TTI Depth Migration – Advantages for Development Offshore Nigeria

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Summary

We show how robust TTI High Definition velocity model building and migration can directly impact field development in the deep water Nigerian offshore.

Introduction

This seismic environment offshore Nigeria has been characterised by a deceptively simple, mainly compaction driven velocity regime. Until quite recently it has been regarded as a straightforward time migration area. However several factors conspire against this simple approach. For the development in question, the target area has steep dips – up to 45 degrees, and is highly faulted and compartmentalised. The maximum offset for the High Definition (HD) data set was 6km and showed considerable 4th order moveout. The simple compaction driven velocity representation can be shown to be too simplistic - in fact the near surface velocity shows quite considerable lateral variation and in the reservoir area shows velocity variations that are both structural and linked to hydrocarbon presence. In this area, AVO is an essential tool for delineating the hydrocarbon accumulations, hence optimal gather flatness after migration is essential.

We will show that a careful application of TTI velocity model building combined with depth error estimation carried out by both a novel correlation approach and verified by the interpreter led to significant changes in the structural understanding of the reservoir connectivity. In addition the AVA results were more structurally consistent.

Velocity Model Building

In total five iterations of velocity model building were undertaken. The initial velocity model was derived from a previous depth migration project. This was run on a vintage non-HD data set using a VTI layer based methodology. This velocity was scaled back to an isotropic equivalent using the supplied delta field and smoothed.

![Figure 1](image_url) Final TTI velocity is on the left with the Gaussian form of the final delta function on the right. The maximum value of delta was 12.5%

It was decided to use grid based tomography as the main velocity model building tool. Layer based and hybrid velocity model building works well in hard rock areas with clear, abrupt and easily identifiable velocity boundaries. This is not the case in this area as the velocities have an overall compactional form with some structural modulation. There are also shallow velocity anomalies that are very hard to represent in a layered parameterisation.
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Two isotropic iterations were initially run using a fast beam migration. However the beam migration was judged to be a little too smooth and it was difficult for the interpreters to compare with the vintage data set. Hence subsequent iterations were run using Kirchhoff migration.

Up to eight wells were available for estimating residual depth errors and delta. Three different approaches were tried for estimating delta. These were

- Inverting for delta in tomography using time depth curves
- Using a very simple linear parameterisation for delta hung from the seabed
- Inverting for epsilon only in the tomographic update, and calculating a Gaussian shape for delta hung from the seabed using the epsilon result as a guide for the depth and width of the Gaussian function

The direct inversion of delta produced mixed results. Indeed we can invert for combinations of delta, epsilon and velocity, and can produce flat gathers with this approach but the velocities can become a little erratic.

The benefit of hanging a simply parameterised function from the seabed is that we avoid having too many degrees of freedom in the inversion. In addition we just need to optimise for a small number of parameters – depth below sea bed, slope, maximum delta in the linear case, width (standard deviation) and maximum delta in the Gaussian shape case. The final Gaussian delta is shown in the right hand panel of Figure 1

Two iterations were run using the linear and three using the Gaussian approach. The final velocity model is shown on the left hand panel of Figure 1.

Depth Error Estimation

The data being studied has steep dips – up to 45 degrees, and some of the wells are situated in these steep dip areas. Initially it was thought that well markers could be used to calculate depth errors against depth horizons. However the TTI depth migration changed the lateral positioning of the data to such an extent that this proved difficult to re-pick horizons in a timely manner.

![Figure2](image)

**Figure2.** Vertical depth error estimation using a continuous correlation between VSP corridor stack and depth migrated data along the well track. On the left is the initial estimate (after iteration 3). Vertical error varies from approximately 0 to 45m. On the right is the final estimate (after iteration 5). Depth error for this well is approximately -5m to +5m. The horizontal axis is vertical depth error -100m to +100m. The vertical axis is TVDSS.

VSP corridor stacks mapped to depth were available for some of the wells and synthetics for the rest. Migrations of mini-cubes around the wells were run using HD parameters (frequencies up to 130Hz, 6.25m x 12.5m x 3m). Depth data were extracted from mini-cubes along the well paths. This migrated data was then correlated with the corridor stacks in depth using a tool originally developed for correlating between p-wave and c-wave data. In analysis mode this produces semblance panels that can be picked as depth error versus depth (Figure 2). This depth error data is then used to update the delta function to give a best global error reduction. The initial (iteration 3) depth estimate is compared to the final result (iteration 5) in figure 2. The area of high correlation is the roughly linear trend near the centre of both plots. The correlation coefficients are between 0.7 and 0.9.
In parallel with the correlation estimation approach, the mini-cubes were delivered to the interpreter for their estimation of error. These estimates were remarkably similar for each iteration. The mean depth error for all the eight wells using the final model is of the order of 10m.

**Figure 3** Upper Image is a structural stack of the HD time migration (VTI) through a well. The inset is an amplitude display of a seed pick of an important hydrocarbon bearing sequence. The lower image is a structural stack of the HD TTI depth migration converted to time with the equivalent seed pick inset. In the lower inset the onset of the high amplitude (red) event can be seen to have shifted by 50-100m relative to the time migration. In addition the overall area has increased considerably.
VTI vs. TTI

A previous depth migration project was carried out using VTI anisotropy on a non-HD dataset. The AVA results obtained were not structurally consistent using this approach. The current HD data set was also time migrated using a VTI pre-stack algorithm, and work carried out by Total indicated that TTI anisotropy would give more consistent results (Figure 3 shows the difference between running VTI time migration and TTI depth migration). At the target level the TTI moves data by approximately 100m to the right. The high amplitude event indicating hydrocarbons is more consistent with the well data using a TTI depth migration, and happily the potential reservoir volume is also increased. The HD time migration and depth migration were run with different velocity models, but some VTI PSDM tests were run using the final velocity model and anisotropy volumes. Lateral shifts of the same order of magnitude were seen between the VTI and TTI depth migrations as between the VTI time migration and TTI depth migration.

Final results

The final migrations were run at a spatial sampling of 6.25m x 12.5m x 3.0m with a maximum frequency of 130Hz. Near, mid, far and ultra far angle stacks were produced after simultaneous 2nd and 4th order RMO. The lower panel in Figure 3 is from the raw final structural stack. Figure 4 shows a far angle (30-42deg) stack with a 400m horizontal stack applied to highlight any flat spots using both the HD VTI time migration and the TTI depth migration. A possible fluid contact can be seen in both sections. However the fluid contact from the TTI depth migration is better focussed, more continuous and flatter. It implies that two hitherto separate hydrocarbon accumulations are in fact in communication.

Conclusions

Application of TTI velocity model building combined with a simple and robust parameterisation of delta and a simple depth error estimation technique have led to much reduced depth and positioning uncertainty. In addition the AVA angle volumes are much more structurally consistent. The use of HD data at high frequency has shown the presence of many DHIs. In some cases it shows hydrocarbon bearing compartments to be in communication i.e. they have common oil/water contacts.

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EDITED REFERENCES
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