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Resolving the Challenges of Imaging Steeply-Dipping Reservoirs Against a Complex Salt Diapir

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Summary

The Mungo field in the North Sea is both structurally and stratigraphically complex - salt diapirism has resulted in large dips on the Palaeocene and Cretaceous reservoirs that drape the flanks of the salt intrusion. To improve the imaging, two adjacent ocean bottom surveys were conducted between 2010 and 2011. Despite improvements over the legacy towed streamer data, interpretational challenges, particularly with respect to the salt geometry, remained. Overcoming these challenges was crucial for field development. To achieve the required improvement in imaging within the project's short timeframe, a high degree of technical content had to be adopted to provide early access to a consistent, demultipled dataset that would be used to update the velocity model. Key challenges were the highly channelized nature of the near-surface, the poor ties of the highly deviated wells to the existing seismic data, contamination of the target interval by interbed multiples and poor salt flank imaging. These objectives were achieved by employing a robust pre-processing sequence, including up-down deconvolution, along with an iterative approach to the velocity model build, utilising GWI, FWI, high-density tomography and anisotropic information derived from the PS data.

Resolving the challenges of imaging steeply-dipping reservoirs against a complex salt diapir

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Introduction

The Mungo field is located at the border of blocks 22/20 and 23/16a in the East Central Graben of the North Sea. Structurally, the field is a pierced salt diapir with flanks that dip at an average of 60 degrees and increase to a maximum of around 85 degrees. The reservoir comprises Palaeocene and Cretaceous aged sandstone and chalk, which onlap the salt. In order to improve the imaging of the steeply dipping reservoir, two separate high-density Ocean Bottom Cable (OBC) surveys were conducted between 2010 and 2011, each acquired over half of the field. Due to contractor availability, the surveys had different OBC equipment deployed on the seafloor and were shot with different sources. In addition to resolving these acquisition differences for a consistent interpretational product, specific imaging issues remained from the previous round of processing. These included: the need for a more accurate velocity description of the shallow channel features; improving the ties to the entry/exit points of wells through the salt; addressing the contamination of the reservoir section by localised cross-cutting multiple energy; and improving the understanding of the salt geometry. These challenges were exacerbated by the lack of good well control – most of the wells are highly deviated, with logging limited to the reservoir intervals.

These issues had to be addressed within a timeframe of only nine months to deliver the required improvement in P-wave depth imaging (along with complementary depth imaging of the PS data). In order to meet this objective, a high level of technology had to be adopted, including up-down deconvolution and a flexible and iterative framework for the velocity model build, which involved Guided Wave Inversion (GWI), Full Waveform Inversion (FWI) and high-density (HD) tomography.

Data Processing

By utilizing differences in the up- and down-going wavefields, up-down deconvolution (Wang et al., 2010) produced a good quality primary wavefield that is not only free of all surface-related multiples, but also benefits from 3D directional designature, debubble and source deghosting, and the removal of water column effects (Figure 1). This primary wavefield (Earth's reflectivity) was imaged directly.

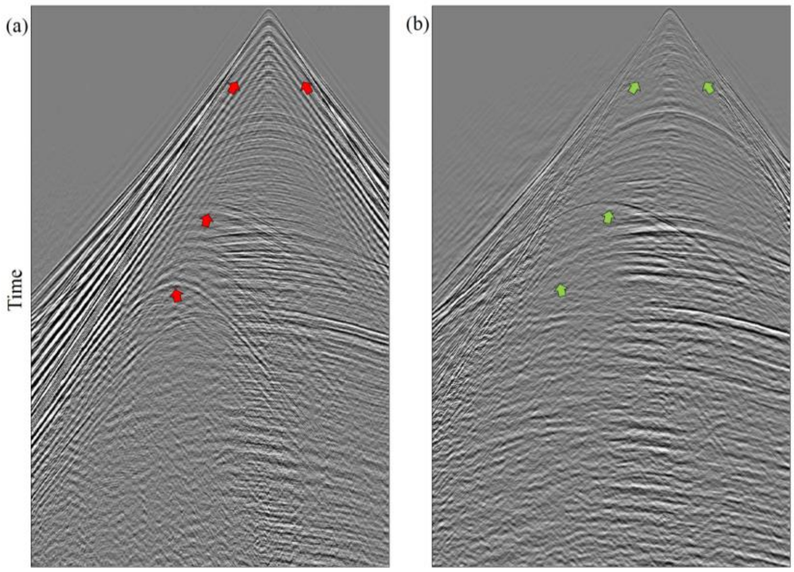

Figure 1: *(a) Receiver gather of upgoing wavefield before up-down deconvolution, and (b) Earth's reflectivity output from up-down deconvolution*

Differences in the signatures of the two surveys arising from the use of different sources were efficiently resolved through the zero-phase output of the deconvolution process. The use of up-down deconvolution was consequently integral to producing an early, demultipled dataset that was consistent in phase across the two surveys and suitable for subsequent velocity model building work. Localised interbed multiples at the target depth, not addressed by up-down deconvolution, were attenuated in the common offset vector domain using the correlation/convolution method (Jakubowicz, 1998) to model the multiples, followed by 3D curvelet domain subtraction of the resulting model from the data.

Velocity Model Update

The initial starting model was a smoothed version of the existing BP regional velocity model. By analysing the dispersion curves of guided waves, an accurate, long-wavelength, P-wave velocity model was estimated in the near surface by GWI (Hou et al., 2018) and was introduced in the shallowest 50 m of the initial model for FWI (Figure 2a). This enhanced the resolution of the FWI in the shallow and improved FWI results at the reservoir level (seen both by the reduction in cost function and decreased cycle skipping), and showed good agreement with legacy 2D high resolution seismic data. Velocity model updates through GWI and FWI provided a high-resolution model that could be directly interpreted. This is illustrated on a depth slice through the updated model in Figure 2b.

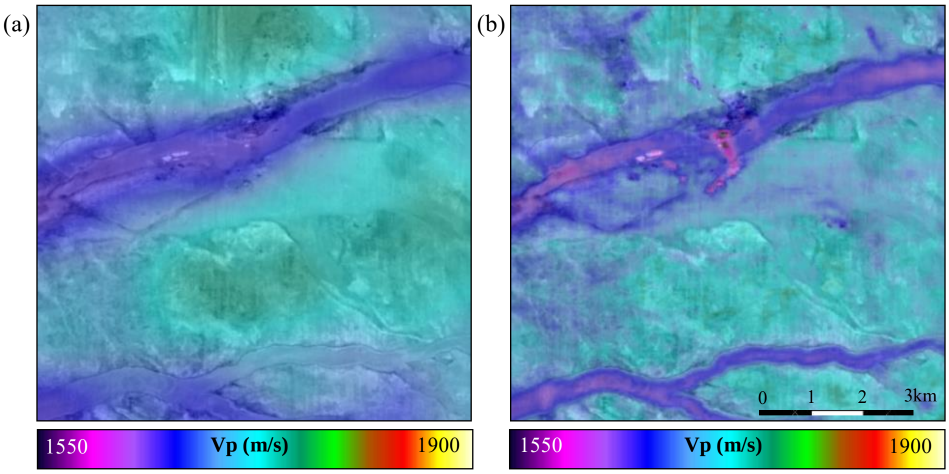

Figure 2: *140m depth slice through the GWI Vp model used as input to FWI (a) and after FWI update (b), overlain on legacy towed streamer seismic. Inclusion of the GWI derived model in the shallow improved FWI resolution.*

The application of FWI around salt bodies is challenging due to the sharp velocity and/or impedance contrast at the salt flanks and the lack of diving wave energy penetrating through the salt body. Therefore, an iterative approach was employed for the Vp model build. Starting from the best available Mungo diapir interpretation, through multiple iterations of RTM imaging and FWI, the Mungo salt body was revised before updating the initial sediment background model through FWI. The results suggested that this iterative approach, using the initial model with a more accurate salt interpretation, could produce a better FWI update and an improved reservoir image. Considerable changes to the shape of the salt body were made in this process, including introduction of the overhangs close to the head of the diapir. Figure 3 illustrates changes in salt geometry through some of the iterations of the model build.

While the updated model showed agreement with entry and exit points through the salt body, much higher velocity was required at the flanks at the reservoir level, indicating that chalk velocities were needed to on-lap the salt, which was consistent with geologic expectations but not honoured by the legacy velocity model. Based on the FWI perturbation, the starting model was adjusted to include such on-lapping velocities; refining the diapir interpretation once again. Simultaneous work on the Vs model build at this time implied that changes to the legacy anisotropy regime were necessary. The starting FWI model was therefore re-calibrated through updates to the Vp and delta fields. The epsilon field was chosen empirically from the response of the PS data (being more sensitive to changes in anisotropy than PP data) selecting different layer-dependent scaled versions of the delta field.

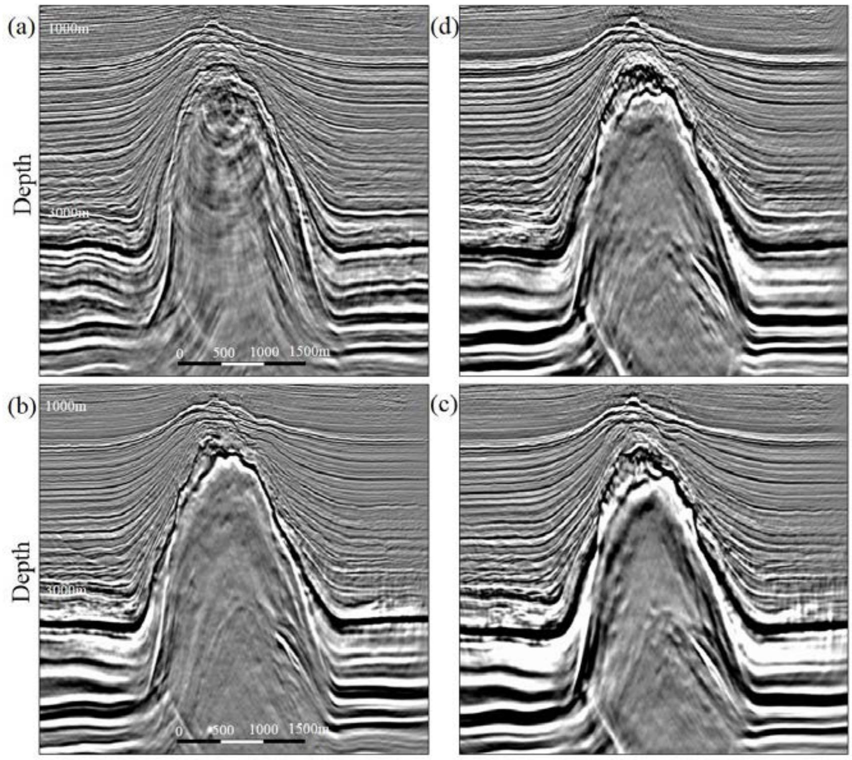

Figure 3: *PSDM results illustrating the improvement in imaging from the evolution in salt flank interpretation from the legacy model (a) through intermediate stages (b,c) to the final (d).*

This revised starting model was updated with 32 iterations of FWI, from 4 to 8 Hz and used as an input to tomographic inversion (Guillaume et al., 2013), followed by a high-density tomographic inversion (Figure 4). Well-tie analysis performed at the end of the model build showed greatly reduced misties at the target level (Figure 5) and good agreement between model and sonic logs.

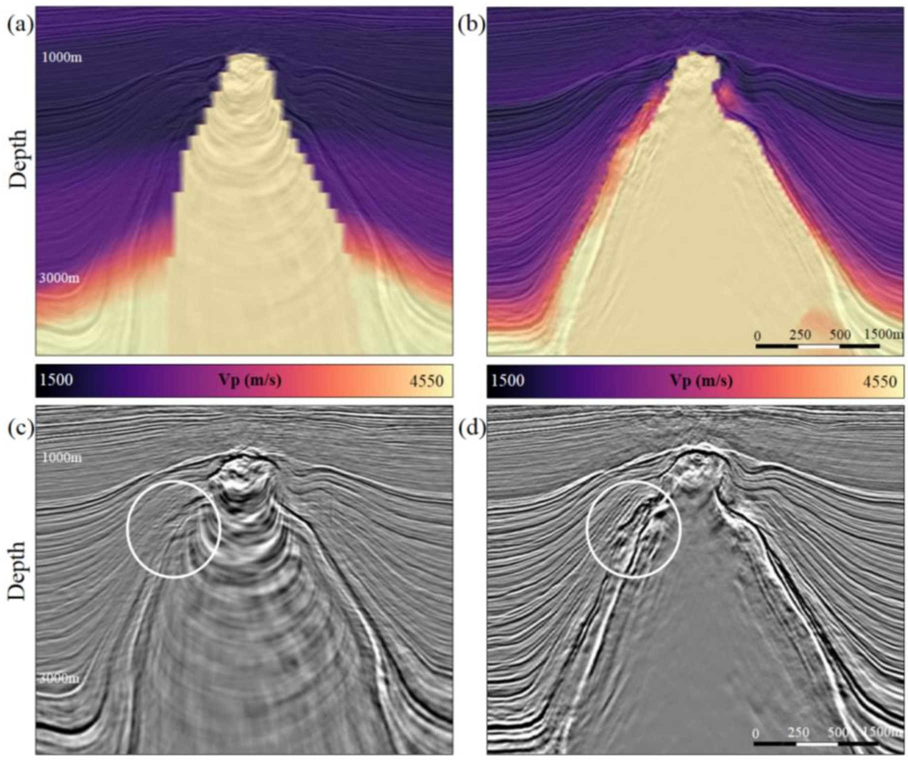

Figure 4: *Legacy (a, c) and final (b, d) velocity models and imaging results. Note the simplification of flank structure and improvements to reservoir imaging (circled) with the updated model.*

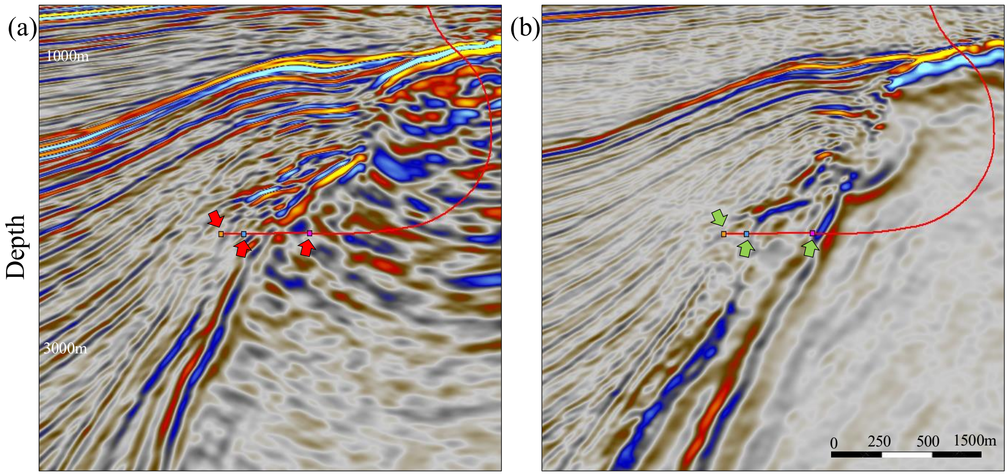

Figure 5: *Flank imaging with legacy (a) and final (b) velocity models overlaid by a wellpath with salt exit and horizon markers indicated. Horizontal misties at the reservoir level greatly reduced with the updated velocity model.*

The velocity model building flow produced a far more geologically-consistent model than historical attempts, providing a better overall understanding of the salt geometry and improving the imaging of the steep reservoir and the potential targets in the on-lapping chalk interval. This was facilitated by the technology available, the complementary PS data and the iterative approach taken to the salt refinement through FWI.

Conclusion

A challenging timeframe for delivery of a step-change in P-wave imaging on the Mungo field was met through adoption of high-end processing technology (up-down deconvolution, GWI, FWI, HD tomography) and a flexible and iterative approach to the model-building process. Consequently, the resolution at the reservoir has been improved and the well misties have been significantly reduced. The delivered products will help to form the basis for improving the future management and infill strategy of this mature North Sea field.

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References

Guillaume, P., Zhang, X., Prescott, A., Lambare, G., Reiner, M., Montel, J.P., and Cavalie, A. [2013] Multi-layer non-linear slope tomography. *75th EAGE Conference & Exhibition,* Extended Abstracts.

Hou, S., Haacke, R., Corbett, A., and Wanczuk, M. [2018] Velocity Model Building with Guided Wave Inversion. *80th EAGE Conference & Exhibition,* Extended Abstracts.

Jakubowicz, H. [1998] Wave equation prediction and removal of interbed multiple: *68th Meeting, SEG*, Extended Abstracts.

Wang, Y., Bale, R., Grion, S., and Holden, J. [2010] The ups and downs of ocean-bottom seismic processing: Applications of wavefield separation and up-down deconvolution. *The Leading Edge*, 29(10).