The application of multi-layer tomography for improved depth imaging in the Dutch North Sea  
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Introduction

In the Q7/Q10 area of the Dutch North Sea, velocities are strongly controlled by the stratigraphy, with large velocity contrasts between layers. Large-scale faulting can displace the high velocity Chalk, so that it is adjacent to the slower Middle and Lower Cretaceous. This type of geology is very challenging for conventional grid-based tomographic approaches. Global tomography is unable to accurately represent major velocity and anisotropy contrasts within the framework of a cell based model representation and will not correctly reposition layer boundaries during the inversion process. These limitations necessitate the use of a layer stripping approach. However, such a workflow is time consuming and prone to velocity errors being propagated into deeper layers as the model building progresses.

A new ray-based multi-layer approach for reflection tomography (Guillaume et al. 2012) overcomes many of the limitations of tomographic methods typically employed on PSDM projects. Multi-layer tomography, utilizing a new hybrid model representation, allows layer boundaries to be accurately represented and repositioned by map migration within the inversion. This allows all units in a complex layered model to be updated simultaneously without the need for a layer stripping workflow. This results in a more efficient velocity inversion workflow and improved quality of both models and imaged seismic data.

Multi-Layer Tomography

Many regions of the world exhibit a complex layered geology with significant velocity and anisotropy contrasts which present a major challenge for standard grid based tomography methods. Using reflection tomography to globally update a model which contains velocity contrasts can introduce significant errors into the inverted model in the vicinity of the layer boundaries, such that the positions of the layer boundaries in the model become uncoupled from the corresponding reflector positions in the updated seismic image.

To help overcome these limitations, layer stripping approaches are used to enable accurate repositioning of velocity and anisotropy boundaries (Evans et al., 2005; Jones et al., 2007). The model is divided into a set of layers defined by the major velocity boundaries, which are updated iteratively in a top-down manner. For the inversion of a particular layer, the velocity and anisotropy from the target layer are allowed to “flood” through the boundary position and residual move out from PSDM image gathers is used only for the layer to be updated. Following the tomographic update of the layer velocities, the data are re-migrated and the correct position of the base of layer boundary re-interpreted prior to final calibration to the wells. For a typical North Sea project, as many as six iterations of layer stripping may be required to correctly handle all the major velocity and anisotropy contrasts exhibited by the geology.

As well as being time consuming, layer stripping is also prone to serious velocity errors. Since the method only treats one layer at a time in a top-down manner, it precludes any intercommunication between connected model layers during the inversion process. In addition, it is common practice to “freeze” a layer once it has been updated. While this avoids corrupting the depth position of carefully interpreted layer boundaries, it also results in residual velocity errors being propagated into deeper model layers.
Multi-layer tomography is an extension of non-linear slope tomography (Guillaume et al., 2008; Montel et al., 2009). It uses a new hybrid model format which uniquely defines the velocity and anisotropy parameters for each model layer as a mesh while also carrying the precise information for the layer boundaries as horizons. The non-linear inversion scheme performs kinematic de-migration and re-migration of both the residual move out picks and the layer boundaries.

Since the layer boundaries are repositioned by map migration during the inversion process, preserving their travel time, the traditional layer stripping workflow can be discarded and all layers in the model updated simultaneously. Residual move out information from all layers contributes to the global inversion scheme, resulting in a significant improvement in overall model stability. Furthermore, the integrated horizon information in the hybrid model allows each model layer to be uniquely parameterized to achieve the best possible inversion result. Layers no longer need to be frozen during the inversion process, since the method will allow any layer to be updated during model building without compromising the result. In addition, since the entire initial model is updated during each pass of multi-layer tomography, improvements to the imaging at deeper reservoir levels can be monitored at all stages of model development.

Improvements in model accuracy and stability should naturally translate into improved seismic images with less reflector distortion. Discarding the traditional layer stripping workflow and returning to a global approach for complex layered geology should also yield significant efficiencies in model building and interpretation effort.

**Dutch North Sea Case History**

In this example we compare model and image results obtained using standard layer stripping and multi-layer tomography on a PSDM project from the Q7/Q10 area of the Dutch North Sea. Velocities within the survey area are strongly controlled by the stratigraphy, with large velocity contrasts between layers. Large-scale faulting has displaced the high velocity Chalk, so that it is adjacent to the slower Middle and Lower Cretaceous. This geology is very challenging for layer stripping tomography since the workflow is unable to fully utilize the pick information in adjacent layers due to the presence of large lateral and vertical velocity contrasts (Figure 1).

Model building and imaging of the area was initially completed using a traditional layer stripping workflow. This consisted of five iterations of velocity inversion, structural re-interpretation and residual well calibration. The initial model was constructed from supplied horizons and velocity profiles estimated from well data within the area. A 1D horizon based update was carried out for the first iteration in order to introduce the long wavelength velocity variations for each of the model layers. This was followed by four iterations of layer stripping (Figure 1).

In order to assess the potential benefit of multi-layer tomography on the area, the initial model and initial RMO picks were used to perform 2 passes of velocity inversion, updating the entire model from top to bottom. Layer boundary repositioning was handled within the tomography and results were calibrated to the well data post inversion.

Comparison of the models from the two approaches (Figure 2) clearly demonstrates an increase in stability and geological consistency with the multi-layer approach. This is particularly noticeable within the Middle Cretaceous and Jurassic, where velocity anomalies are clearly present in the layer stripping result due to the propagation of shallow velocity errors from layers which have been “frozen”. Conversely the multi-layer inversion produces a much simpler and more geologically consistent velocity distribution. Comparison of the PSDM results also reveals a significant
improvement in imaging. Reflectors located within the Middle Cretaceous and beneath the thrust fault show less image distortion and a marked improvement in continuity sub-BCU (Figure 3). Imaging of the complex faulted section within the Middle/Lower Cretaceous is also significantly improved with better sub-fault reflector continuity down to the Jurassic (Figure 4).

Conclusions

The application of Multi-layer tomography for imaging of complex layered geology provides significant advantages over traditional layer stripping. The entire model can be updated with a single pass of tomography, as all layer boundaries are repositioned by integrated map migration. Residual move out from all model layers can contribute to the inversion result producing improvements in both velocity model stability and seismic imaging. Traditional layer stripping can be replaced with an efficient global inversion without compromising on quality.

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References


Figure 1: Model schematic showing layers with significant differences in velocity. The traditional layer stripping workflow divided the model into five iterations.

Figure 2: Final velocities from the different tomography methods.
A) Layer stripping tomography showing model instabilities at the Middle Cretaceous & Jurassic
B) Multi-layer tomography showing improved stability and geologic consistency
Figure 3: PSDM imaging beneath a thrust fault and sub-BCU
A) Layer stripping tomography shows distortion Mid Cretaceous and poor continuity sub-BCU
B) Multi-layer tomography shows reduced reflector distortion and improved reflector continuity

Figure 4: PSDM imaging in a complex faulted region
A) Layer stripping tomography struggles to image faulting and sub-fault reflectors
B) Multi-layer tomography provides improved fault imaging and reflector continuity to Jurassic