Compensating for visco-acoustic affects with an integrated model building flow: a deep water Equatorial Conjugate Margin case study.

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Summary

Cretaceous prospects in deep water Côte d'Ivoire data are impacted by later channel and canyon systems. The structural uncertainty and amplitude fidelity of the plays can be affected if unresolved shallow velocity and attenuation issues are not accommodated in the earth model. Using an integrated visco-acoustic model building flow we solve the impact of complex channel systems on deeper targets. Full Waveform Inversion (FWI) created an accurate and regional scale velocity model, removing the structural uncertainty when used in the imaging step. Tomography was used to compensate for visco-acoustic effects. Integrated into the sequence, the method calculated measures of log spectral ratio in demigrated space, mitigating stretch and tuning effects. The amalgamation of the complete visco-acoustic flow accommodated the structural complexity of the area, whilst improving the amplitude reliability of the dataset.

Introduction

Channel systems of Maastrichtian and Paleocene age impact the seismic quality of prospective Late Cretaceous fan systems in deep water Conjugate Margin data from Côte d'Ivoire (Figure 1). Unresolved intra-channel heterogeneity causes structural uncertainty and a loss to amplitude fidelity for the fan systems they overlay. Amplitude spectra (Figure 1) show a significant attenuation challenge below the major Paleocene canyon. Regional scale basin analysis studies are used to understand the sediment provenance inside the channel systems, as no wells exist in the area.

An inaccurate velocity model, absorption or scattering could cause poor reflectivity below the younger channels. Full waveform inversion (FWI) was used to create a regional scale model. Wavefield modeling studies for this dataset, where the water bottom was between 3000 m and 3500 m, show no transmission energy was recorded at 8000 m of offset, therefore a reflection driven solution was used. The velocity kernel used to drive the update was defined by Ramos-Martinez et al. (2016), and based on the removal of the migration isochron from the kernel. This method removes the reflectivity imprint from the updated model.

Visco-acoustic effects were determined using a fully integrated, tomographically inverted quality factor, Q. Outlined by Liu et al. (2016), the approach calculates a Q model based on log spectral ratio measures of the data. These are then used as constraints in a tomographic inversion scheme. The resulting model is used to compensate for frequency dependent attenuation of amplitude and distortion to phase.

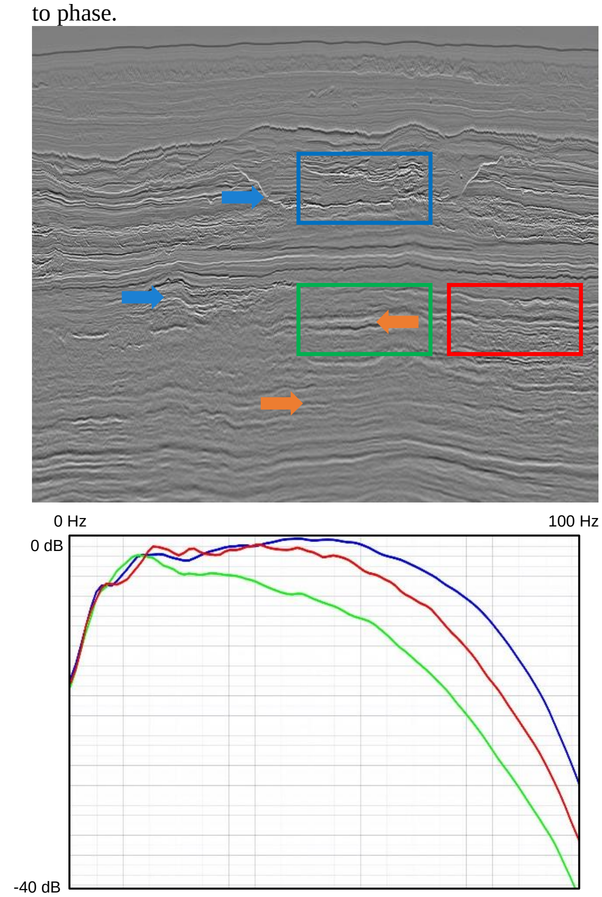

Figure 1. Top - A vertical section through the data showing the Maastrichtian and Paleocene channel systems (blue arrows) and their effect on older Cretaceous leads (orange arrows). Bottom – Colour identified amplitude spectra taken from three locations in the data.

Methodology

As no transmission energy was recorded in the data, FWI relied on reflection energy. The method used was first introduced by Ramos-Martinez et al. (2016), and determines a gradient such that the high wavenumber reflectivity isochrones are removed, preserving low wavenumber back-scatter energy from the two-way wavefield extrapolation imaging condition. This is achieved using impedance-velocity parameterization to apply the inverse of the dynamic weights defined by Whitmore and Crawley (2012).

10.1190/segam2019-3212188.1

The velocity sensitivity kernels of a source and receiver from a single velocity layer over a half-space are shown in Figure 2. Figures 2a and 2b demonstrate the kernels for the bulk-modulus and density respectively, whilst Figure 2c shows impedance. Figure 2d represents the velocity kernel, freeing the resulting model from the impact of impedance.

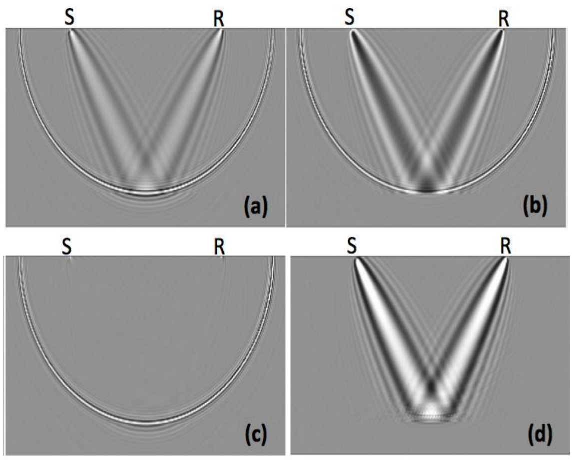

Figure 2.Velocity sensitivity kernels for a single velocity layer over a half-space. (a) bulk-modulus, (b) density, (c) impedance and (d) velocity.

To accommodate the visco-acoustic effects of the earth and their potential to attenuate amplitude and distort the phase in a frequency dependent manner, we implemented a fully integrated visco-acoustic model building sequence.

Log spectral ratios are determined on demigrated common image gather (CIG) data (Liu et al., 2014), avoiding stretch and tuning effects that can hinder accurate measurements of relative amplitude content. As the log spectral ratio measurements constrain the tomographic inversion, they should ideally be evenly and densely sampled over the dataset in space and time. The Cretaceous sequence in this Transform Margin dataset is comprised of a sequence of laterally discontinuous channels and fans that are deposited in acoustically quiet shales. A combination of semi-automated data interpretation, and semblance-driven data measurements ensured a good sample population for the inversion. Integrated into the greater model building sequence, the final imaging step uses both the full wavefield FWI model and the tomographically derived Q model in a Q migration to compensate for both velocity and attenuation effects on the imaging.

Examples

The data used for this case study was acquired in 2015 using dual-sensor acquisition with 10 streamers each separated by 100 m. The seismic character of the older Late Cretaceous fan systems were obscured by younger Late Cretaceous and Paleocene channel systems. FWI was used to create an accurate, long wavelength velocity model that captured both the regional trend and localized velocity variations. Used in conjunction with tomographic methods to update anisotropy, the model produced an improvement in gather flatness and focusing of events below the Late Cretaceous and Paleocene channel systems. Figure 3 illustrates the benefits of the FWI, where the model is more conformable to the expected velocity profile; lateral continuity aligns with reflectivity, whilst vertical resolution is better than the historical model. The structure below the main channel system is simplified and the stack response has been improved. Despite the uplift achieved in the seismic response with the FWI model, there was still a residual impact on resolution and amplitude fidelity on the deeper Early Cretaceous fan systems.

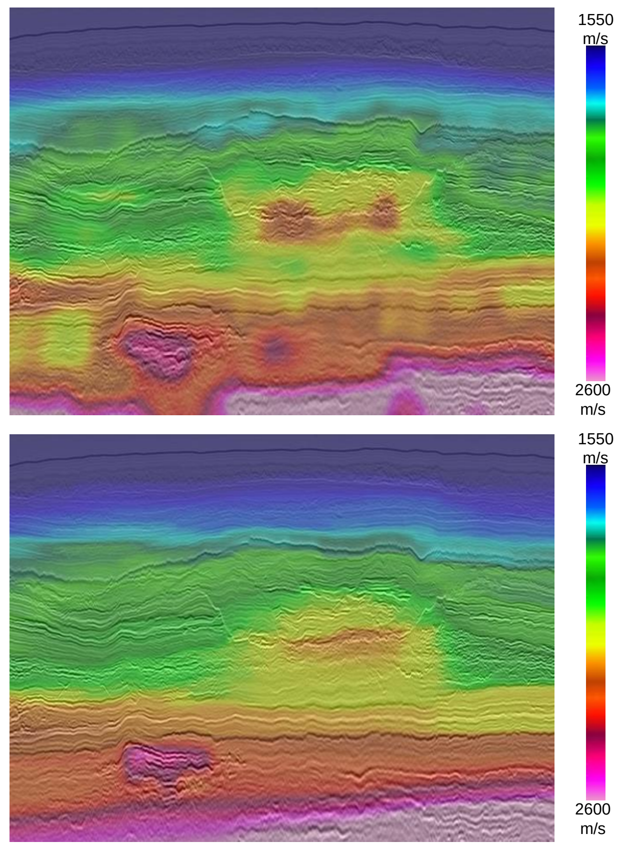

Figure 3.Legacy velocity model (top) derived using ray-tracing tomography and new reflection only FWI model (bottom). Note the improvement in stack response and simplification of the structure under the main channel feature.

Application of the results from Q tomography are shown in Figures 4 and 5. Figure 4a show the input seismic data to the visco-acoustic model building flow. Figure 5a shows a depth slice through the resulting Q model. The spatially varying

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log spectral ratio for a 50 Hz sample measured between the reference water bottom and an event below the Paleocene canyon (orange horizon Figure 4a) are shown on Figures 5b and 5c. The channel effect is visible on both the seismic and spectral ratio metrics (Figures 4a and 5b). The log spectral metric shows a strong correlation with the depth slice through the Q model. Figures 4b and 5c show the same after a Q migration using the models derived from the integrated flow. Blue arrows (Figure 4b) indicate compensated amplitudes. The log spectral ratio metric (Figure 5c) shows a consistent metric close to the desired value of 0, demonstrating that the amplitudes extracted at the orange horizon after Q migration are equivalent to the water bottom reference.

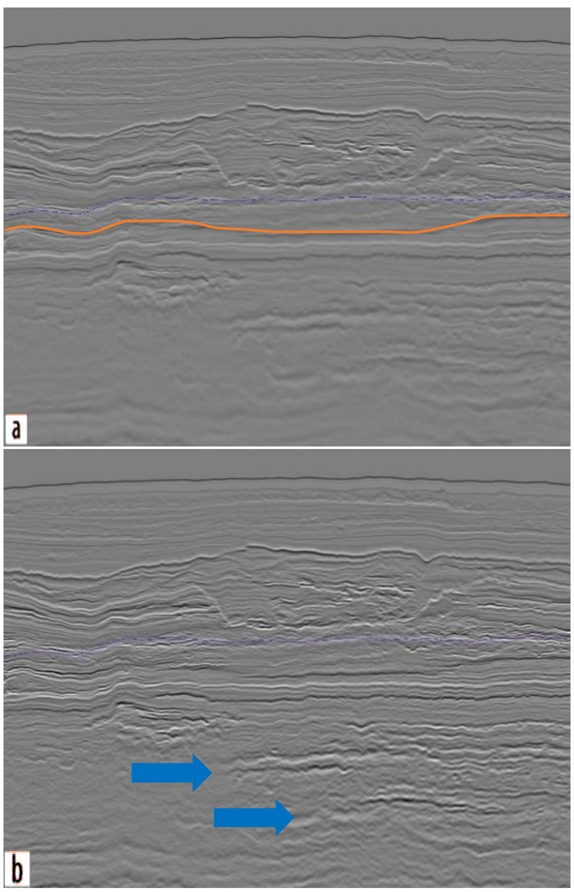

Figure 4. a) is before compensating for visco-acoustic affects, b) is after compensation. The blue arrows indicate improved event continuity, and a seismic character consistent with data outside the zone of influence of disruptive shallow channels.

In addition to the quantitative metrics, a relative impedance (RI_p) volume was generated for the legacy and final Q migrated dataset. The results are presented in Figure 6 and 7. The continuity of the impedance data is significantly improved using the integrated visco-acoustic model building flow products. The orange boxes highlight deeper Early Cretaceous fan systems that have a consistent impedance response after imaging with the models from the combined flow.

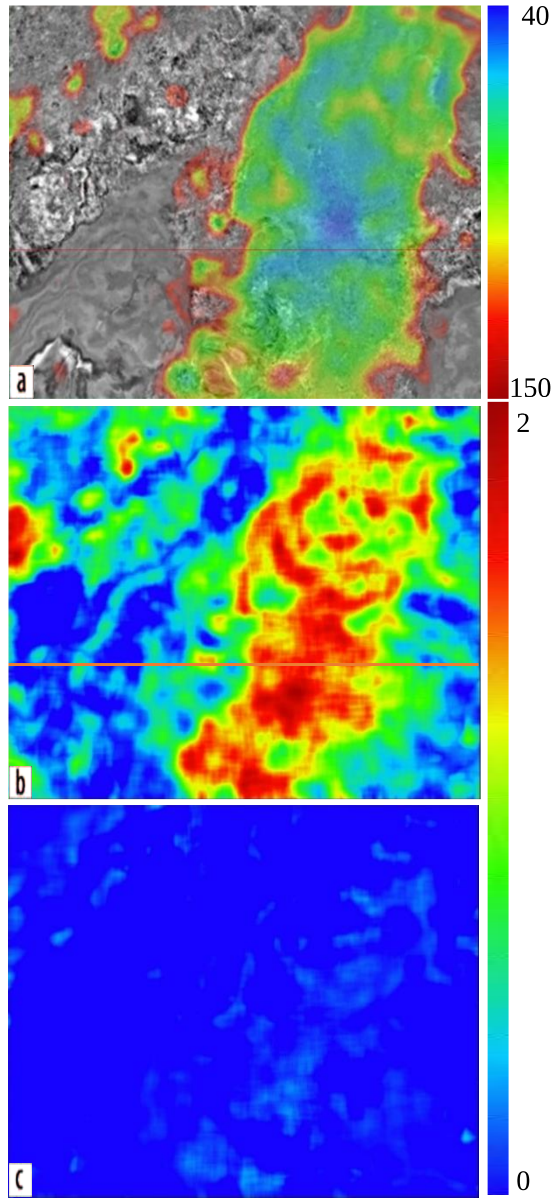

Figure 5. a) is a slice through the Q field derived from tomography. The extraction is indicated by the purple horizon (Figure 4a and 4b). b) and c) are the log spectral ratio slices for a 50 Hz sample, before and after compensating using the Q field. Note the ratio after (c) is close to an ideal value of 0. The red line in b) indicates the location of the vertical sections shown in Figure 4.

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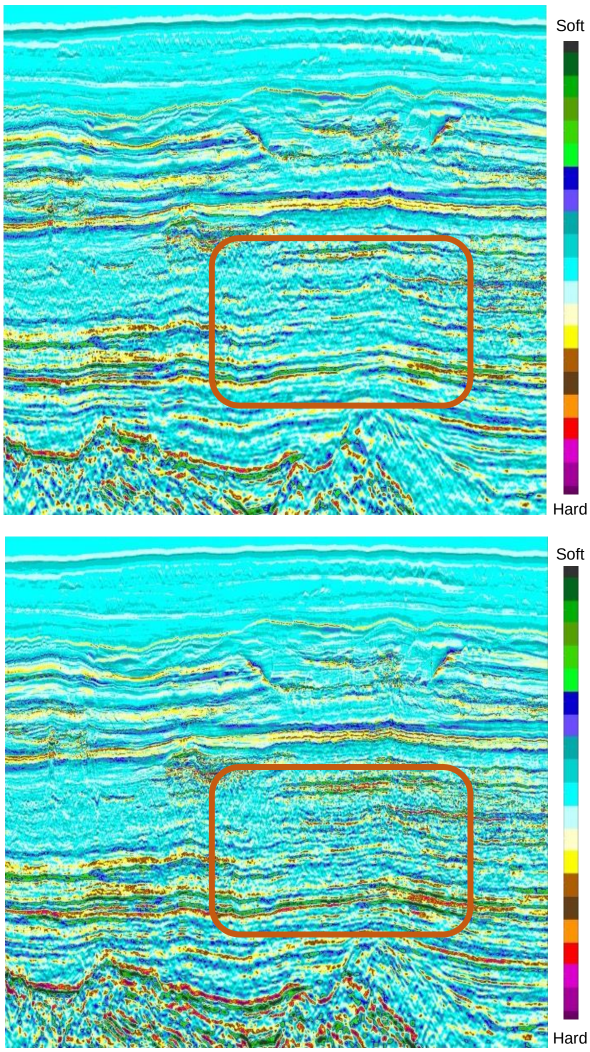

Figure 6. Legacy RI_p (top) and after full visco-acoustic model building RI_p (bottom). Note the improvement in the older Late Cretaceous fan system impedance continuity indicated by the orange boxes.

Conclusions

We have presented a case study using a pragmatic and integrated visco-acoustic model building sequence. The flow has been used to solve seismic characterization challenges of a complex set of deep water Maastrichtian and Paleocene channel systems on deeper fan systems in deep water Conjugate Margin data.

The acquisition geometry and geological setting enabled a full wavefield FWI to be used as part of an integrated visco-acoustic model building sequence. FWI determined an accurate long-wavelength velocity model, with a regional trend. In conjunction with FWI, a Q model was derived tomographically. The resulting Q migration produced a seismic image where Late Cretaceous prospectivity is more readily defined, with less structural uncertainty, and higher amplitude fidelity.

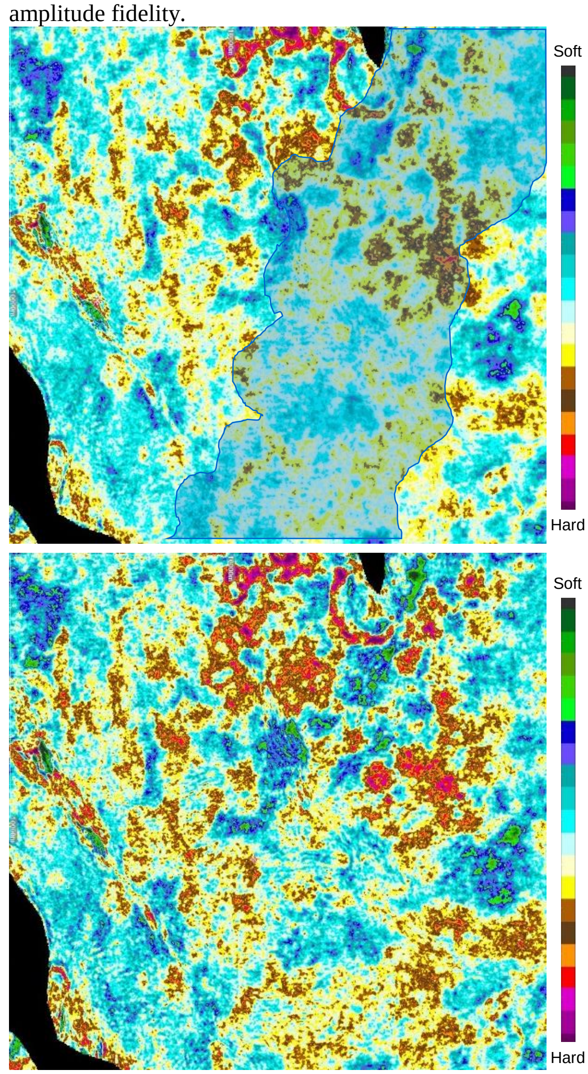

Figure 7. Legacy RI_p (top) and after full visco-acoustic model building RI_p (bottom) for a deep extraction from a Late Cretaceous sequence. The outline of the base of the Paleocene canyon is overlain on the top image.

Acknowledgements

We thank PGS for permission to present this paper and to publish the results. We thank Stuart Fairhead, Alejandro Valenciano and Nizar Chemingui for helpful discussions.

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