High-Resolution 3D Tomographic Model Muilding Using Automatic, Dense Volumetric Picking

Volker Dirks[1], Stephen Pharez*[2] and Vetle Vinje[3]
[1]CGG Americas Inc.,, Texas, USA;
[2]CGG, , Middlesex , U.K.
CGG, Oslo, Norway

Summary

Pre-stack depth migration is increasingly being applied to larger exploration surveys and thus 3D tomography, as the key component of today's velocity model building workflows, has to be performed on large data volumes within acceptable turnaround times. To provide high resolution velocity models, dense volumetric picking is required, which in turn leads to even larger data volumes. It is therefore paramount to automate as many processing steps as possible to free the time of the geophysicist for the necessary QC. We present a modified workflow for high resolution 3D tomography addressing the need for process automation. The flow is well suited to the geology in the Gulf of Mexico, offshore Brazil, West Africa and India, and we illustrate the flow with examples from the regions.

Introduction

Pre-stack depth migration has evolved from a very expensive and time consuming 'specialist tool' to a processing service that is now offered routinely on the majority of exploration plays. The demand therefore for very accurate yet fast depth velocity model building has increased. This combined with the fact that the average survey size of PreSDM projects has been increasing each year poses a number of challenges for the successful execution of such projects. The main challenges are associated with the amount of data that is generated when seismic velocities need to be estimated accurately over a very large survey area. As 3D tomographic update methods have become the industry standard for high-resolution velocity estimates and this requires an abundance of prestack residual curvature information (Wang et al. 1995, Guillaume et al. 2003), such curvature information needs to be picked very densely resulting in a tremendous increase of data to be handled through the process. We examine an improved workflow for sediment velocity estimation, which seeks to solve the problem of combining fast project turnaround with accurate large-scale velocity analysis work. The main idea of this workflow is to automate as many steps of the velocity analysis as possible in order to shorten significantly the cycle time of the model building. The proposed workflow is applicable in all areas where the seismic velocity field can be approximated by a piecewise smooth V(x,y,z) velocity field.

Dense volumetric residual curvature picking

One of the key steps in estimating the correct seismic velocity field is to accurately compute the residual curvature (RC) present in the PreSDM data after migration with an initial velocity field. We examine in more detail the steps we have added to improve the picking efficiency and reliability:

- *Data pre-conditioning. Noise removal (random noise and multiples) and filtering*
- *Dense full volume RC picking*
- *Volumetric 3D geostatistical filtering of RC picks* - After picking of residual curvature on dense CIP prestack gathers we use geostatistical filtering techniques (Hoeber et al., 2003) to clean the pick volume and remove outliers. Figure 1 shows a set of CIP gathers with the initial RC picks (A) and after pick filtering (B). In addition to the geostatistical pick harmonization and outlier removal we also applied salt masking (see below).
- *Automatic salt masking* - To remove all those picks that are not sediment picks the top of salt is usually interpreted and all picks below this horizon are removed. This is a time consuming process and the top salt interpretation would have to be re-done once the sediment velocity are updated. We have therefore derived a way of computing a salt mask from the nearoffset migration stack volume itself. Figure 2 displays such a stack volume with a salt mask attribute overlay (color).
- *Computation of quality factor (Sigma) for pick highgrading* - Tomography algorithms are very sensitive to errors in the pick information that is provided to them. We therefore further improve the quality of our residual curvature picks by filtering and weighting them with a "pick quality factor", which we call Sigma. Sigma is a combination of the local RC pick semblance and th

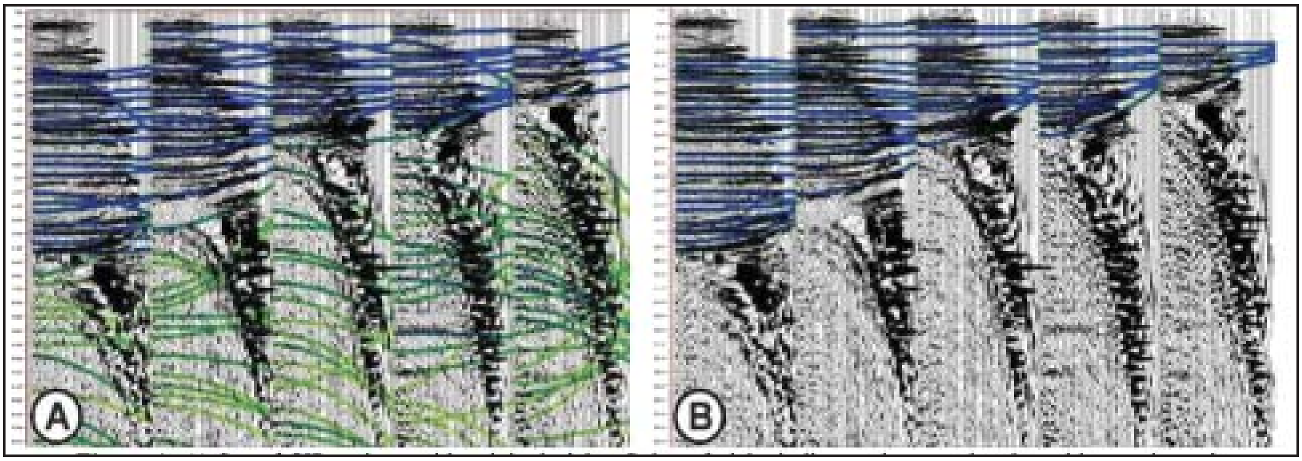

Fig. 1: A) Set of CIP gathers with original picks. Color of picks indicates the associated semblance along the pick curve (blue = high semblance). B) Same set of gathers as A) but with residual curves after geostatistical filtering and salt masking.

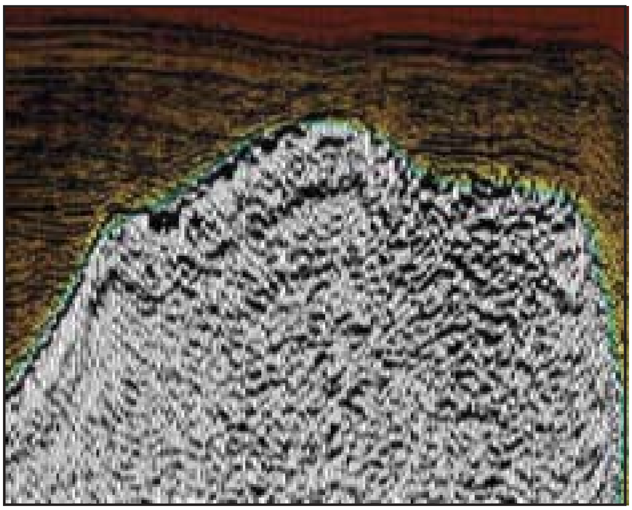

Fig. 2: Overlay of near-offset stack volume and salt mask attribute (color). The salt mask attribute is computed by detecting the frequency change in the data between the sediments and the salt.

spatial structural semblance. Figure 3 shows examples of 2D sections through a RC semblance volume (A), a structural semblance (B) and a sigma volume (C). The RC semblance volume reflects the reliability of the RC picks, which decreases with depth, whereas the structural semblance volume carries information about the spatial coherence of the picks. The Sigma volume indicates where the RC picks are both reliable and spatially coherent (green and red areas in Figure 3 (C)). Once combined with local dip estimates, the RC picks are ready for use in the 3D tomography engine.

3D finite offset depth tomography and inversion QC

The main challenges in using dense volumetric pick attributes for 3D depth tomography are firstly to ensure that all RC picks are reliable and only contain information about the sediment velocity field. Secondly, the inversion needs to be performed quickly even though several million individual picks are used. We ensure fast inversion turnaround by running the tomographic inversion on multi- CPU machines.

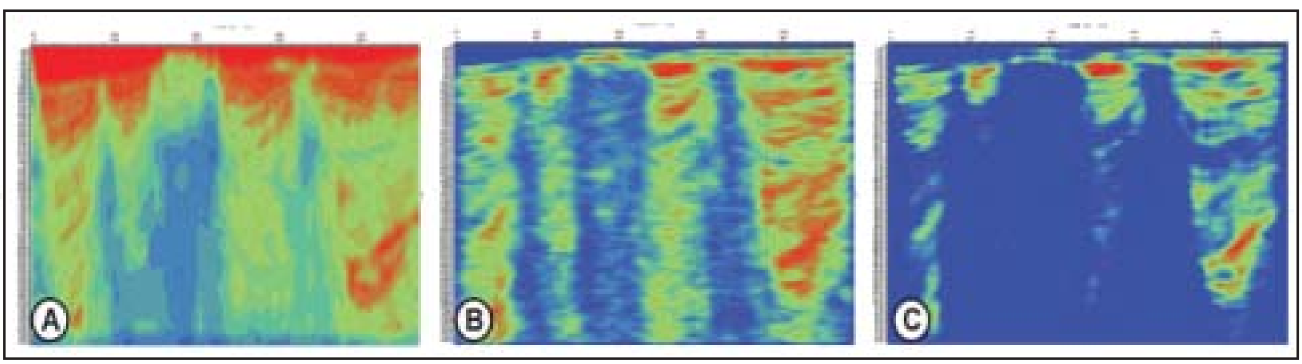

Fig. 3: 2D sections through a RC semblance volume (A), a structural semblance (B) and a sigma volume (C).

Finally, an effective and meaningful inversion QC needs to be available to assess the quality of the updated velocity field quickly without necessarily having to re-migrate data.

Ray-based high-grading - In our workflow we address the pick reliability with a ray-based high grading or further elimination of RC picks during the de-migration phase of the individual picks. If either the ray path between the image point and the source location or the image location and the receiver location traces a path through salt, the pick is removed from the inversion process (see figure 4).

Improved pick weighting - It is well known that deriving a high-resolution velocity field for the shallow section of the overburden using global tomography is a challenge due to the influence of deeper picks. Based on our experience, the key to derive a high-resolution shallow velocity model is through proper weighting of the shallow picks.

Automatic RC prediction - Finally to assess the quality of the updated velocity model without having to re-migrate we use volumetric estimates of residual curvature in the new velocity model, which are computed using ray tracing based kinematic migration (Guillaume et al., 2001). Figure 5a shows 2D section display from the initial RC volume before tomographic update and figure 5b after successful update. Comparisons between predicted and observed curvature confirm the reliability of the prediction. Automatic RC prediction allows for very fast quality control of the inversion results. Figure 6 shows the improvements achieved with the described workflow on a typical Gulf of Mexico dataset. Figure 6 (A) shows the initial velocity model and figure 6 (B) the final model. In figure 6 (C) and (D) cutouts from the initial and final seismic volume are displayed, showing a significant improvement in the image quality after dense, volumetric velocity estimation.

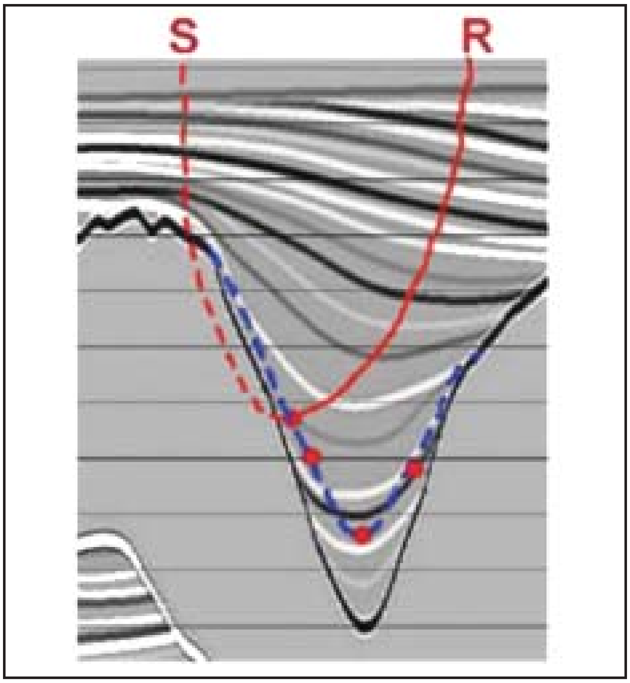

Fig.4 : Ray-based RC pick removal during the tomography update. Picks associated with a ray path that penetrates the salt are eliminated.

Conclusion

We have demonstrated the use of a modified workflow for high-resolution sediment velocity estimation. Most of the processing required for accurate picking of

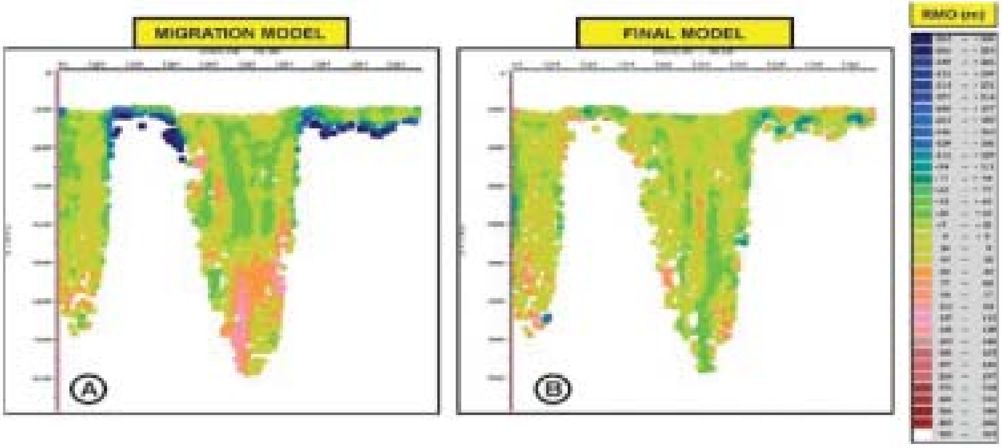

Fig. 5: Residual curvature as measured in the initial migration model (A) compared with the curvature as predicted by the tomography for the final inversion model (B). Comparisons between the predicted and the observed curvatures after actual remigration show a good agreement between the two.

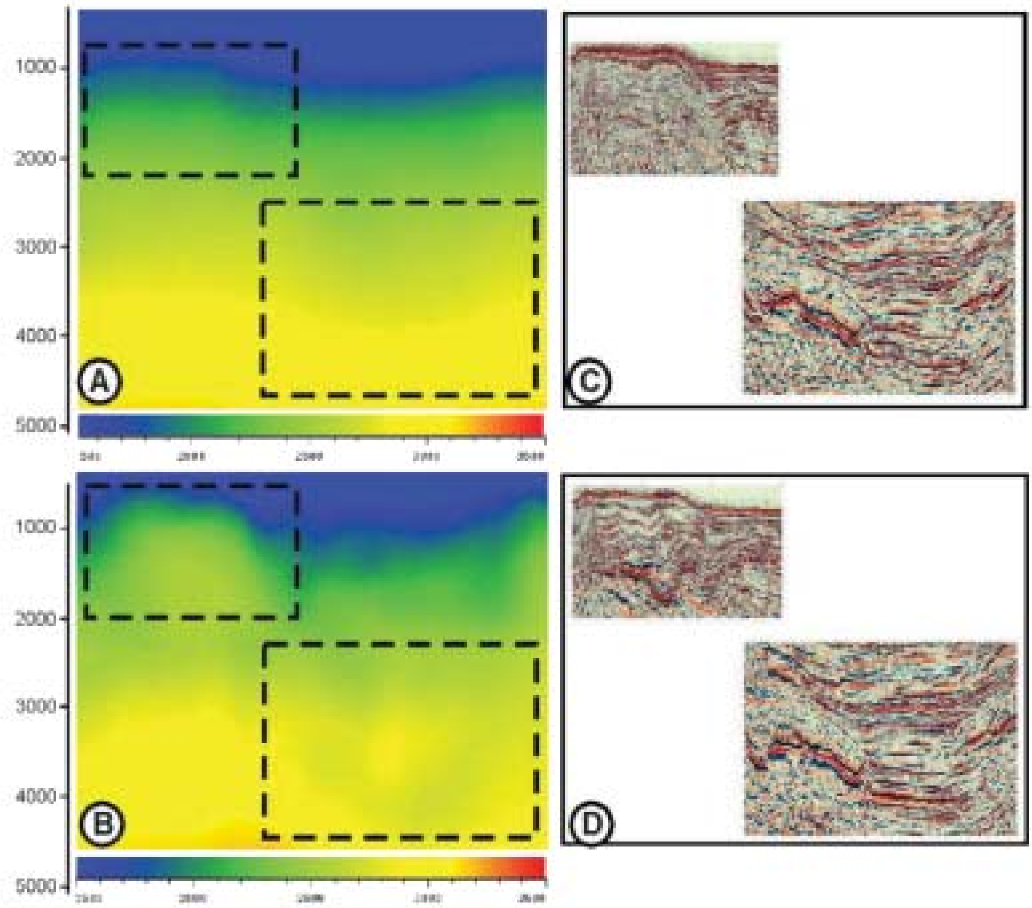

Fig. 6: 2D section of initial (A) and final (B) velocity model after the workflow described in this paper has been applied. The image cutouts in (C) and (D) highlight those areas on the 2D section where significant image quality improvements can be observed.

residual curvature on CIP gathers has been automated and may be performed on full volume 3D datasets. We have successfully utilized geostatistical filtering and pick highgrading to improve the pick reliability. Both the modifications made to the RC picking sequence as well as to the tomographic update and inversion QC have enabled us to reduce our model building turnaround significantly. The real case tests show a significant improvement in the image quality after dense, volumetric velocity estimation.

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