

GABON OFFSHORE - NEW TECHNOLOGY ENHANCING IMAGING OF COMPLEX SUBSURFACE IN GABON

P. Gabrielli¹, S. Drummie¹, E. Kaszycka¹, S. Thompson¹, Y. Zhan¹, R. Hover¹, S. Mannem¹,
M. Ubik¹, N. Morandini¹, P. Upadhyay¹, B. Bosbach¹, M.S.B. Sulaiman², C.L. Slind²

¹ CGG; ² PETRONAS

Summary

Offshore Gabon has several challenges for seismic exploration. The major difficulty is obtaining a detailed and accurate velocity model. Complicated salt structures with overhangs, variability within the salt and carbonate rafts with Karst features pose difficult challenges to conventional velocity model building. Moreover, these introduce illumination issues which are not addressed by traditional migration. This is particularly important in the pre-salt areas where the target generally lies.

With this paper we show how the recent technological advances in velocity model building through Full Waveform Inversion (FWI) and particularly Time-Lag FWI (TL-FWI), followed by imaging through the Least-Squares (LS) migration have provided a step change improvement in the pre-salt image of narrow azimuth data acquired in the West African Atlantic margin of Gabon.

To overcome cycle-skipping and amplitude discrepancy between synthetic and recorded data in the presence of sharp velocity contrasts and large scale geo-bodies, typical for Gabon context, we propose the use of a robust FWI cost function like the one employed in TL-FWI. The alignment of the resultant estimated velocity model with the geology of the margin allows the generation of considerable imaging uplifts.

Additionally, the LS migration mitigates the noise generated by the migration operator and illumination deficiencies.

Introduction

The data utilized in this study comes from a large exploration survey acquired in 2014/2015, and processed in 2016 (Gabrielli et al. 2016, Twigger et al. 2016). Intervening subset studies have given incremental improvements, but there were still velocity model issues that could not be resolved by the technology available at the time.

The main obstacle to resolve the remaining issues were the limitations of conventional tomography and the inability of least squares full waveform inversions to handle the problems posed by the complicated salt and carbonate structures. This study shows that the use of Time-Lag FWI (TL-FWI), and Least-Squares (LS) migration overcomes these issues, and provides a step change uplift in the final result.

Geology and background

The South Gabon Basin is a continental passive margin with post-rift sediments that are extremely deformed by gravitational gliding and contemporaneous halokinesis. In the north-east portion of the survey there is an upslope extensional domain with normal faulting where thin salt, salt pillows and carbonate rafts (turtleback structures) dominate the area. The deep-water offshore area in the south-west of the survey is a downslope compressional domain with reverse faulting, tilted salt diapirs and complex extruded salt structures enhanced by the gravity driven system. A transitional domain joins the extensional and compressional domains with straight up, vertically developed, salt diapirs and local welds.

Apart from the usual problems posed by salt and carbonates, such as the limited penetration of the diving waves due to high velocity contrast, there are also other concerns related to mini sedimentary basins, which can extend longitudinally. These are known to cause illumination problems for narrow azimuth surveys and to generate additional difficulties for conventional tomography.

The data used in this study is a 3,700 km² subset from a larger CGG Multi-client survey (25,000 km²) data acquired in 2014/2015 in offshore Gabon, with a broadband variable-depth streamer approach (Soubaras, 2010). The whole survey was acquired using a narrow azimuth (NAZ) setup with a 10 km streamer length.

Prior to the current 2019 processing, the survey had been processed through a comprehensive state of the art sequence available in 2015/2016 which included: 8 Hz conventional diving wave FWI to update both velocity and anisotropy, multi-layer tomography which included an extra anisotropy update, high definition tomography to delineate the carbonate layers, structurally constrained tomography to correct distortions in the top of the pre-salt sequence caused by mini sedimentary basins, followed by a pre-salt gather scanning tomography. As previously mentioned, other intervening studies were performed in 2017 and 2018 on different areas, both showed additional incremental improvements in the PSDM velocity model and the subsequent image, but still some imaging issues remained at the pre-salt level, such as the continuity of reflectors, which need to be fully resolved.

In the 2019 re-processing, model building was started with conventional tools, followed by TL-FWI, which gave the biggest uplift in the velocity interpretability and structural continuity compared to the legacy result. Both RTM and Kirchhoff imaging results have been generated. The Kirchhoff output was enhanced by leveraging the LS migration method in order to give a further improvement over previous results. Both TL-FWI and LS had been developed and applied successfully in several projects since the processing of the original 25,000 km² project, but had not yet been applied on projects involving data from offshore Gabon.

Methodology – Time-Lag FWI and least-squares migration

During 2019/2020 the aforementioned 3,700 km² portion of the larger survey had a focused velocity model building and imaging exercise performed on it.

The initial velocity model was a combination derived from the previous models created in 2016 and in the 2018 re-processing. On the top of the initial model a conventional FWI using diving wave was run up to a frequency of 8.5 Hz. Due to the salt and carbonates structures and their associated velocity contrasts, the penetration of this FWI was limited to above the salt and carbonate layering. Including reflections in this least squares FWI inversion was not beneficial because of the amplitude discrepancy between synthetic data and recorded data. Following a further general long wavelength tomography, which retained the FWI detail, the salt geometry was redefined using RTM imaging and, with this new salt geometry, a complete tomography update was run for the sediment and carbonate layers. The attempts to update the salt velocity via tomography were hindered by the lack of usable picks within the salt, and the use of the picks around the salt did not give an acceptable model.

At this stage a new flavour of FWI was performed: Time-Lag FWI. TL-FWI uses a cost function proposed by Luo and Schuster (1991) with a frequency-dependent time-window for travel-time measurements and a cross-correlation coefficient-based weight function to promote travel-times with high quality. The use of this cost function has been shown by Zhang et al. (2018) to be an appropriate and robust method to update salt models, overcoming the two major issues that cause conventional FWI to fail: cycle-skipping and amplitude discrepancy between synthetic and recorded data. TL-FWI allowed also the use of reflections to update through the carbonate and salt into and across the pre-salt section without encountering the limitation due to the amplitude discrepancy that affects the least squares based cost function used in conventional FWI. From well information it was known that there is a fast-slow-fast trend bounded by the layers in the carbonate. The conventional FWI and tomography only gave a model which tentatively and sporadically correlated with this carbonate layering as seen in Figure 1a. Figure 1b shows TL-FWI model which strongly correlates with the carbonate layering.

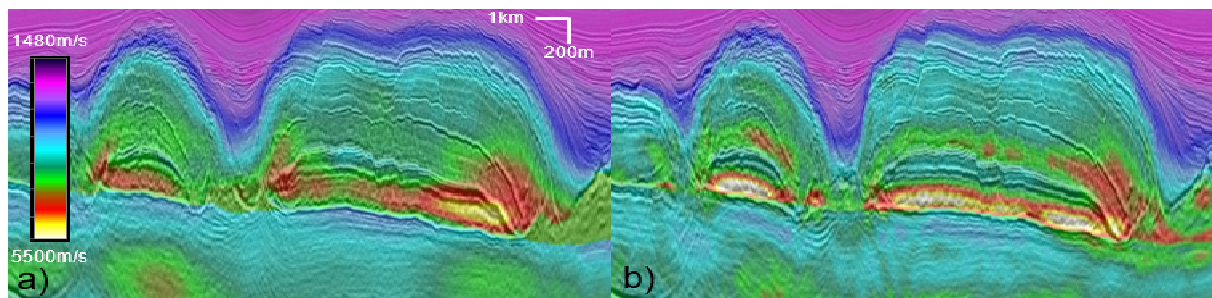


Figure 1 TL-FWI results on turtleback carbonate structure. (a) Input model where the velocity trend was originally inserted with High Definition tomography, (b) TL-FWI results where the layering and contrast within the carbonate bodies are clearly delineated.

Regarding the salt bodies, the TL-FWI picked out areas where salt interpretation was less certain, and drove some alterations to the interpretation of the salt geometry. The salt in this area is thought to be not completely clean, containing variations in composition and velocity. In Figures 2a and 2b it can be seen how TL-FWI inserted a significant amount of velocity variation within and around the salt, which seemed to agree with this salt/dirty salt presumption. The updated velocity model produced an improved imaging especially around the salt bodies and along the base salt/base carbonate area as displayed in migrated sections in Figures 2c and 2d.

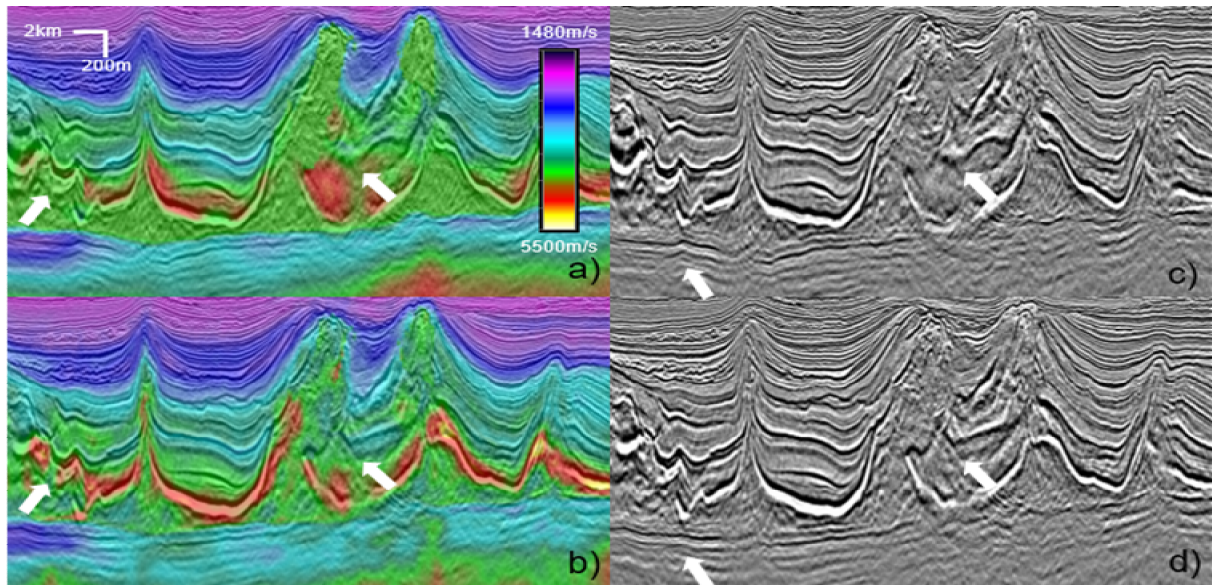


Figure 2 TL-FWI velocity update with migration comparison. TL-FWI (b) captures a significant amount of detail around and within the salt compared to the input model (a). All these details help to improve the imaging around and below the salt (d) compared to the initial image (c).

Other areas showed much better continuity in the pre-salt, resolving conflicting pre-salt events (see Figure 3) in a zone crucial for exploration.

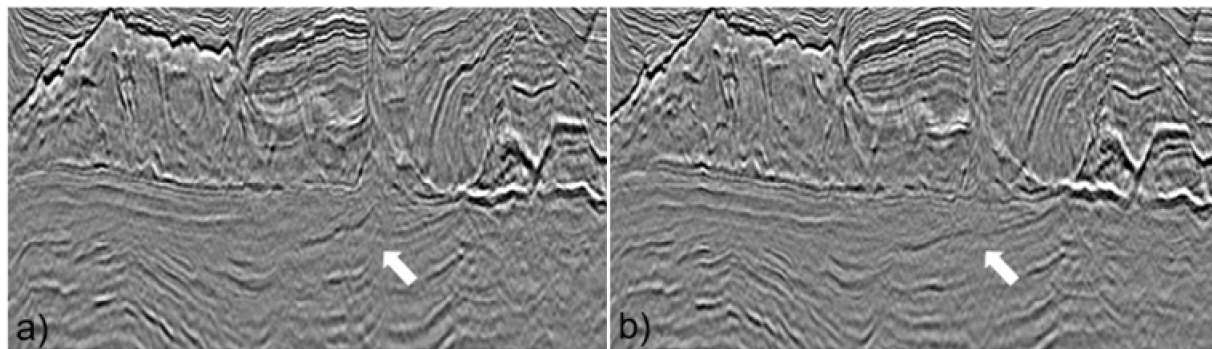


Figure 3 TL-FWI velocity produced an uplift in imaging in the pre-salt section. (a) Section migrated with velocity model without TL-FWI, (b) section migrated with velocity model with TL-FWI included.

The velocity model derived by TL-FWI was used to perform the LS migration. LS migration aims to mitigate the standard migration's issues of operator noise and illumination deficiencies. In the LS flow a model of reflectivity is approximated by deriving an inverse Hessian filter, a matching filter which makes use of the relationship between migration and re-migration at each image location (Casasanta et al. 2017).

Figure 4a shows a Kirchhoff stack image where crosscutting noise is affecting the continuity of post- and pre-salt reflectors and fractured carbonate structure, these cannot be easily recovered with post migration processing as the dips of the crosscutting noise can coincide with the primary signal. The area highlighted by the box shows a pre-salt section affected by illumination issue caused by the salt bodies. Figure 4b shows how the use of LS migration improves event coherency, reducing noise and producing a more balanced illumination when compared to standard Kirchhoff migration, helping to identify the real fractures and faults in both the carbonate and the pre-salt target sands.

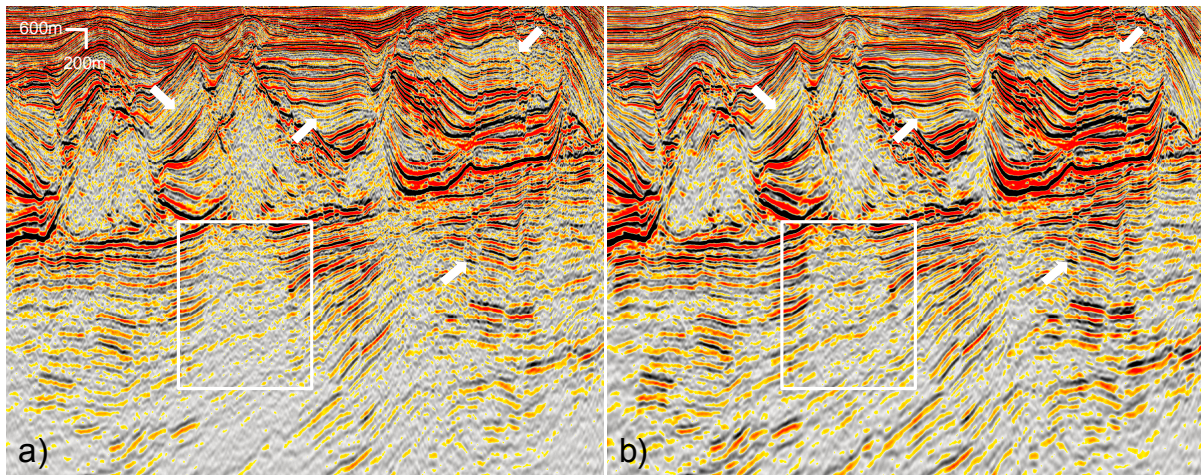


Figure 4 Kirchhoff migration (a) and Kirchhoff Least-Squares migration (b). The LS section shows improved coherence events and reduced noise levels in the post-salt sediment, carbonate (arrows) and pre-salt section together with the recovery of illumination deficiency in the pre-salt section (box).

Conclusions

We have described and shown that Time-Lag FWI has been able to derive a velocity model which is more closely aligned with the geology, providing considerable uplift to the imaging of the target zones. We have also shown that Least-Squares migration can improve the continuity of the pre-salt structure of the final image. Both of these technologies have led to a greater ability to interpret and decipher the notoriously difficult offshore Gabon pre-salt structures.

Acknowledgements

We thank CGG and PETRONAS for permission to publish this work and CGG's Multi-Client & New Ventures business line for their kind permission to show the Gabon dataset.

References

- Casasanta, L., Roberts, G., Perrone, F., Ratcliffe, A., Poole, G., Wang Y. and Xie Y. [2017] Practical benefits of Kirchhoff least-squares migration deconvolution. *79th EAGE Conference and Exhibition, EAGE, Expanded Abstract*.
- Gabrielli, P., Jouno, F., Xiao, B., Iliev, I., Page, C., Schouten, R., Thompson, S., Cowley, j. and Ratcliffe, A. [2016] Velocity model building offshore Gabon – a vast step into the unknown. *PETEX / PESGB - Petroleum Exploration Society of Great Britain*.
- Luo, Y. and Schuster, G. T. [1991] Wave-equation travelttime inversion. *Geophysics*, **56**, 645–653
- Soubaras, R. and Dowle, R. [2010] Variable-depth streamer – a broadband marine solution. *First Break*, **28**(12), 89–96.
- Twigger, L. Schouten, R., James, G. and Firth, J. [2016] Seismic efficiency on a vast scale – a case study from offshore Gabon. *First Break*, **34**(5), 83–88.
- Zhang, Z., Mei, J., Lin, F., Huang, R. and Wang, P. [2018] Correcting for salt misinterpretation with full-waveform inversion. *88th Annual International Meeting, SEG, Expanded Abstracts*, 1143–1147.