Velocity model building in complex media by multi-layer non-linear slope tomography.
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Summary
Tomography algorithms using gridded model description and ray tracing have made continuous progresses in terms of resolution and efficiency. However one strong limitation is the difficulty to recover strong velocity contrasts encountered in area with salt bodies or chalk layers. The traditional solution for velocity model building in such a context is to perform a layer stripping approach. In this approach velocities and horizons are updated layer after layer recursively from top to bottom. Such a workflow is however time consuming and prone to velocity errors being propagated into deeper layers as the model building progresses. We present here a solution to remedy these drawbacks. Our solution involves on a non-linear tomographic approach combining information of dense dip and residual move-out picks and of picked horizons to update a multi-layer velocity model. While dip and RMO picks are used to update grid velocity globally within the layers by non-linear slope tomography, picked horizons are kinematically demigrated and remigrated recursively from top to bottom to reposition major discontinuities in the velocity model. We present an application of the method to a real North Sea dataset with a comparison to the layer stripping approach.

Introduction
Ray based migration velocity analysis (MVA) remains the standard for velocity model building in the oil and gas industry. The conventional approach involves several loops of Pre Stack Depth Migration (PreSDM), dip and residual move out (RMO) picking and linear update of a gridded velocity model (Liu, 1997, Woodward et al., 1998; Zhou et al., 2003). In the case of strong velocity contrasts in the velocity model a layer stripping approach is often used (Evans et al., 2005; Jones et al., 2007). The workflow proceeds sequentially from the top to bottom layers. In each layer the velocity is updated by grid tomography while lower horizon is picked on the PreSDM. The need for several loops of PreSDM and picking makes the workflow time consuming and prone to the propagation of velocity errors from top to bottom.

A potential improvement can be brought into the process by the use of a non-linear scheme for the tomographic update. Two great classes of non-linear tomography have been then proposed. First, those that invert for data picked on pre-stack horizons (Bishop et al., 1985; Farra and Madariaga, 1988, Adler et al., 2008). Such approaches can invert globally for a multi-layer velocity model corresponding to the picked horizons, but they remain drastically limited by the need for a highly interpretative picking. Second, those inverting for data corresponding to locally coherent events (Guillaume et al., 2001) which are non-linear slope tomographic methods (see Lambaré 2008 for a review). As they consider local events they can be coupled with dense automated dip and RMO picking tools (Silici et al., 2007) as standard MVA approaches. These approaches offer a very nice improvement for grid tomography (Guillaume et al., 2008, Montel et al., 2009) but so far they had not been extended to a multi-layer version.

Our goal in this paper is to present an extension of non-linear slope tomography to the update of a multi-layer model. Our approach consists of a complex workflow involving first a dense dip and RMO picking and horizon picking. Both are kinematically demigrated to compute kinematic invariants (Guillaume et al., 2001). The multi-layer velocity model is updated through a sequence of global non-linear slope tomographic updates of the gridded velocities and a top to bottom map remigration of horizons. Several iterations insure the convergence of the process. In the present paper we first review non-linear slope tomography. We then present its extension to multi-layer tomography. Finally we conclude by an application to a real dataset demonstrating the benefit of the approach compared to a layer stripping approach.

Non-linear slope tomography
Kinematic information for slope tomography consists of locally coherent events in the prestack un-migrated domain. The locally coherent events are characterized
by their central position \((r,s,T_{obs})\) and by their local slopes in the un-migrated data-cube \((\partial T_{obs}/\partial m, \partial T_{obs}/\partial h)\) \((m\) denotes the mid-point position and \(h\) the offset). For a given velocity model these events can be kinematically migrated in depth. We then obtain the location and dip of the associated migrated facet and even the local derivative in offset of the RMO curve, \(dRMO\) (Chauris et al., 2002). Slope tomography aims at minimizing \(dRMO\) through a non-linear local optimization of the grid velocity model. Note that in most cases the locally coherent events are not picked directly in the un-migrated domain but in the migrated domain and then kinematically demigrated to build a set of kinematic invariants (Guillaume et al., 2001). See Figure 1 for a general sketch of non-linear slope tomography.

Figure 1: Non-linear slope tomography for updating a gridded velocity model from a set of kinematic invariants.

**Multi-Layer Tomography**

Multi-layer tomography is an extension of non-linear slope tomography. It uses a 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. Data for multi-layer tomography consist of a set of dense dip and residual move out (RMO) picks picked on the initial PreSDM common image gathers (CIGs), and a set of horizons picked on the initial PreSDM stack. Both dip-RMO picks and horizons are kinematically demigrated to build kinematic invariant and horizon invariants, respectively (a zero offset kinematic demigration is performed for the horizons).

The update of the hybrid model (the velocity and the horizons) is done by a non-linear iterative relaxation method. During each iteration, the velocity inside the layers is first updated by non-linear slope tomography and then horizons are updated by map migration from top to bottom (Figure 2). The non-linearity of the process is insured by the kinematic remigration of kinematic invariants and of horizon invariants. The convergence is rapidly obtained with typically 5 iterations.

Figure 2: Multi-layer non-linear slope tomography for updating a set of layers characterized by gridded velocity models and horizons. Picks invariants are used to update the gridded velocity while horizon invariants are used to update horizons through map migration.

Since the layer boundaries are repositioned 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 and constrained 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.

Real data application

Our case study exhibits typical geological structures from North Sea area. It is centered on a large Zechstein salt dome bordered by two basins composed of Triassic and Jurassic sediments (Figure 3, Model Building Unit MBU4+5+6) on one side and only Triassic on the other side. The Base Cretaceous Unconformity (BCU) is the base of MBU3, while the Chalk is MBU2 and the Tertiary is MBU1. We observe strong velocity contrasts at the top and bottom of the Chalk but also at the BCU and the salt. These strong vertical contrasts need to be considered during the depth velocity model building, which is an ideal case for multilayer tomography.

In this context, multi-layer tomography allowed building a consistent 7 layer TTI model in only two PreSDM-picking passes. For comparison, the velocity model was also updated in parallel using the layer stripping approach (Figure 4). Figure 5 shows that the depth migrated result obtained from the multi-layer updated model is superior to the result obtained from the layer stripping approach demonstrating the improved accuracy obtained by a global update of layers.

Conclusions

We have proposed a new multi-layer tomography approach. Our approach combines non-linear slope tomography with map migration providing an accurate, efficient and robust solution for velocity model building in areas characterized by strong velocity contrasts. As demonstrated by our real data application, it definitely surpasses the standard layer stripping approach.

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References

data, with or without anisotropy, 71st annual SEG meeting, Expanded Abstracts, 718-721, INV2.2.

**Figure 4:** Depth velocity model and imaging comparison between the layer stripping (a) and the multi-layer (b) approaches.


**Figure 5:** PreSDM comparison between the layer stripping (a) and the multi-layer approaches (b).