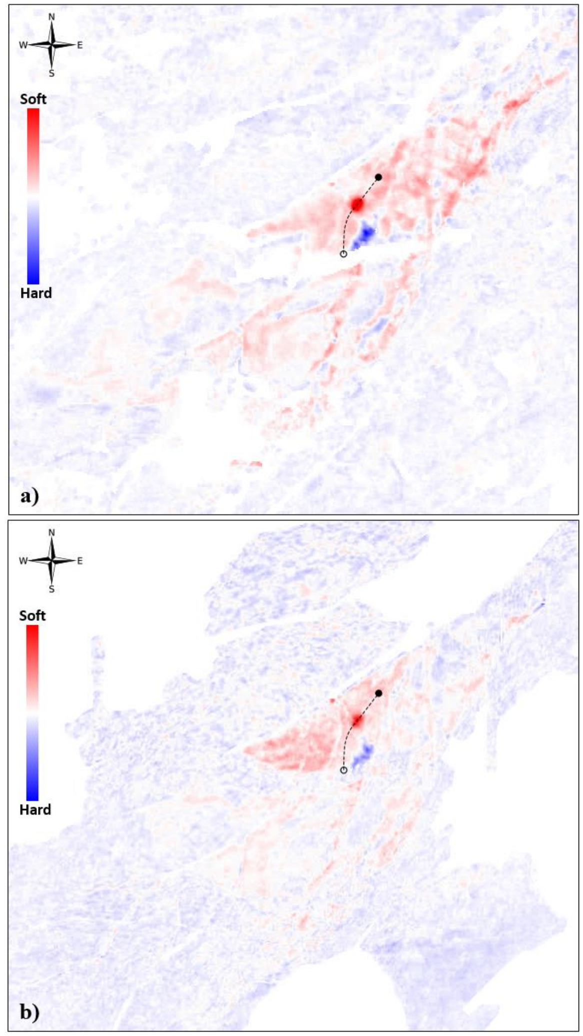

Figure 10: 4D difference map for shallow reservoir a) before and b) after Q-compensation

Applying Q-compensation to both the baseline and monitor 4D surveys improves the consistency of the 4D response, leading to more reliable placement of development wells. This should lead to enhanced production and improved reservoir management.

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