Example of Transverse Collaboration During Ocean-bottom Node High-resolution Velocity Model Building, Deep Offshore Nigeria

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ABSTRACT

In this paper, we present the velocity model building (VMB) processes and imaging results obtained from Ocean-Bottom nodes (OBN) seismic data acquired in a deep-water Niger delta field. We highlight the transverse collaborative work done between Total E&P Nigeria (Total) teams and IDSL/WesternGeco (IDSL/WG) consortium that led to an improved structural image of the field. One important objective of this imaging project was to build a high-resolution velocity model using OBN data that could resolve the imaging issues present in previous seismic streamer vintages.
The VMB started from an existing TTI (Transverse Tilted Isotropic) model derived from vintage streamer data. The flow included two passes of full azimuth common image point (CIP) tomography, providing a robust starting model for least-squares full waveform inversion (FWI).
After FWI, a final tomography update was necessary to further improve the velocity in the deeper area. An initial attempt, using conventional tomography technique degraded the events at the reservoir interval, due to very challenging residual moveout picking, making it necessary to review the strategy in order to improve the final model.
Several routes were tested with constant interaction and collaboration between Total's teams and the IDSL/WG imaging team. As a result, a final horizon driven bounded tomography update with reservoir interval exclusion was chosen.
This transverse collaboration integrating actors from different technical domains helped in taking time effective decisions, while obtaining a final velocity model which globally improved the seismic image and
increased the level of details at the reservoir level.

Keywords:

INTRODUCTION

The Egina field, deep-water offshore Niger Delta, is the latest major oil producing field in Nigeria. In 2017, Total acquired an ocean-bottom node (OBN) seismic survey in order to improve reservoir characterization and to also serve as a baseline for subsequent 4D seismic monitoring and support field development optimization. OBN acquisition is a preferred acquisition technique for 4D seismic monitoring as it is extremely repeatable, even in the presence of obstructions associated with field production activities. In addition to this, OBN acquisition is very suitable for VMB using full-waveform inversion (FWI), as it benefits from long-offset and full-azimuth data.

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The Egina field is in oil mining license (OML) 130, approximately 200 km offshore the Nigeria coast and is in a water depth ranging from 1400 m to 1750 m. Figure 1 shows the map of the survey and OBN seismic acquisition layout. The Egina 3D OBN survey, comprises a shot

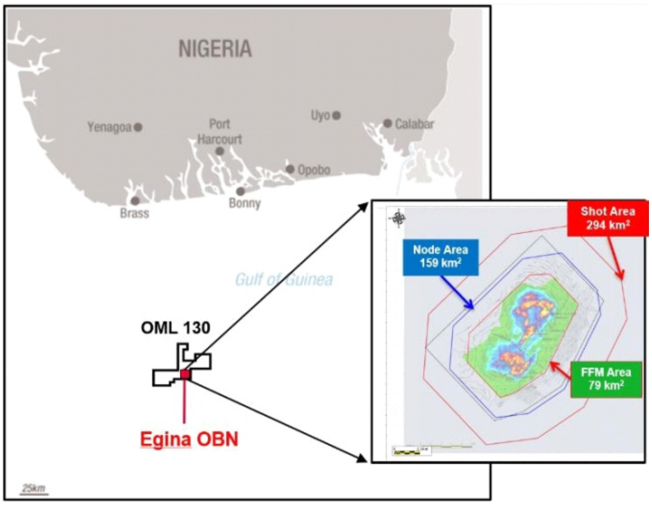

Figure 1: Survey location and OBN acquisition layout.

surface area of approximatively 300 km2, accounting for 210,000 shots on a 37.5-m grid and a 160 km2 receiver patch area of 1,164 four-component autonomous nodes. The node patch is subdivided into two areas: the core area with a denser node sampling (300 m x 346 m) and the outer ring with a coarser sampling (600 m x 346 m) for optimization purposes.

The processing sequence for this project consisted of four main phases: Time processing from field data (Hydrophone and geophone XYZ components), Imaging and velocity model building from OBN data, Kirchhoff Pre-stack Depth migration and Post-Migration processing, Stack and post-stack processing.

Our focus will be set on the imaging and velocity model building phase. We first briefly describe the earth model building flow used to obtain the high-resolution model necessary to improve the imaging issues present in previous seismic streamer vintages (due to shallow gas effects and mud volcanoes). Then we review the final tomography update step, where we highlight the importance of the collaboration between Total's teams (Asset and Operations teams) and the IDSL/WG imaging team, each one with different technical skills helping to achieve a final velocity model which globally improved the structural imaging and at the same time increased the level of details at the reservoir level.

Initial velocity model and Full Wave Inversion (FWI)

Velocity model building started from an existing TTI model derived from vintage streamer data. It must be noted that OBN acquisition is very suitable for velocity model building as it provides better illumination as it benefits from long offsets, wide azimuths and low frequency data with high signal-to-noise ratio (Chakraborty et al., 2017).

The flow for updating the model included two initial passes of common image point tomography using down-going data in offset vector tile (OVT) domain. This provided a robust starting model for least-squares FWI. To obtain the necessary details in the model a total of 5 frequency bands of FWI were performed starting from a peak frequency of 3Hz to a final frequency of 10Hz. Figure 2, presents an example of how the updated model, obtained from the association of OBN data and FWI workflow, provided a great level of details, like, for instance, the definition of the narrow gas chimney (Chen, S., et al., 2020).

Final Tomography update: Model set-up

After FWI, the model already achieved some of the initial objectives, capturing velocity heterogeneities and resolving distorted features at the reservoir level. To further improve the velocity model in the deeper section below the FWI illumination limits, where the confidence in the details was low, it was necessary to run at least one more pass of tomography.

The first step was to define a suitable model for tomography update by merging the updated model after FWI (shallow part) with the smoother legacy model below the depth of FWI illumination but keeping as much as possible the features improving the reservoir area. Here is where the use of the geological knowledge from the seismic interpreter combined with the capabilities of the processing team to estimate the FWI illumination area helped to optimize the merge limit. In Figure 3, is displayed the ray tracing experiment defining the illumination zone together with the horizon provided by the seismic interpreter which drapes the reservoir to ensure geological coherence to the velocity merge.

In Figure 4 we can see the results of the merge guided by the horizon from the Asset team. This horizon was used to define a taper zone to merge the models to obtain the input model for subsequent tomography update.

Final Tomography update: Model Update challenges

Once the input Model for tomography was defined, the actual tomography flow started. Data pre-conditioning prior to move-out picking was done using structural smoothing and Radon denoise techniques. The CIP picks in the reservoir area, guided by the horizons provided by the Asset, were discarded because their

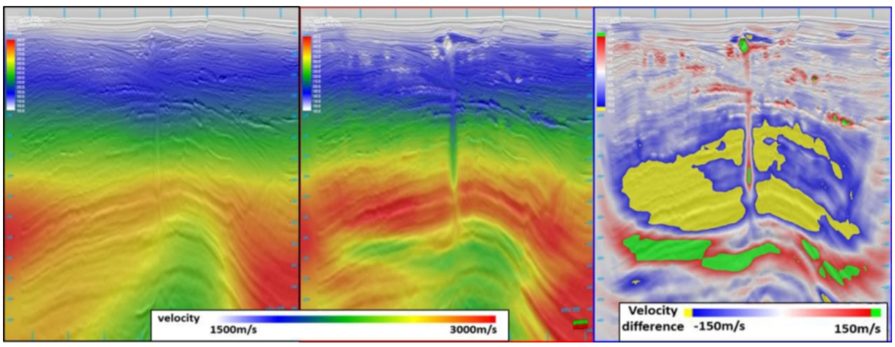

Figure 2: Full wave Inversion (FWI) updated Velocity model (Middle) compared to the initial narrow azimuth velocity model input (left) and the difference between the two (right).

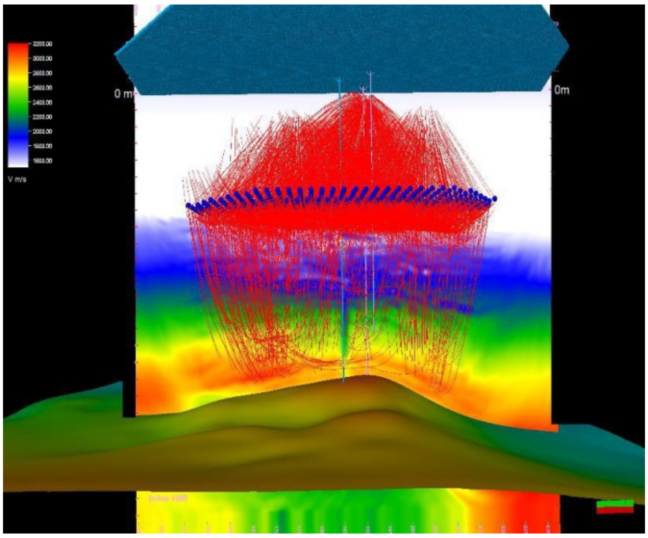

Figure 3: Ray tracing experiment highlighting the zone of FWI good illumination with proposed horizon to guide the merge.

computes a displacement field for the picked events between two consecutive OVT, from near to far offset. By looking at the displacement in a 3D sense, a better consistency of the picks in deeper section is achieved. An example of the picking results is presented in Figure 6.

Following the picking route described, CIP tomography updates were tested using a longer (6km) and shorter (3.5km) scale length. The tomographic update using a longer scale length provided an overall good quality result and the most stable gather flatness specially in the deeper part of the data. Still, at the reservoir level, strong residuals were observed. As noted when initial picking testing was done, it was not clear if these results were not linked to AVO Class IIp effect exhibiting polarity reversal and misleading the tomography update, thus introducing a strong slowdown in the velocity model. Figure 7 shows an example of such gathers before and after tomography update.

After analyzing the results together with the interpreter's

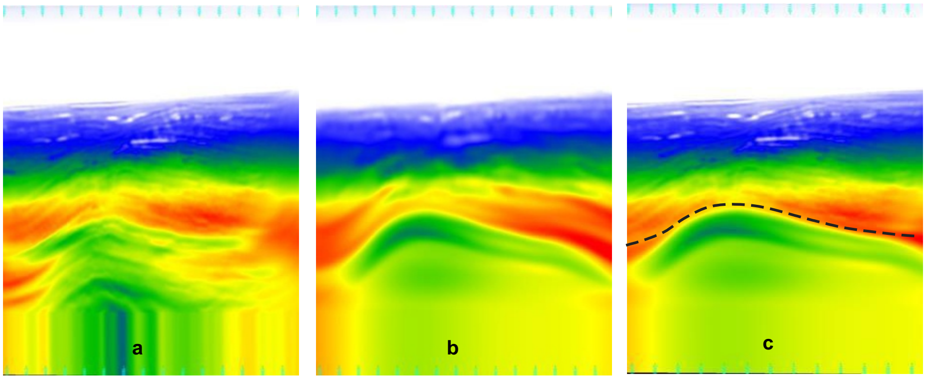

Figure 4: FWI Model (a), Legacy Smooth Model (b), Merged Model with horizon defining the taper area(c).

quality was inconsistent due to polarity reversal events in this area (potentially caused by AVO Class IIp effects). In Figure 5, we can see the area where picks are discarded, and we can also observe the limitations of the conventional picking in the deeper section where some events are wrongly picked.

Since these initial results did not provide a consistent quality improvement, another picking approach was proposed by the Imaging team. Since single OVT shows strong residual noise and limited illumination, to allow consistent picking of the residual move-out, it was recommended to perform a stronger clean-up based on a geological structural smoothing using a structure tensor (dip and azimuth) calculated from the full OVT stack. Also, an additional Radon denoise was applied on Gathers. Once the data was structurally smoothed and cleaned, picking using Non-Rigid Matching (NRM) was performed for the 8-azimuth sections. This method team, it was decided to test the option of running a tomography update with bounds to limit the update above the deeper section and avoid misleading picks. The horizon to define the area not to be updated was provided by the interpreters. The results of the tomography test with and without bounds on migrated stacks showed that, in the stack migrated with the bounded model, the fault planes were sharper and better placed. In addition, wells mis-ties analysis done by the asset interpreters showed that, with the bounded velocity model, the mis-ties were reduced and within the velocity model uncertainty. Figure 8 displays a well synthetic on a stack migrated with and without the bounded velocity model. It was then commonly decided by all teams involved to select the model issued from the bounded tomography update for the final Kirchhoff Pre-Stack Depth Migration.

RESULTS

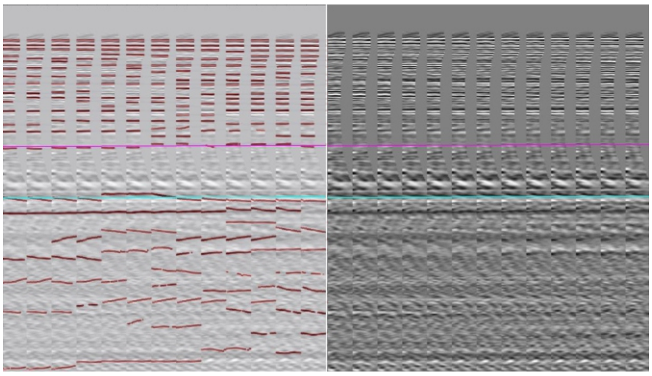

Figure 5: Left image shows CIP picks overlaying the gathers displayed in the right image. Reservoir area left unpicked is limited by two horizons and below some inconsistencies in the picking are present.

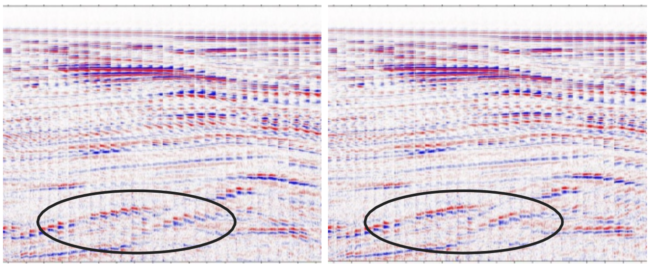

Figure 6: Example of NRM picking results on a series of gather before (left image) and after (right image) the residual move-out picking.

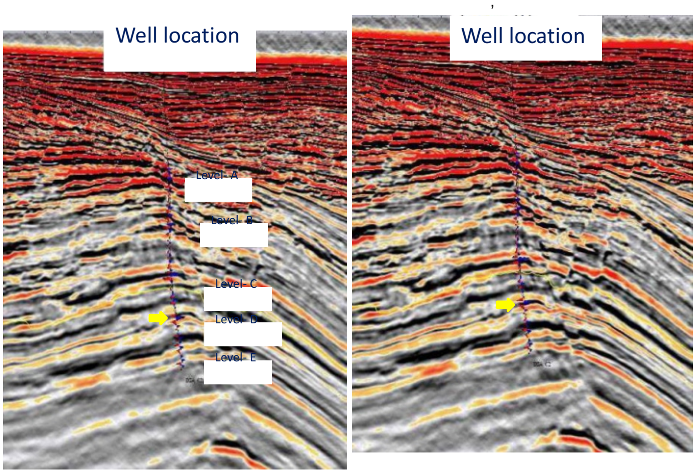

Figure 7: Stack migrated with bounded model (right) shows a better match with the well synthetic than the stack migrated with non-bounded model. This is particularly clear for Level-D as indicated by the yellow arrow. For reference water bottom is represented by a black positive value.

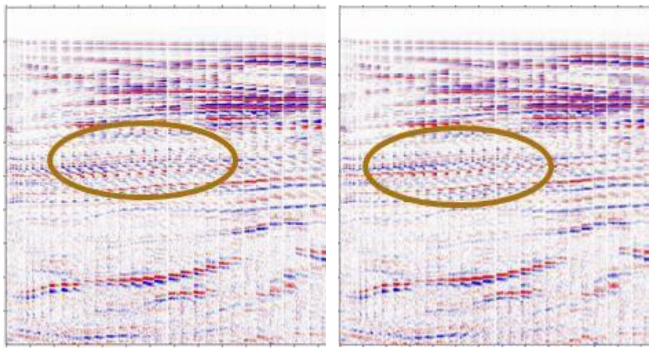

Figure 8: Gathers before (left) and after (right) tomography update with still a strong residual move- out not fully corrected.

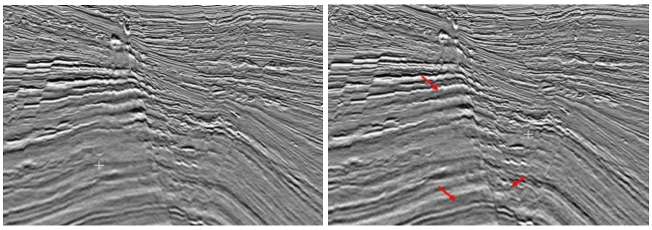

Figure 9: Kirchhoff prestack depth migration image using legacy model (left) and new obtained model (right).

The imaging process combining tomography in azimuth sectors and FWI using full azimuth long offset OBN data yielded a detailed and high-resolution model that addressed to a large extend the issues present in previous vintages. As an example, Figure 9 shows a comparison between an OBN section migrated using the vintage velocity model and the same section migrated using the final velocity model obtained using FWI and bounded tomography update. In this example, we can see that the fault compartmentalization and definition are improved when using the new model, together with a better continuity of some seismic events. Results had also an impact on the reservoir seismic characterization. The elastic inversion results achieved an excellent level of correlation not only at the input wells but also at blind development wells (Amoyedo, S., et al, 2020).

CONCLUSION

The process of building a velocity model involves different teams with different skills: from the imaging team, in this case represented by IDSL/WG, to the data end user, in this case represented by the Asset team, passing through the team in charge of supervising the technical work and ensuring the expected data quality for the final end-user. A good transverse interaction and communication between these teams is always necessary to obtain good results. Taking this project as an example of such collaboration, we can see that the technical tools and skills supplied by the imaging team to overcome the challenges faced during the velocity model building process, fed and benefited from the Asset team's geological input and guidance. The Asset involvement, providing geological horizons, defining the taper zones for velocity models merge, reviewing impact of the model updates at the reservoir level and performing controls using well information, ensured a final model geologically consistent, and without unpleasant surprises.

This project is a good example of how a transverse collaboration between teams from different backgrounds with a shared goal, allowed taking right decisions at the right moment, and greatly helped to obtain a new

model which globally improved the structural imaging and at the same time increased the level of details at the reservoir level.

As a lesson learnt, for the upcoming processing and imaging projects, a clear project organization and an open line of communication between all the stake holders (technical supervision teams, Asset teams, inversion and AVO/AVA teams …), will be for sure a key aspect for a successful project execution.

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