Unifying Tomography & Pre-stack Anomaly Detection in PreSDM to Correct for Near Surface Channels in Exploration Settings

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SUMMARY

A streamlined and semi-automated Pre-stack depth migration velocity model building approach has been used to solve imaging distortions caused by near surface channel systems in offshore Tanzania. In this abstract we show how,

• an automated shallow channel extraction algorithm, and,
• a whole volume based pre-stack anomaly extraction algorithm,

were used in unison to identify potential prospects impacted by shallow channels. An automated shallow channel extraction algorithm was developed and used in PreSDM velocity model building. Coupled with wavelet shift tomography this successfully solved the imaging distortions associated with the shallow channel systems.

We focus on key aspects of the PreSDM velocity model building, which are transferable to other areas where the near surface impacts deeper imaging, and are suited to exploration schedules. The main learning's have been:

• PreSDM is preferred over PreSTM even for compressed exploration schedules, and,
• Whole volume analysis of pre-stack migrated gathers complements prospectivity assessment and processing objectives.

Introduction

A streamlined and semi-automated Pre-stack depth migration (PreSDM) velocity model building approach has been used to tackle imaging issues associated with shallow channel systems in offshore Tanzania, where there has been three years of continuous processing of over 13,000 km^2 of 3D seismic data. The seismic acquisition, processing and interpretation were subject to compressed schedules to take advantage of drilling rig availability. At the outset the main processing challenges in the area were considered to be (Figure 1):

(1) Complex water bottom multiple from deep channel incisions
(2) Diffracted multiples from bright shallow channels
(3) Potential for large lateral velocity contrasts associated with shallow channels

Tackling objectives (1) and (2) were the main focus because it was not known at that stage how extensive the shallow channel systems were or whether they were located above potential prospects. Combining this with the compressed schedule and the previous experience (Jones et al., 2013) of the manual intervention required to tackle shallow complexities in travel time tomography a lower risk Pre-stack time migration (PreSTM) processing strategy was initiated.

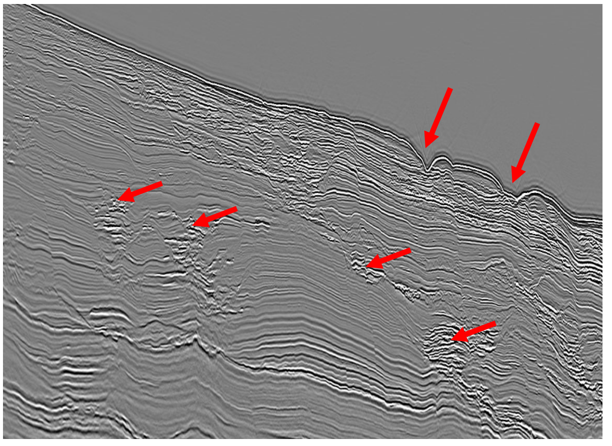

Figure 1 *Full stack section from PreSTM showing deep channel incisions in water bottom and shallow channels, indicated by red arrows.*

Early rock physics modelling and near-versus-far analysis highlighted the importance of incorporating pre-stack seismic analysis into early exploration. This gave a strategy for assessing whether (3) would have any impact on prospectivity assessment by finding whether shallow channel systems overlaid AVA anomalies. Performing this assessment on large 3D volumes requires automation. To this end the PreSTM angle stacks were used in a whole volume based anomaly extraction algorithm (Selvage and Edgar, 2013) and to automatically extract shallow channel systems an algorithm was developed in OpendTect. As will be shown below, this was refined by PGS for use in PreSDM velocity model building. Using these two volumes in unison made it possible to prioritise areas for PreSDM processing.

Once areas were prioritised for PreSDM processing a reliable automated travel time tomography was required for velocity model building. Several tomography methods have been developed to invert seismic reflection data into velocity models. Among them, ray-based post-migration grid tomography (Woodward et al., 2008) and stereotomography (Lambare, 2008) have served as significant tools. In the last decade, Beam PreSDM (Sherwood et al., 2008 and Rieber, 1936) has evolved into an effective way to prepare data for tomography. It consists of decomposing pre-processed data into wavelets, migration to map the wavelets to the depth domain, and reconstruction. The wavelet shift tomography technology presented in this paper utilizes 3D time residuals and many other wavelet attributes (Sherwood et al., 2011). The method possesses the features of both post-migration tomography and stereotomography – where we not only utilise reflected waves, but also diffracted waves and turning waves, since both un-migrated and migrated information are considered. The method enables us to perform rapid cycle updates; with, at least, one iteration per day (an iteration consisting of full output 3D Beam PreSDM, dense 3D time residual picking & high resolution tomographic inversion).

This abstract focusses on key aspects of the seismic processing and quantitative interpretation learning's, which are:

- PreSDM is preferred over PreSTM even for compressed exploration schedules, and,
- Whole volume analysis of pre-stack migrated gathers complements prospectivity assessment and processing objectives

Pre-stack seismic based anomaly extraction

The angle stacks output from the PreSTM were screened for AVA anomalies using the framework described in Selvage and Edgar (2013). The outputs from this framework are geobodies that indicate potential fluid related anomalies. Dynamic intercept-gradient inversion (Edgar and Selvage, 2012) of seismic angle stacks or angle gathers are used to produce a minimum energy chi projection volume. Through statistical analysis of the projection volume an anomaly probability volume is created and used in a 3D connectivity algorithm. These geobodies can then be visualised and manipulated in 3D (Figure 2).

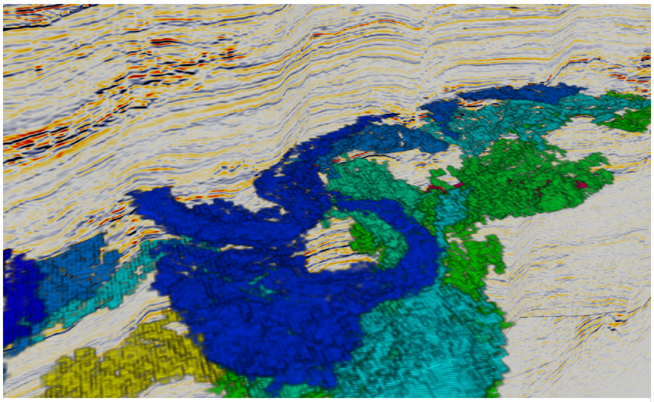

Figure 2 *3D volume render of automatically extracted channels from PreSTM angle stacks. These represent potential fluid related anomalies.*

This framework was mainly applied to feed into prospectivity assessment and drill decisions, but also made it straightforward to identify whether shallow channels overlaid potential prospects. Ahead of further exploration and appraisal wells targeted PreSDM was used to build a geologically consistent model which captured the shallow channel systems.

Velocity model building (VMB)

The first prioritised area for PreSDM covered an area 1060 km^2 and had a very complex overburden with several channel systems at different depths. The main objectives of velocity model building were to remove false structures associated with the channels (Figure 3). The velocity model building was separated in 2 main units. Velocity model building consisted of initial model construction followed by global velocity updates by means of wavelet shift tomography. Using the final PreSTM velocity model as the initial velocity model for PreSDM was tested, but this was found to be unsuitable. The shallow channel velocities were not correctly positioned and were difficult to filter out/remove due to the large size of these bodies.

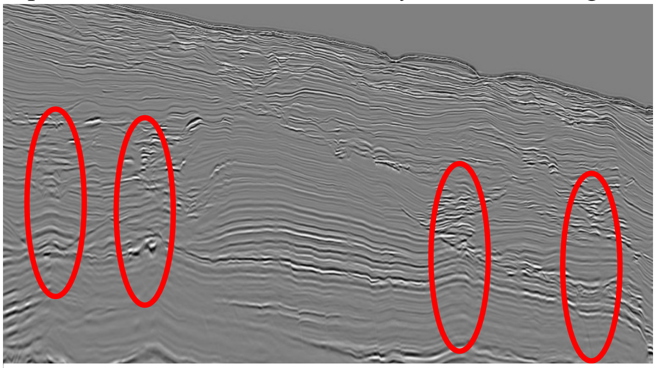

Figure 3 *Full stack section from PreSTM showing false structures associated with shallow channels (red ovals).*

The final approach was based on two intercept-gradient models (V0-K) and a variance attribute for the channel detection. Based on the available VSP checkshot velocities, we built one V0-K model to describe the background geology and another V0-K model to describe the channel velocities with both models hanging off the water bottom. A variance attribute was generated from the final PreSTM stack. This attribute mapped areas where the amplitude changes rapidly (laterally) in the 3D volume. With this attribute, the channel systems stood out from the background geology with high variance values. The variance attribute was transferred to a model mask with zeroes and ones. The two V0-K models were then merged with this model mask (Figure 4). The output from this step was then used as the starting velocity model for the tomographic inversions.

The first step in the velocity update was a global inversion of the background model. This was achieved through several iterations of tomographic inversion using large smoothing diameters after each update. The smoothing diameter in the inversion started with 6 km for the first updates and decreased to 2.5 km for the last iterations. A model mask was built to prevent smearing of channel velocities into the background sediments. This mask was used to allow updates to take place only outside of the channel areas.

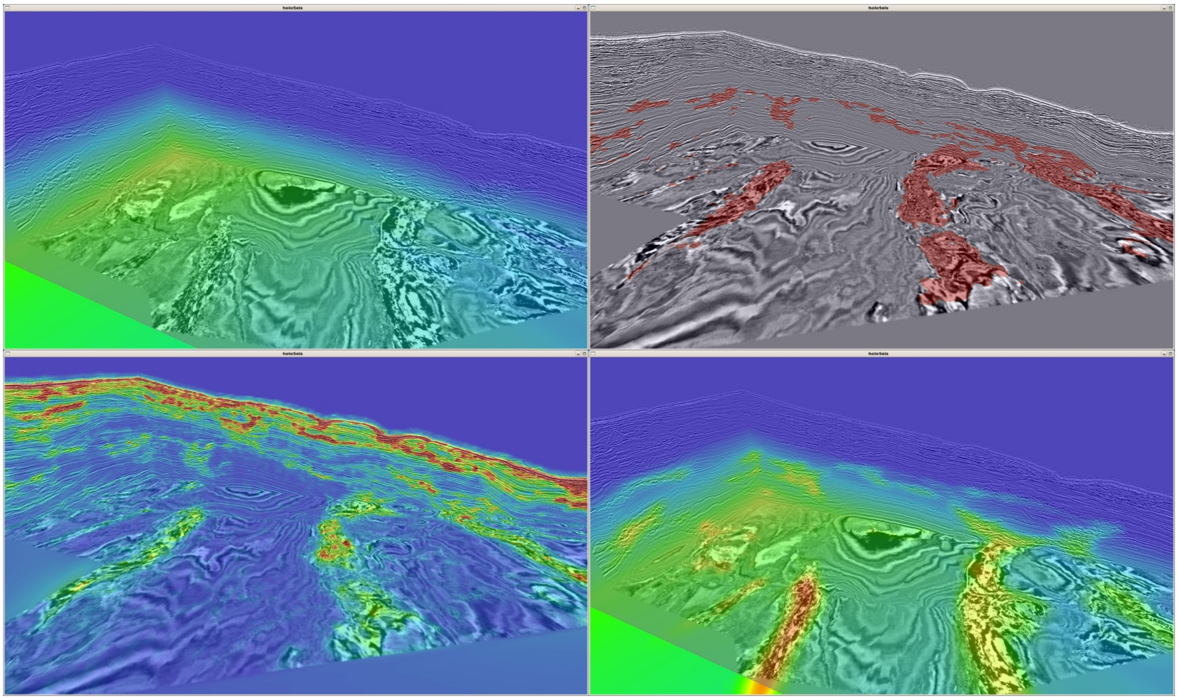

Figure 4 *3D displays showing velocity model building steps. Top left – Initial V0-K model with no shallow channels inserted. Bottom left - PreSTM stack with variance attribute to extract shallow channels. Top right - Mask generated from variance attribute to delineate shallow channels. Bottom right – PreSDM starting model with background V0-K model and shallow channel V0-K model merged.*

In the next step, the complete model (including the channels) was updated. This took place when the lateral smoothing diameter in the inversion approached the extension of the channels (approx. 2.5 km smoothing). The shortest smoothing diameter used was 1.5 km.
With the ability to perform rapid cycle tomographic iterations the bottleneck for project turnaround is the ability to perform appropriate quality control between iterations. Whilst running the first few updates extra care was taken to make sure that the 3D residual time shift picks were robust and accurate (Figure 5).

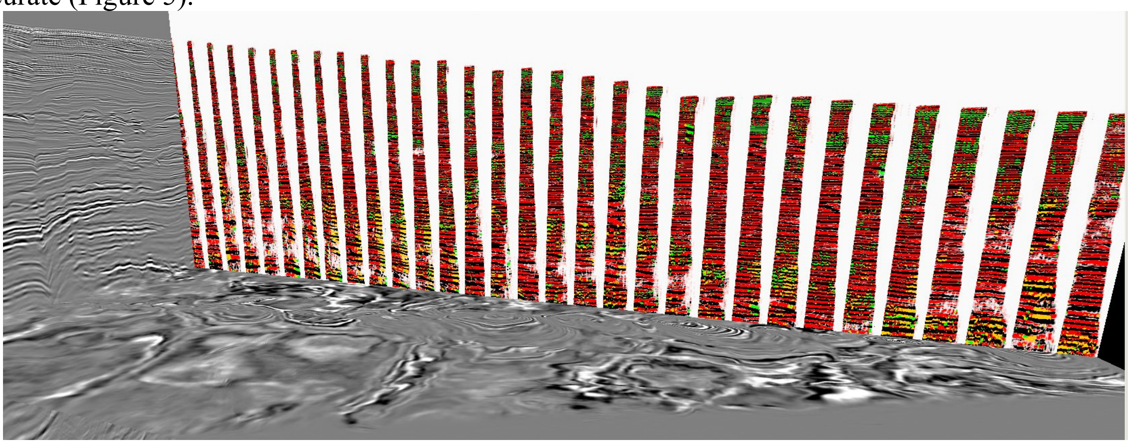

Figure 5 *Wavelets for inversion are selected from several attributes in both the migrated and un-migrated domain. This figure shows scanning and reconstructing wavelets with different time-shifts (Red = shifts +/-4ms, Yellow = shifts -4/-12 ms, Green = shifts -12/-24 ms), corresponding to different velocity errors along the ray path.*

After each tomographic iteration the velocity difference was reviewed for anomalous values, and a Beam PreSDM run with the updated model was checked on gathers every 50m for the full area. Finally, after picking the 3D residual time shifts using the updated velocity model a gamma cube was computed and compared to the one from the previous iteration, where gamma is a volumetric estimate of velocity error in per cent (Figure 6).

Conclusion

Whole volume automated techniques have been used in unison to identify and resolve false pull-up structures associated with shallow channel systems. The pre-stack seismic based anomaly extraction helped to identify areas where imaging of potential prospects may have been impacted by channel systems; and the modified variance attribute provided a detailed and well defined mapping of the channel systems and was used to build a starting model for the tomographic inversion. This enabled the wavelet shift tomography to insert sufficient detail into the velocity model to resolve false structures caused by the shallow channel systems in the overburden (Figures 6 and 7).

The main learning has been that automation streamlines PreSDM velocity model building to timeframes suitable for exploration schedules. This has led to PreSDM processing being used to replace PreSTM processing in new exploration areas.

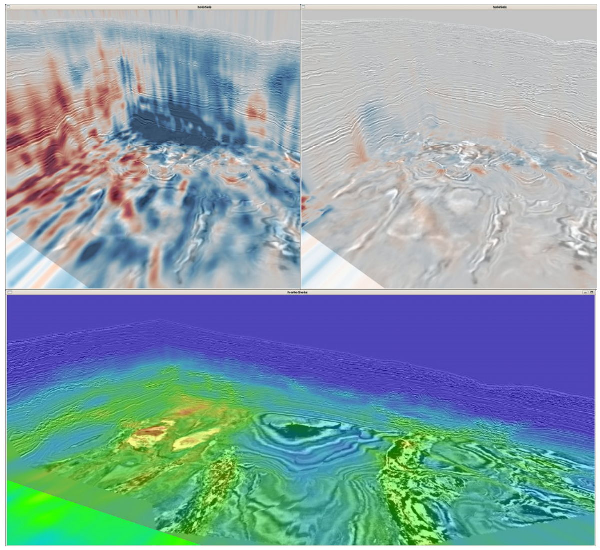

Figure 6 *Velocity error (gamma in %) in the initial (top left) and in the final (top right) velocity models. Near zero gamma values are white, red indicates that velocity is too slow and blue indicates that velocity is too fast. The final velocity model has sufficient detail to resolve the imaging issues (bottom).*

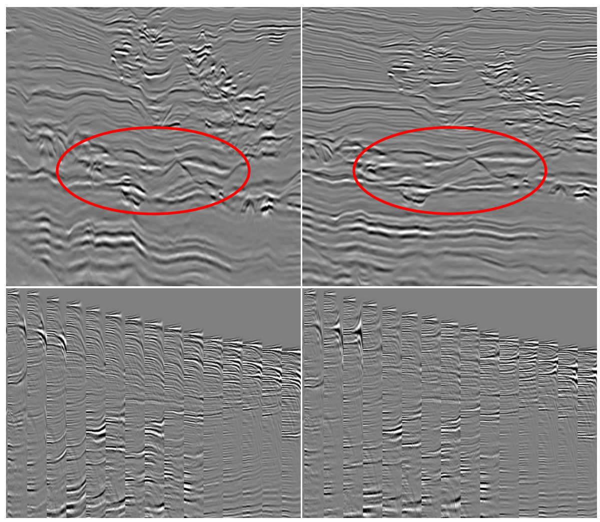

Figure 7 *Beam PreSDM section and common image gather displays before (left) and after (right) wavelet shift tomography. The targets (flat spots) indicated by the red oval have false structure associated with the shallow channels in the overburden (top left) and the CDPs indicated that velocity anomalies have not been accounted for (bottom left). After wavelet shift tomography false structure at and beneath the targets has been reduced (top right) and the CDPs indicated that velocity anomalies have been resolved (bottom right).*

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