High resolution velocity model building over the Hoop Fault Complex.

M.J. Hart (TGS), O.A. Adewumi (TGS), C. Lang (TGS), G. Hilburn (TGS) & G. Rodriguez (TGS)*

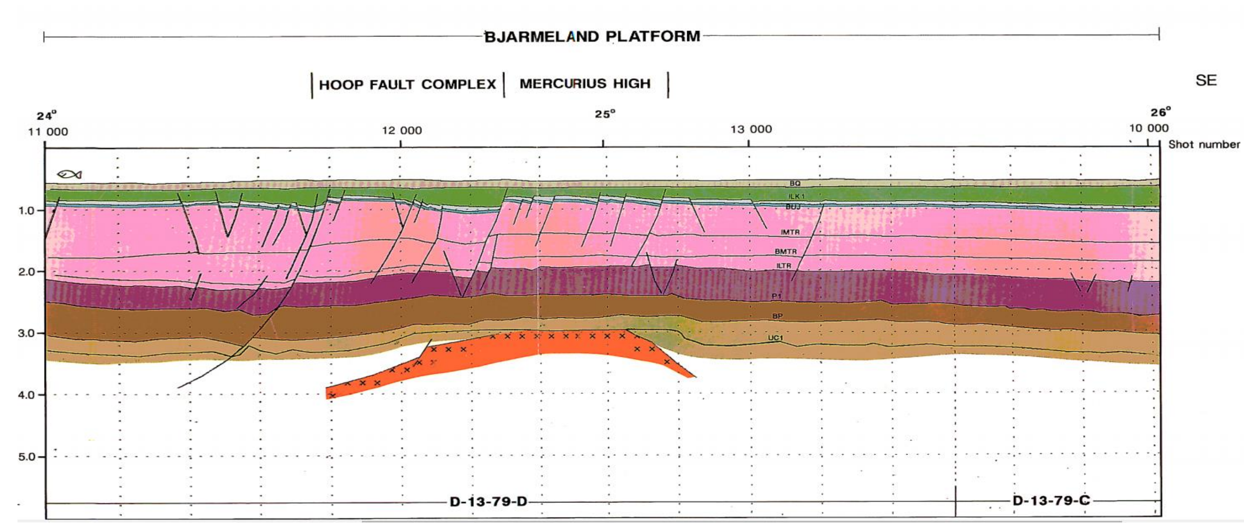

Figure 1 Hoop Fault Complex – geology schematic (Gabrielsen et al., 1990).

Summary

The Hoop Fault Complex presents a significant imaging challenge, most notably where large velocity-induced sags are evident in the footwall of the major areal extensional faults. These sags arise from large velocity contrasts across the fault. Resolving the velocity contrast is made more challenging by illumination issues resulting from the narrow single azimuth of acquisition. Previously, this velocity complexity had been addressed using both fault and horizon-constrained tomography. Though largely successful, both of these approaches require subjective interpretation.

We present an objective data-driven approach to resolve fault sags, which generated a more geologically realistic model of the Hoop Fault Complex than previously obtained via conventional tomography. Multiparameter offset-dependent picking was applied to model the complex moveout associated with this structure, in place of single parameter residual curvature picks. The tomographic update was then constrained by an image-guided inversion. This resulted in a more geologically plausible velocity model, where layering and faulting are better honoured by the inversion update.

Introduction

Since TGS' acquisition of 2770 km^2 of narrow azimuth data during 2009, the Hoop Fault Complex, which divides the Loppa High and Bjameland Platform in this region of the Norwegian Barents Sea, has presented a significant imaging challenge. A schematic of the geology present in the area can be seen above in Figure 1. This highlights the main NE-SW extensional faults of the Hoop Graben, along with a shallow strike-slip component. Large fault sags were immediately evident within the footwall of the major NE-SW trending extensional fault in the survey area, as well as numerous smaller distortions associated with complex faulting within the high velocity Lower Cretaceous overburden. These sags were seen to be highly prevalent in the prospective Triassic Top Kobbe formation.

In their 2013 investigation into the fault shadows causes, Hardwick and Rajesh (2013) demonstrated they resulted from poor illumination due to acquisition azimuth, which is orthogonal to the major extensional fault of the Hoop Graben. This agreed with earlier studies into such fault shadow phenomena by Fagin (1996) and later Birdus (2007). They concluded that to avoid such fault-related sags in areas of more than one major structural trend, multiazimuth acquisition would be required.
Prior to this study, Rodriguez et al. (2011) attempted to solve this fault shadow problem in depth, using a number

of different methods. Initially, a conventional gridded tomography approach was attempted, starting from a smoothed time migration velocity volume, with a shallow 1550 m/s interpreted Quaternary horizon in the shallow. Two passes of tomography were carried out between the Base Quaternary and Base Permian. The results showed an overall improvement in imaging, but failed to resolve the problem of the fault sags at Top Kobbe. Fault-constrained tomography was then applied, where velocity models were separated by an interpreted fault and updated independently (Birdus, 2007). This produced some improvements, but the fault sags were still evident.

A solution of sorts was found in Interpretation Driven Modelling or horizon-constrained tomography (Rodriguez et al, 2011). Here the tomographic update was constrained by the interpretation of a realistic geological horizon and incorporated the difference between this and the current picked horizon into the model building.

This combination of fault and horizon-constrained tomography was successful in reducing the fault sag, as can be seen in Figure 2c below. Manual interpretation of the faults and affected horizons were required for this approach to work. Although results were sufficient, a data-driven approach was desirable for instances where an interpretation may not be readily available.

As such, we decided to reinvestigate this fault sag problem using a higher resolution and more geologically consistent approach to tomographic model building. Offset-dependent picking and image-guided tomography should allow us to produce a higher resolution model and subsequently better resolve these problems (Hilburn et al., 2014b), despite the low illumination limitations of the current acquisition.

Offset dependent picking

Conventional curvature picking, where a best-fit parabola or hyperbola are used to approximate residual moveout, can often be sufficient for the purposes of velocity model building in areas of structurally simple, largely isotropic geology. For more complicated structures, such as here in the Hoop Fault Complex, fitting a simplistic best-fit polynomial to the data may actually cause the resulting image to deteriorate.

Our offset-dependent picking treats each gather as a 2D plot and, by calculating its displacement field, attempts to find the optimal paths through each gather (Hilburn et al, 2014a). This results in picked residual curvatures with multiple turning points, as seen in Figure 3b. The standard polynomial curvatures can be seen in Figure 3a.

Horizon-guided picking was later adopted, in order to attain a more structural update.

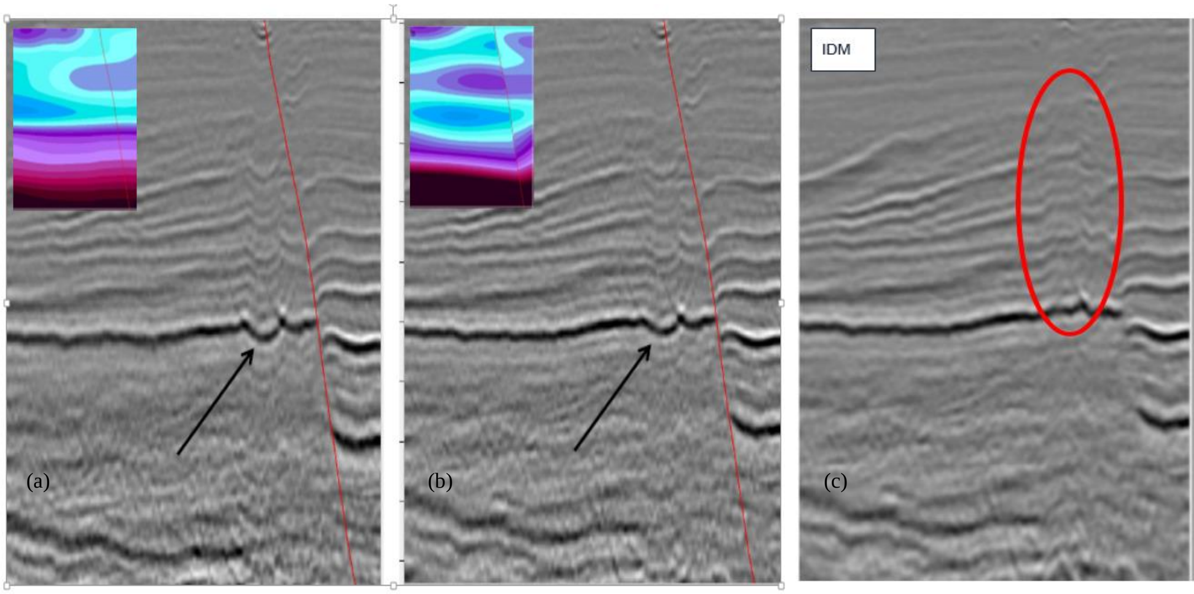

Figure 2: Results of (a) Conventional tomography, (b) fault-constrained tomography and (c) Interpretation Driven Modelling (Rodriguez et al, 2011).

DOI http://dx.doi.org/10.1190/segam2015-5907902.1

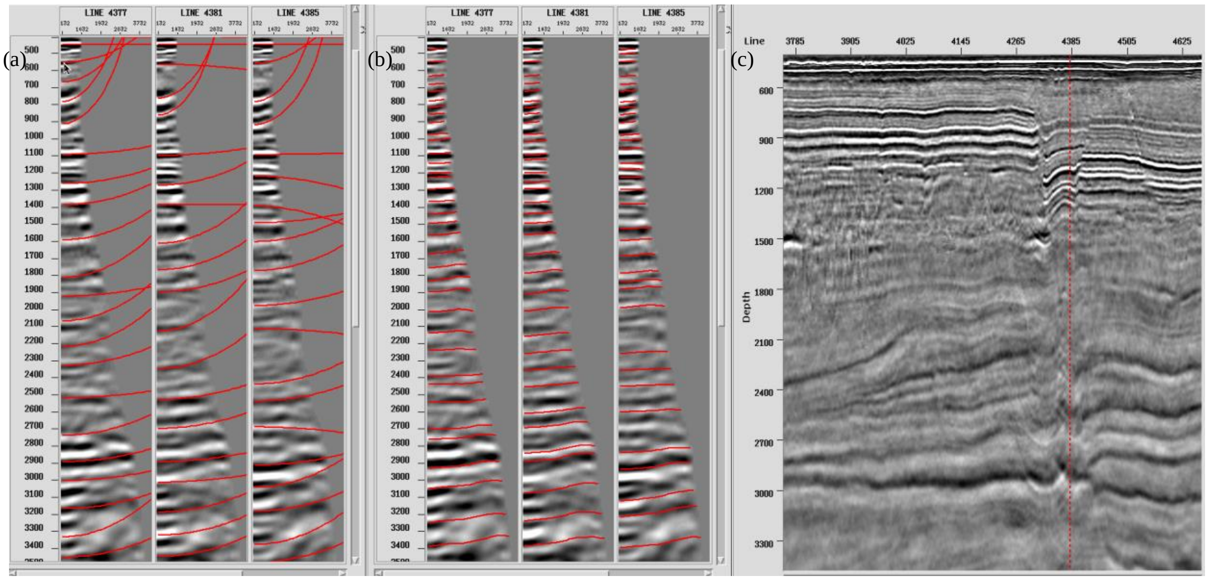

Figure 3: (a) Hyperbolic single-parameter vs. (b) multi-parameter offset dependent curvature picking & (c) stack image showing gather location.

Image-Guided Inversion

Image-guided tomography divides the update area into a sparse selection of small zones as seen in Figure 4b. During each iteration of tomographic inversion, updates are averaged within these zones and then blended along geological structures observed in the stack image, such as the large fault which is also represented in Figure 4b. This leads to the generation of more geologically realistic velocity perturbation models (Figure 4c), which should closely reflect layering and faulting better than standard grid-based tomography. It should also produce higher resolution results as the updates are interpolated along structures. Concurrent structure-oriented smoothing eliminates the need for external smoothing to remove raypath related artefacts, further increasing the resolution of the results (Hilburn et al, 2014b).

Initially, we attempted to solve between Base Quaternary and Base Permian as had been attempted with previous passes of standard tomography. The results, although showing some imaging improvements, weren't entirely resolving the sags present in the Top Kobbe.

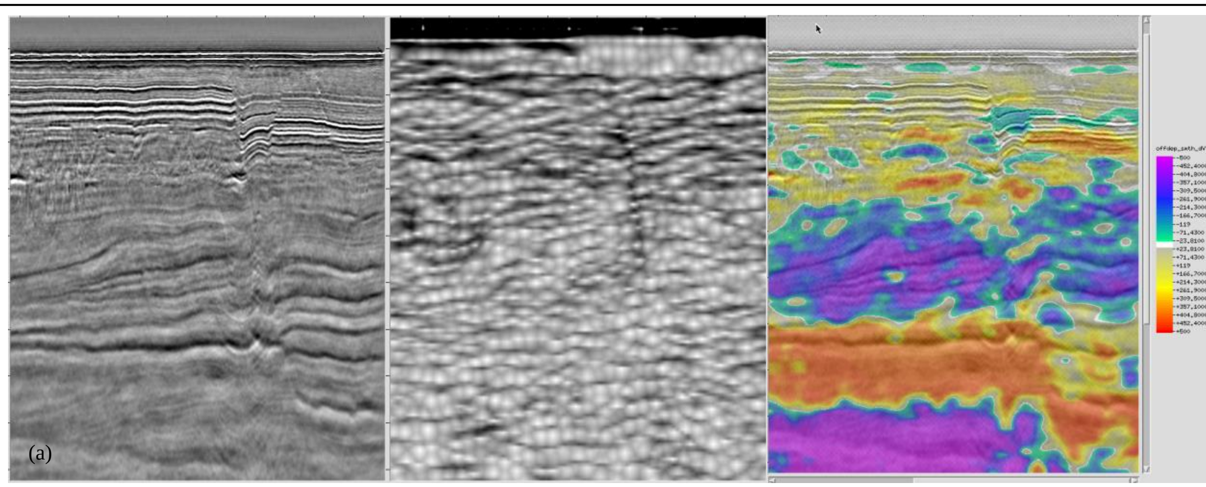

Figure 4: IGT (a) Input stack (b) update zones & (c) resulting δV model

DOI http://dx.doi.org/10.1190/segam2015-5907902.1

It was decided to try to increase the resolution of the shallow update with finer gather spacing being used by the offset dependent picking. We also adopted a more layer-based approach at this point and updated only Base Quaternary to Jurassic with the initial inversions. Subsequent high-resolution tomography passes were then extended through the Snadd and Top Kobbe to Base Permian.

Conclusions

The resulting velocity model improves imaging around the large extensional fault and elsewhere within the area, but does not entirely resolve the fault-sag issue, at least not to the same extent as previous interpretation-driven modelling updates. This supports acquisition-related illumination issues, as demonstrated by Hardwick and Rajesh (2013).

It does however provide an alternative data-driven approach, where the complex events around the fault were better represented by the nonparabolic offset-dependent picking, whilst the structural constraints of the image-guided preconditioning during tomographic inversion allowed for a more realistic geologically consistent update. When compared to data migrated with the original fault-constrained model (Figure 5a), the Triassic structures on either side of the main extensional fault have been simplified and are better focused, despite the increased complexity of the updated model (Figure 5b). A combination of both interpretive and data driven modelling would likely result in further imaging improvements.

Acknowledgements

The authors would like to thank TGS for the permission to present this work.

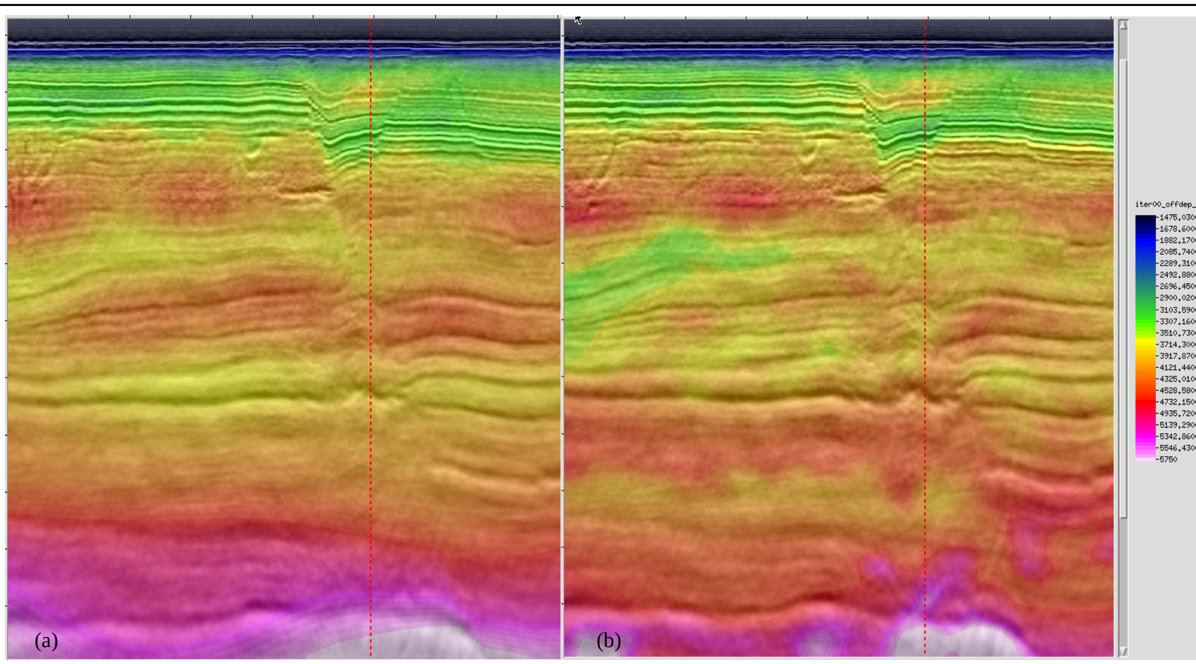

Figure 5: (a) Fault constrained vs. (b) Offset dependent picking & Image Guided Tomography

DOI http://dx.doi.org/10.1190/segam2015-5907902.1

EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2015 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Birdus, S., 2007, Removing fault shadow distortions by fault constrained tomography: 77th Annual International Meeting, SEG, Expanded Abstracts, 3039–3043.

Fagin, S., 1996, The fault shadow problem: Its nature and elimination: The Leading Edge, **15**, 1005–1013. http://dx.doi.org/10.1190/1.1437403.

Gabrielsen, R. H., R. B. Færseth, L. N. Jensen, J. E. Kalheim, and F. Riis, 1990, Structural elements of the Norwegian continental shelf, Part 1: The Barents Sea region: Norwegian Petroleum Directorate, Bulletin 6, 33.

Hardwick, A. J., and L. Rajesh, 2013, A 3D illumination study to investigate fault shadow effects over the hoop fault complex: 75th Annual International Conference and Exhibition, EAGE, Extended Abstracts, http://dx.doi.org/10.3997/2214-4609.20130422.

Hilburn, G., Y. He, F. Sherril, T. Kim, and Z. Yan, 2014a, Image-guided tomography: Structure-conforming inversion for complex overburden: First Break, **32**, 99–105.

Hilburn, G., Y. He, Z. Yan, and F. Sherril, 2014b, High-resolution tomographic inversion with image-guided preconditioning and offset-dependent picking: 84th Annual International Meeting, SEG, Expanded Abstracts, 4768–4772.

Rodriguez, G., A. Lundy, M. Hart, C. Lang, J. Cai, I. Chang, and Q. Zhang, 2011, Imaging the hoop fault complex via horizon and fault constrained tomography: 81st Annual International Meeting, SEG, Expanded Abstracts, 4025–4029.

DOI http://dx.doi.org/10.1190/segam2015-5907902.1