Tu N118 05

Fault Shadow Removal over Timor Trough Using Broadband Seismic, FWI and Fault Constrained Tomography

Y. Guo* (CGG), M. Fujimoto (INPEX), S. Wu (CGG) & Y. Sasaki (INPEX)

SUMMARY

Thrust-complex imaging in the Timor Trough suffers from fault shadows due to strong lateral velocity variation. We demonstrate a new workflow to tackle this. Broadband seismic data were acquired with high signal-to-noise ratio for the low frequency content. With broadband input, FWI derived a better velocity model in the shallow water thrust area where the reflection tomography has limitations. Compared to conventional tomography which has difficulty in addressing the sharp velocity boundary properly, fault constrained tomography (FCT) uses the interpreted fault planes as constraint for inversion. FCT also benefited from the better low frequency content in the broadband data which provided better imaging penetration in the severe fault shadows. Broadband seismic and depth imaging with FWI and FCT made a step change in the image quality to improve the understanding of the thrust-complex structures and the underlying potential reservoirs.

Introduction

This case study is from a project in East Indonesia which was carried out from 2013 to early 2014. The block is located in the Timor Trough which was developed by the subduction between the Sunda and Australia plates. The target Mesozoic layer (green and yellow layers shown in Figure 1) is buried under the fold and thrust belt of thick Cenozoic carbonates developed in the foreland of the collisional zone, as shown on Figure 1. Legacy seismic image has severe fault shadow problems due to strong lateral velocity variation and poor low-frequency content of the data which limited imaging penetration in the thrust area. These are the major challenges to overcome in order to better understand the petroleum system and evaluate the risks of exploration target. With these goals in mind, broadband seismic was chosen for good low frequency to improve imaging penetration due to its long wavelength. Full waveform inversion (FWI) and fault constrained tomography (FCT) were then employed to resolve the velocity variation across both the shallow and deep portions, both of which benefit from the extended bandwidth of broadband seismic.

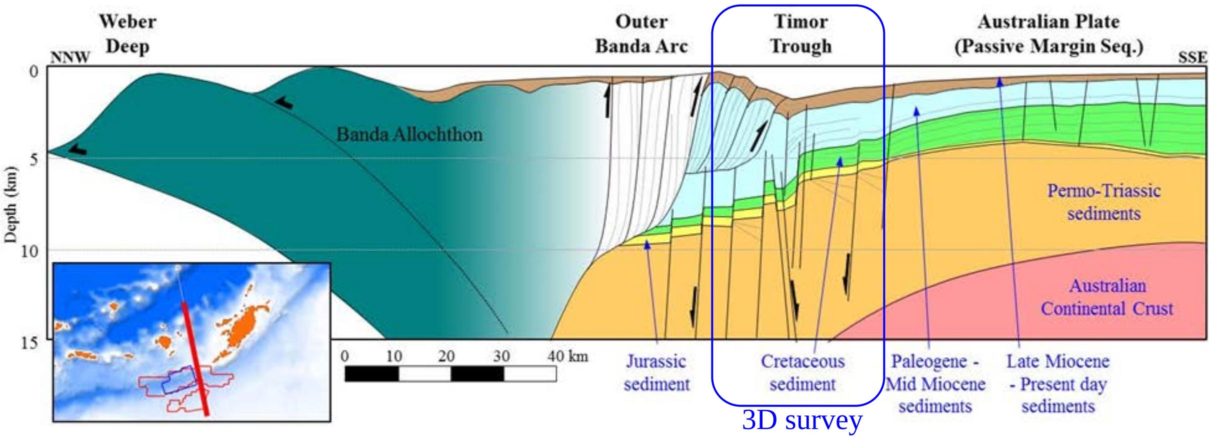

Figure 1 *Schematic SSE to NNW regional section across the study area. The Mesozoic target is indicated by the green and yellow layers. The blue box indicates the approximate coverage of the 3D seismic with respect to the structure. The inset map shows the orientation of the schematic cross section.*

Broadband Seismic

3D broadband seismic data was acquired in early 2013. A cable length of 7050 m was selected to image the deep target using a variable-depth profile from 6 m to 50 m to provide optimized ghost diversity (Soubaras et al., 2010). Ghost Wavefield Elimination (GWE) was then applied pre-stack to effectively remove the receiver ghost (Wang and Peng, 2013) and to provide a much wider bandwidth with enhanced high- and low-frequency content.

A pre-stack time migration (PSTM) stack of the broadband data and frequency panels are shown on Figure 2. As expected, the broadband variable-depth streamer data exhibit a high signal-to-noise (S/N) ratio even for very low frequencies (2-4 Hz). It is also observed that the 2-8 Hz energy penetrates to very deep targets, while higher frequencies are absorbed more at the target level. Although the PSTM image is quite distorted near the fault and at the target level (highlighted area on Fig 3), it’s expected that the presence of strong low frequency content in the data will help obtaining a much better pre-stack depth migration (PSDM) result.

FWI

In the shallow water thrust area, due to the steep dip of the reflectors, the residual curvature picking in common image gather (CIG) can be extremely challenging. The reflected energy appears limited only to the near offsets, so reflection tomography gives a poor velocity update. Diving wave tomography was also tested but it did not update as deep as would have been expected from the actual diving wave depth of penetration, probably because the information used (first break time only) was not enough for this complex under-determined problem.

FWI makes use of mainly transmitted energy with full waveform and does not require CIGs, so it can produce much more accurate velocity models. Since the initial model used as the input to FWI is not accurate in our case, low frequency energy is critical for FWI to avoid cycle skipping. In this case study, good low frequency content and the long offset information (up to 7 km) contained in broadband data made FWI robust in spite of a poor initial velocity model in the shallow water thrust area.

Figure 3 compares the initial and FWI velocity model and PSDM stack. The FWI velocity model has a much higher resolution and matches the folded structures in the thrust zone very well. As pointed by the left arrow, the seismic image is over-migrated before FWI but more focused after FWI. Near the middle arrow, structures cross each other before FWI and move to the correct position after FWI. As indicated by the right arrow, the folded carbonate and sediment layers are much sharper and less distorted after FWI.

Fault Constrained Tomography

The CIG S/N ratio is quite low within fault shadows if the data is migrated with a smooth initial velocity. Residual curvature picking is very challenging, but it's also very critical for tomography to give the correct updates. With broadband data, the low frequency reflection has better penetration and less distortion due to the longer wavelength. Therefore more reliable residual curvature can be picked for tomography using this broadband dataset.

The initial velocity model may contain large errors in the area around the faults. Conventional velocity tomography is not able to solve the large velocity errors due to internal regularization used to stabilize the inversion (Zhou et al., 2003). FCT was firstly presented by Birdus (2007). It updates the velocity only near the fault planes and tries to restore the velocity contrast across the fault.

In this case, the fault was used to constrain tomography regularization. Major faults were still supplied to tomography together with residual curvature picks. The velocity update was not limited near fault planes but done for whole tomographic layers. The internal tomographic regularization was also modified to honor the velocity contrast across the faults. So FCT tolerates low S/N ratio CIG within fault shadow because it can use bigger internal regularization to stabilize the inversion, but still keeping the velocity contrast sharp across the fault.

The result after three tomographic iterations is shown in Figure 4 (left). An interval velocity model in depth with good horizontal and vertical resolution has been achieved but a strong fault shadow can still be seen in the corresponding PSDM image. In Figure 4 (right), several major faults are picked and used in FCT, and as a result, the velocity model has much better resolution across the fault. In the corresponding PSDM image, the fault shadow effect is much reduced and even secondary faults beneath the major fault are clearly imaged.

Results and Conclusion

The PSTM image is stretched to depth domain with a smooth depth-velocity function for comparison with PSDM in Figure 5. With velocity from FWI and FCT, the PSDM image shows significant improvement compared to PSTM in this thrust-complex geological situation as shown in Figure 5. The PSDM image provides better-focused events and more reasonable geological structures which are distorted in the PSTM image. This will help to reduce the structural uncertainty (particularly in the deeper section) and allow a better understanding of the petroleum system of this frontier exploration target.

Fault shadows have always been a challenging problem, especially in thrust-complex areas. In this case study, broadband variable-depth streamer acquisition, FWI and FCT made a step change in addressing the fault shadow problem.

Acknowledgements

The authors thank INPEX, Pertamina Hulu Energi, SKKMIGAS, MIGAS and CGG for the permissions to publish the paper. Also we would like to thank the other QC and processing team members for their great effort.

References

Soubaras, R. and Dowle, R [2010] Variable-depth streamer – a broadband marine solution. *First Break*, **28**(12), 89-96.

Wang, P. and Peng, C. [2013] Premigration deghosting for marine streamer data using a bootstrap approach in Tau-P domain. *83rd SEG Annual Meeting*, Expanded abstracts, 4221-4225.

Zhou, H., Gray, S.H., Young, J., Pham, D. and Zhang, Y. [2003] Tomographic Residual Curvature Analysis: The Process and its Components. *73rd SEG Annual Meeting*, Expanded abstracts, 666-669.

Birdus, S. [2007] Removing fault shadow distortions by Fault Constrained Tomography. *77th SEG Annual Meeting*, Expanded abstracts 3039-3043.

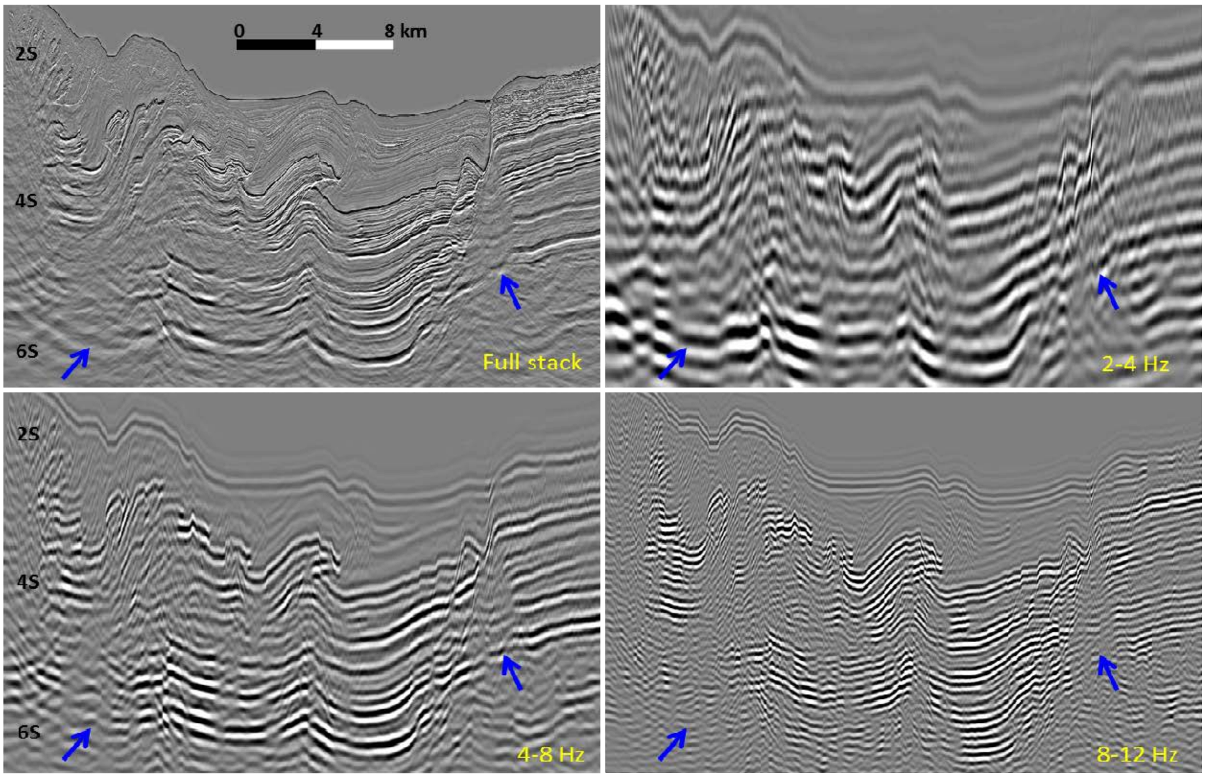

Figure 2 *PSTM of the broadband seismic data with full stack and selected frequency panels.*

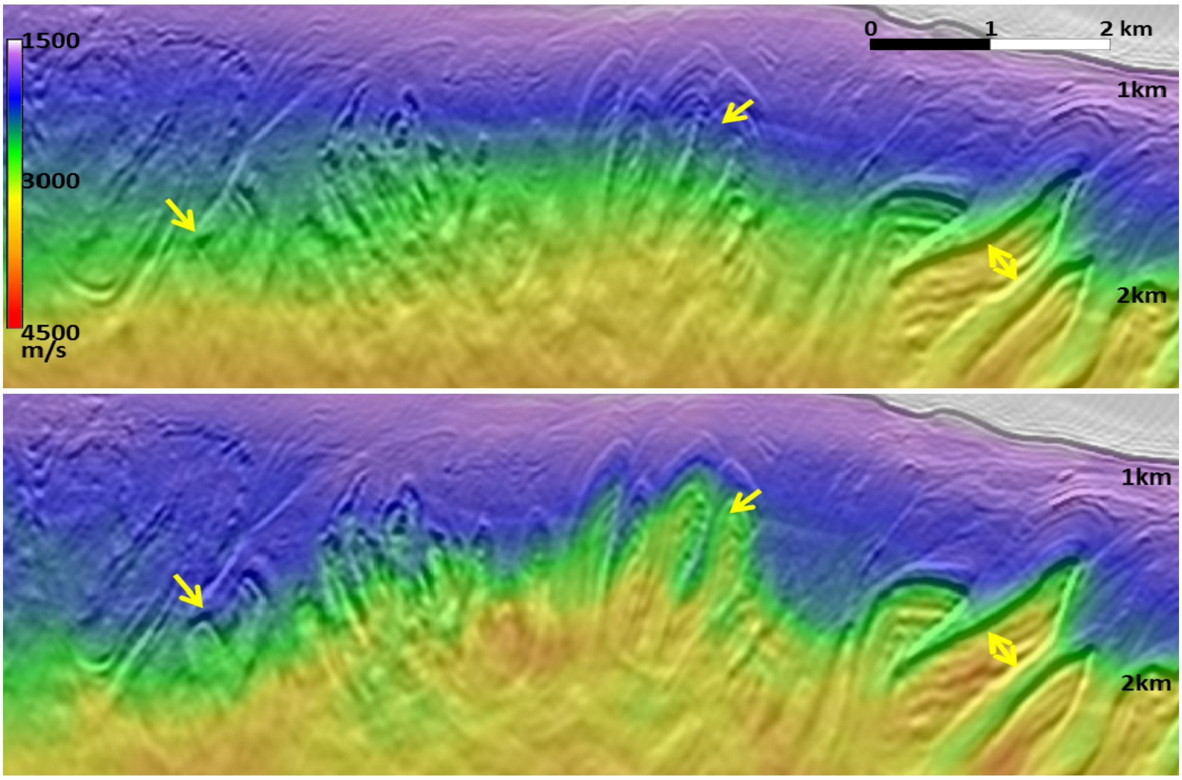

Figure 3 *Top: velocity and corresponding PSDM stack after 3 tomographic iterations used as the input to FWI, and bottom: after FWI.*

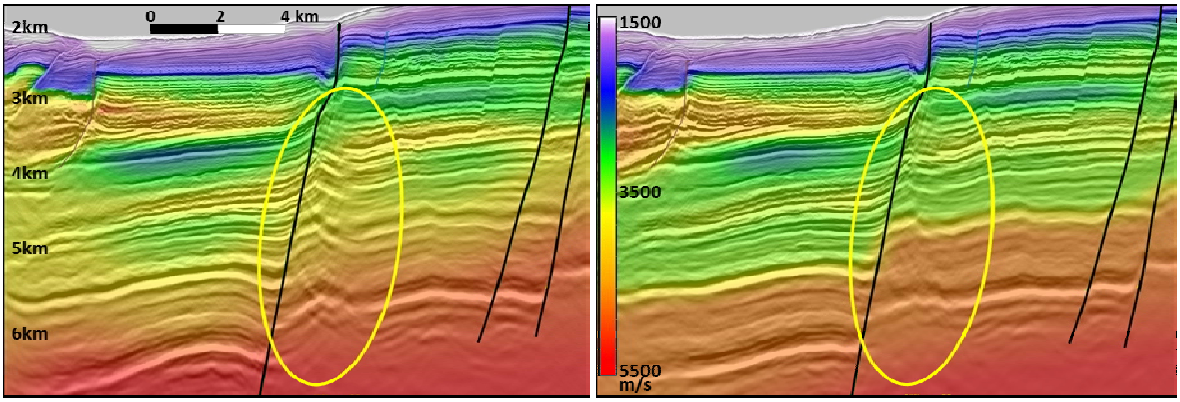

Figure 4 *Velocity and corresponding PSDM stack across the fault. Left: before FCT, right: after FCT.*

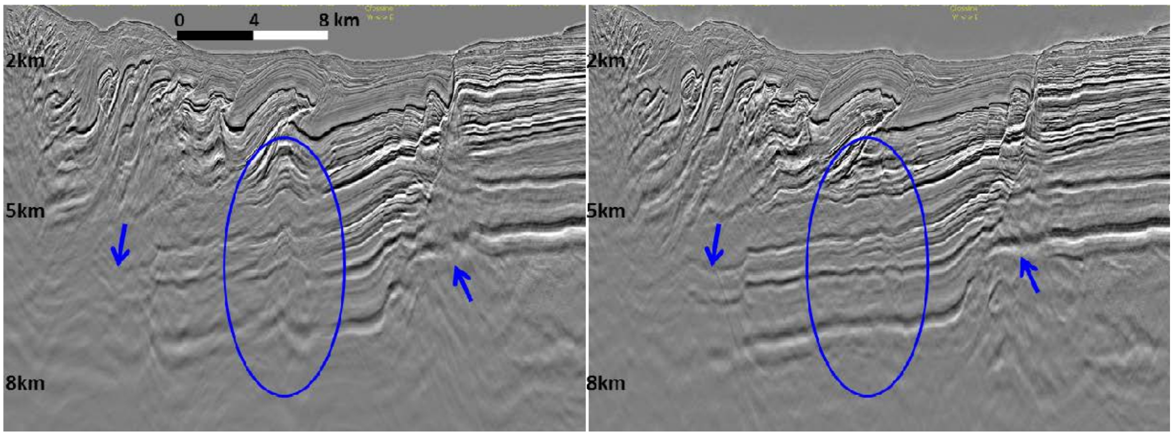

Figure 5 *Left: PSTM stack stretched to the depth domain, and right: PSDM stack.*