A case study: Geologically guided tomography to improve image below the Aptian unconformity, offshore Gambia

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Summary

This case study presents results from 3D Gambia Blocks A1 and A4 Kirchhoff prestack depth migration (KPSDM) project offshore Gambia. The main purpose of this project is to produce a more accurate velocity model which would enhance event placement and improve the sediment events below Aptian unconformity. TTI anisotropic prestack depth migration and tomographic velocity updates including image guided (IG) and horizon constraint tomography are used. Because of the complex geology above the unconformity, the stratigraphic horizons were interpreted for the high-resolution tomography.

Introduction

This case study presents results from 3D Gambia Blocks A1 and A4 Kirchhoff prestack depth migration project covered approximately 2600 km^2 offshore Gambia which lies within the prolific offshore MSGBC (Mauritania, Senegal, The Gambia, Guinea-Bissau, Conakry) basin along the North-Western African coast (Brownfield et al., 2003; Pedley, 2016).

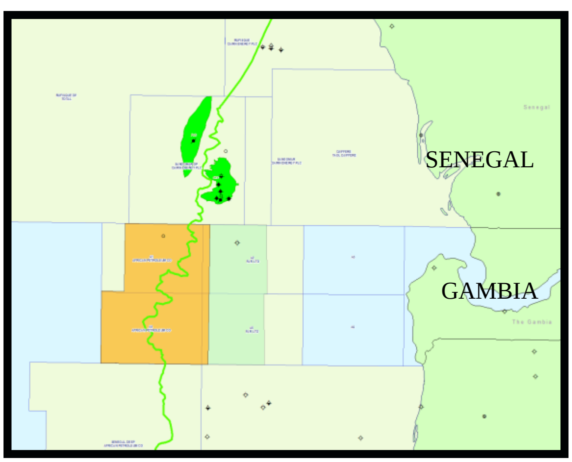

Figure 1: Location map of 3D Gambia Blocks A1 and A4 Area (Orange polygon) in North West Africa Atlantic Margin

The stable Jurassic carbonate platform is covered by the Aptian-Albian shelf. The Jurassic to Aptian carbonates are overlain by a series of Albian sequences with large-scale basinward prograding clinoforms. These clinoforms are laterally extensive across the shelf edge and the slope area. The clinoforms are channel sands, turbidite deposits. The Gambia river delta to slope system shows different stratigraphic packages with erosional unconformities. The Deepwater clastic deposits produce structures as dip closures and fault-bounded closures. The erosion of the Aptian carbonates, and overlying late Cretaceous sequences with incised canyons, make the area challenging. Shallow eroded incised-sand deposits are sealed by Cenomanian shale and mud deposits. Overall Gambian geology shows prospective Cretaceous-Tertiary petroleum system.

We have mapped the following stratigraphic horizons for detailed high-resolution tomography updates both in the outboard shelf-slope break and in shelf areas:

- Top Oligocene unconformity;
- Top Santonian unconformity;
- Top Albian;
- Top Aptian unconformity.

The Gambia project encompasses the prestack Kirchhoff time and depth migrations including Clari-Fi™ (Deghosting) processing. The data was acquired by Fugro's MV Geo Caribbean in an East-West fashion with 12 streamers and 2 sources.

The Gambia Time Processing consists of multidomain noise attenuation, source and receiver deghosting to improve the bandwidth of the data and minimize ghost notches, 3DSRME for multiple removal, 4D Regularization to give better data coverage, and wavelet processing and phase-only Q to insure phase consistency. The data is then input for depth imaging work.

Depth imaging processing flow

The TS Dip velocity function is used as a basis for the water velocity model for this project. The TS Dip is measured at several points throughout the 3D Gambia area. The average water velocity function is calculated and extrapolated to provide a good approximation of the water velocity across the survey area.

To create the initial KPSDM velocity model, the rms prestack time migration velocity from the current velocity picks is smoothed and converted to an interval velocity in depth. This initial velocity model is used for the isotropic KPSDM.

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One of the challenges of this study is the approach to estimate anisotropic parameters, epsilon and delta, for TTI processing, because there is no well information in the survey area. Before estimating anisotropic parameters, an isotropic shallow tomography is applied to flatten the near-offset gathers. Anisotropic parameters, epsilon and delta, are derived using a focusing analysis approach (FAN). The derived epsilon and delta are confirmed by values derived from nearby well information. The derived anisotropic parameters are extrapolated over the entire survey area along the stratigraphic horizons. The estimated epsilon and delta models are used for all subsequent iterations of anisotropic migrations. The anisotropy analysis yields a maximum of about 7% for epsilon and about 5% for delta. Figure 2 shows a seismic section with an epsilon and delta overlay, respectively.

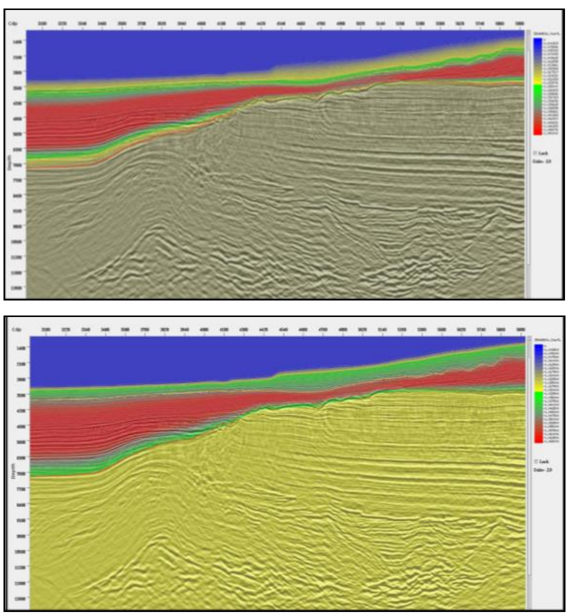

Figure 2: Anisotropic parameters, delta (top) and epsilon (bottom), as a color overlay on a Kirchhoff PSDM stack.

A general top-down approach is applied for the velocity update. Anisotropic Kirchhoff prestack depth migration gathers are used for the high-resolution tomography. To enhance the signal-to-noise ratio, super gathers are used for RMO picking by applying the offset-dependent picking method. There are three image-guided (IG) tomographic updates above the top Aptian unconformity (the red horizon in Figure 3). The inversion grid was 100 m by 100 m (x and y). Figure 3 shows one of the updates (DV) using the image-guided tomography. The DV is overlaid on a migration stack.

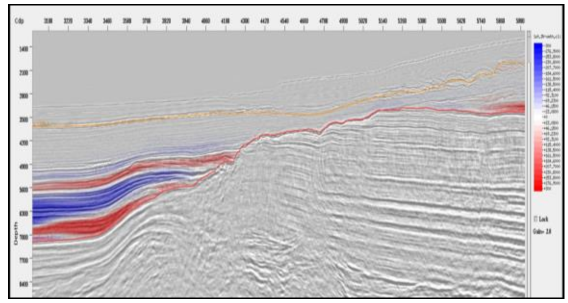

Figure 3: The tomographic update (DV) is overlaid on a stack. Image guided tomograpy provides the updates along the geological structure.

Under the Aptian-Albian shelf, there is a stable Jurassic carbonate. The previous North-West African Atlantic margin (NWAAM Ph1 and Ph2) 2D project experience verified that the velocity in the carbonate area is more than 4000 m/s. After inserting the fast velocity under the Aptian unconformity, the migrated image is significantly improved (Figure 4).

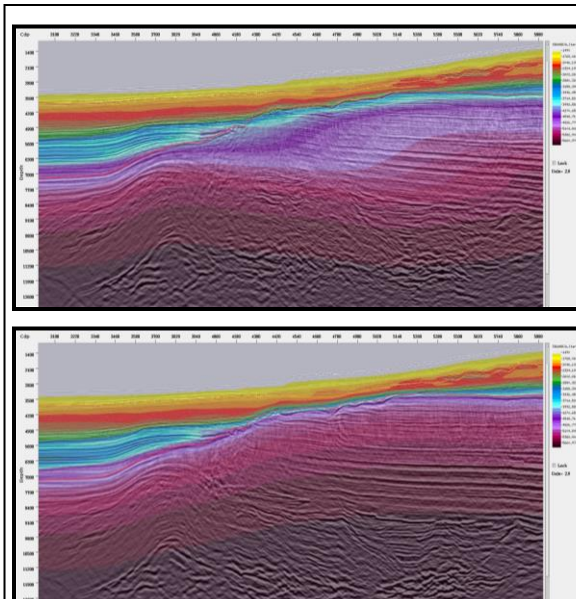

Figure 4: Before (top) and after (bottom) inserting fast velocity below the Aptian unconformity, the velocities are overlaid on a stack. The Jurassic carbonate events are well-focused and continuous.

Some Jurassic carbonate events have small undulations due to the complex geology above the unconformity, such as the low-velocity channels shown in Figure 5. Below the low-velocity channel, the Jurassic carbonate events are

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distorted. After one more high-resolution IG tomography on a 50 m by 50 m grid above Aptian unconformity, the undulations were reduced, but not significantly. To further reduce the Jurassic carbonate undulation, a horizon-constrained tomography was applied.

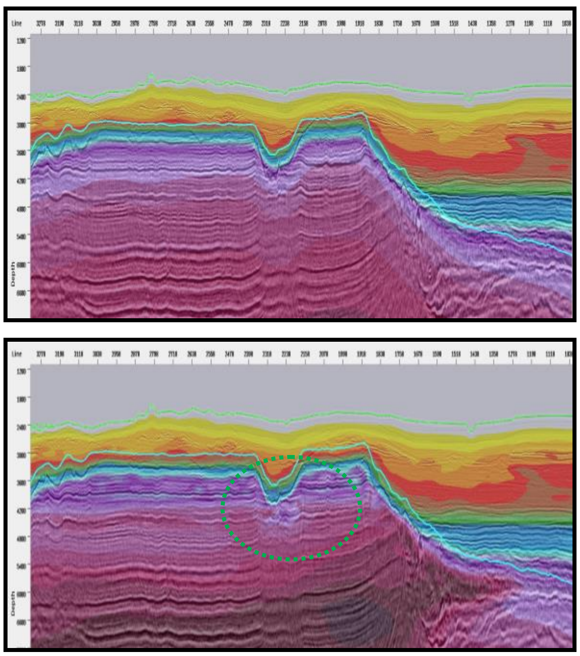

Figure 5: Before (top) and after (bottom) the high-resolution tomography. The event continuity is enhanced and the relatively high frequency undulations are reduced.

Horizon constrained tomographic update

The seismic tomographic process relies on depth moveout picked from migrated gathers, suggestive of the total velocity error at each event, to update the velocity model through an inversion process. While accurate in simplistic geological situations, this method may begin to break down in areas with complex structure or sharp velocity contrasts. Including geological or structural information can help stabilize the tomographic result by providing additional constraints on the update magnitude and pattern, beyond the kinematic information contained within the gathers.

Rodriguez et al. (2011) described a method to enforce geological features during a tomographic update by including an extra set of travel time errors, generated by tracing vertical rays from seismic and targeted horizons, in the inversion. This additional set of rays is weighted appropriately alongside the rays describing the picked velocity errors, and the inversion considers both gather flatness and horizon repositioning in its solution. In this way, depth errors will be minimized during the usual process of updating the velocity to flatten gathers, and this additional constraint helps ensure geologically reasonable models and imaging.

In the Gambia project, two structural control horizons in the Jurassic carbonate layer were used for the horizon-constrained tomography. Figure 6 shows before and after the tomography, which flattened the nongeological undulating events and made the images more focused and continuous, especially below the Aptian unconformity.

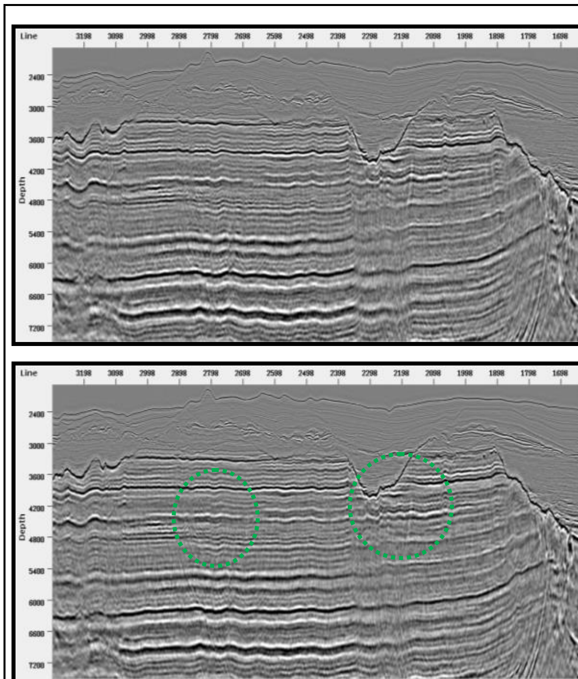

Figure 6: Before (top) and after (bottom) the horizon-constrained tomography to ruduce the undulations of Jurassic carbonate. The tomography reduced the undulations, which are not geologically plausible.

In the Gambia A1 and A4, there are different stratigraphic packages with erosional unconformities, fault, and erosional channels. However, 3D prestack depth migration (PSDM) was not available before. Figure 7 shows the comparison between the legacy prestack time migration (PSTM) and the final prestack depth migration. It is very difficult to interpret the Jurassic carbonate layer in the PSTM. However, in the PSDM result, the structure below the Aptian unconformity is very clear and interpretable. Especially, the carbonate events are truncated well to the unconformity.

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Conclusions and future works

The detailed velocity-update flow results in more geologically feasible models and seismic images. The velocity model is also truncated well against the Aptian unconformity, (Figure 5). Significantly, the Jurassic carbonate events below the complex Aptian unconformity are continuous and geologically stable.

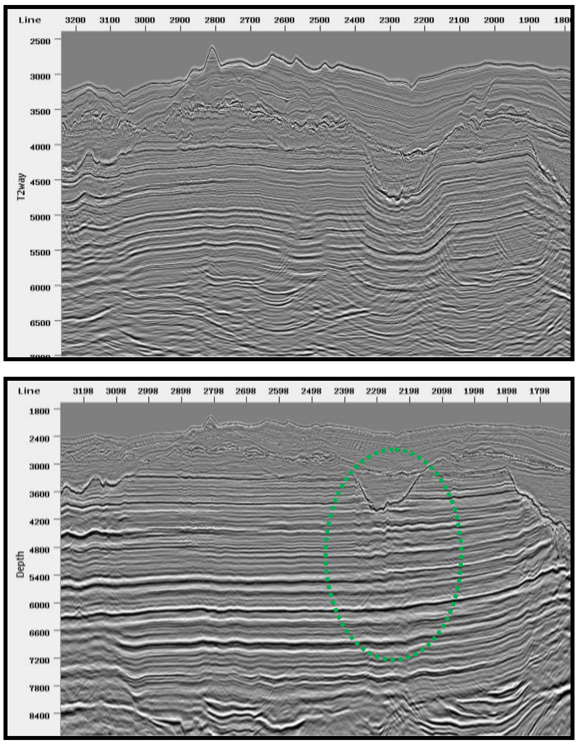

Figure 7: PSTM (top) vs PSDM (bottom). The carbonate layers are well imaged and truncated to the unconformity in PSDM.

Although the high-resolution and the horizon-constrained tomography produce a reasonable solution and the updated velocity captures several small anomalies above the Aptian unconformity, the velocity variation under the Aptian unconformity is a bit suspicious. It is possible that there is leakage of the velocity update above the unconformity because the ray-based tomographic updates in the complex geology didn’t provide a precise high-frequency detailed velocity model. Figure 8 is an example of the complex shallow geology above the Aptian unconformity. Recently, an FWI engine is widely used in the seismic industry (Mao et al., 2016; Yoon et al., 2014). We believe that FWI can help to capture the detailed velocity corresponding to geology and produce even better images.

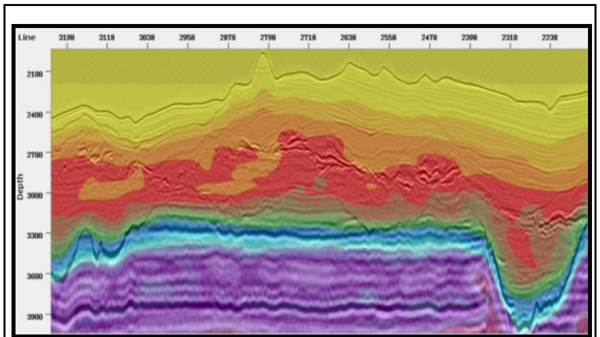

Figure 8: The complex geology above the Aptian unconformity. The high resolution tomography update captures the local velocity anomalies. However, FWI can produce a more detailed velocity.

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