Non-linear 3D tomographic inversion of residual moveout in depth Kirchhoff migrated CIG.

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Introduction

It is well-known that depth imaging brings viable solution to complex problems and helps interpreters to quantify and to understand the architecture of the reservoir under study. This recognition leads to a pressure to depth-image larger and larger areas and to shorten the delivery delay. However, the success of a depth imaging projects requires testing of different methodologies and relies on several trial and errors during depth velocity model building. This means the use of costly iterative sequential scheme of full PSDM followed by linearized tomographic inversion.
We present here a new method for depth velocity building which we believe will help us to achieve a fast turnaround of depth imaging project and give us full flexibility for testing and adjusting our model parameterisation and inversion setting.

Method

Reflection travel-time tomography (e.g. Bishop et al, 1985, Chiu and Steward, 1987) was developed for velocity model building long before 3D PSDM was routinely used in the industry. The principle of reflection travel-time tomography is formulated as an inverse problem of fitting invariant pre-stack travel-times T^{obs} and the associated classical objective function to be minimized with respect to the velocity model **m** is

$$\boldsymbol{C}(\mathbf{m}) = \left\| \boldsymbol{T}^{obs} - \boldsymbol{T}(\mathbf{m}) \right\|^2 \qquad (.1.)$$

Reflection travel-time has the major advantage of using the invariant prestack travel-time allowing us to solve the non-linear tomographic problem by iterative linearization and to ensure convergence even if the starting velocity model is different from the optimal one. The main drawback of the classical reflection travel-time tomography is the required difficult access to kinematic information in pre-stack un-migrated time domain. Several methods were proposed to add some robustness in this task. Some of these methods rely on the use of different analytical move-out description (Guiziou et al, 1996, Sexton, 1998, Duveneck, 2004) or use automated local coherent picking (Billette & Lambaré, 1998, Whiting, 1998).
Another approach of reflection tomography, so called migration velocity analysis (MVA), was developed by accessing pre-stack kinematics in post migrated (time or depth) domain (van Trier 1990, Stork, 1992, Whitcombe, 1994, Lui and Bleistein, 1995, Adler, 1996). Indeed, interpretation of reflected events is more reliable on migrated gathers and nowadays, such migrated seismic gathers are always available at hand. The MVA inverse problem can be formulated as minimisation with respect to the unknown tomographic velocity model **m** of the following cost function

$$\boldsymbol{C}(\mathbf{m}) = \left\| \Delta \boldsymbol{z}^{obs}(\boldsymbol{h}, \mathbf{m}) \right\|^2 = \left\| \boldsymbol{z}^{obs}(\boldsymbol{h}, \mathbf{m}) - \boldsymbol{z}(\boldsymbol{h} = 0, \mathbf{m}) \right\|^2 . \qquad (.2)$$

Many implementation of such MVA optimisation exists and they came with different subtle differences. However, they almost share the point that they are solving only a linear inverse problem and they need re-migration of pre-stack data for the next linear iteration. This sequential and iterative scheme leads to a costly workflow and sometimes prevents us to reach the full potential of depth imaging projects.

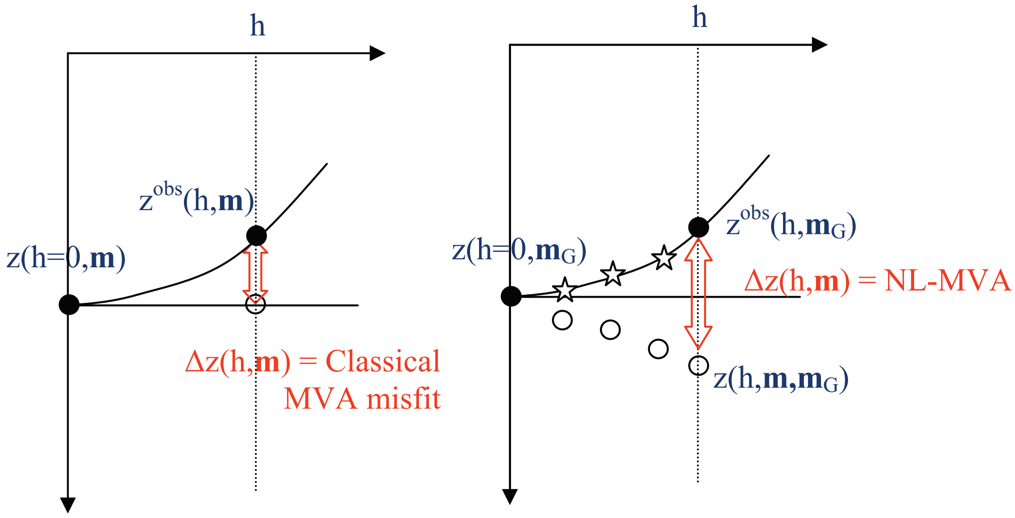

Figure 1: Left: Classical MVA with the goal of minimization of depth shift relative to zero offset depth position. Right : Our Non-linear MVA approach defined with the principle to predict the depth positioning (or moveout) for all finite offset. Both approaches try to flatten the gathers after model updating

We present here a new non-linear tomographic inversion method in post migrated depth domain (Adler & al , 2008). The fundamental concept in our MVA approach is that we consider the depth of reflected events in migrated images (using the initial migration velocity $\mathbf{m}_G$) as the invariant observable data. Note, that this is similar to the use of invariant observed travel-time T^{obs} in classical reflection travel-time tomography while in classical MVA approach, the lack of depth model independent data exclude the ability of a non-linear scheme. The full non-linear inverse problem is now formulated as fitting of this invariant observed depth position with predicted depth position in the tomographic velocity model $\mathbf{m}$ (see figure 1) and the associated objective function is then written as:

$$C(\mathbf{m}) = \left\| z^{obs}(h, \mathbf{m}_G) - z(h, \mathbf{m}_G, \mathbf{m}) \right\|^2 \quad (.3.)$$

Here, we explicitly write the dependence of predicted migrated position *vs*. the initial (possibly wrong) depth migration model $\mathbf{m}_G$ and the optimized tomographic velocity model $\mathbf{m}$. We do so, to emphasize another important feature of our new MVA approach: Our non-linear inversion scheme operates with two distinct velocity models. The consequence of such splitting of migration velocity and updated tomographic velocity are two fold:

- First, doing so, it allows predicting depth position $z(h, \mathbf{m}_G, \mathbf{m})$ to be matched to invariant depth position observed in migration velocity images. This problem is solved (Adler & al, 2008) by pre-stack demigration using tomographic model of depth interpretation to get a set of invariant data in time domain. Then we simulate depth migration processing to get depth position in the fixed migration velocity. Simulation of depth migration kinematics can be done by implementing pre-stack map migration. However, we prefer to solve the imaging condition equations (Liu and Bleistein, 1995) using travel-time tables used by the full PSDM.

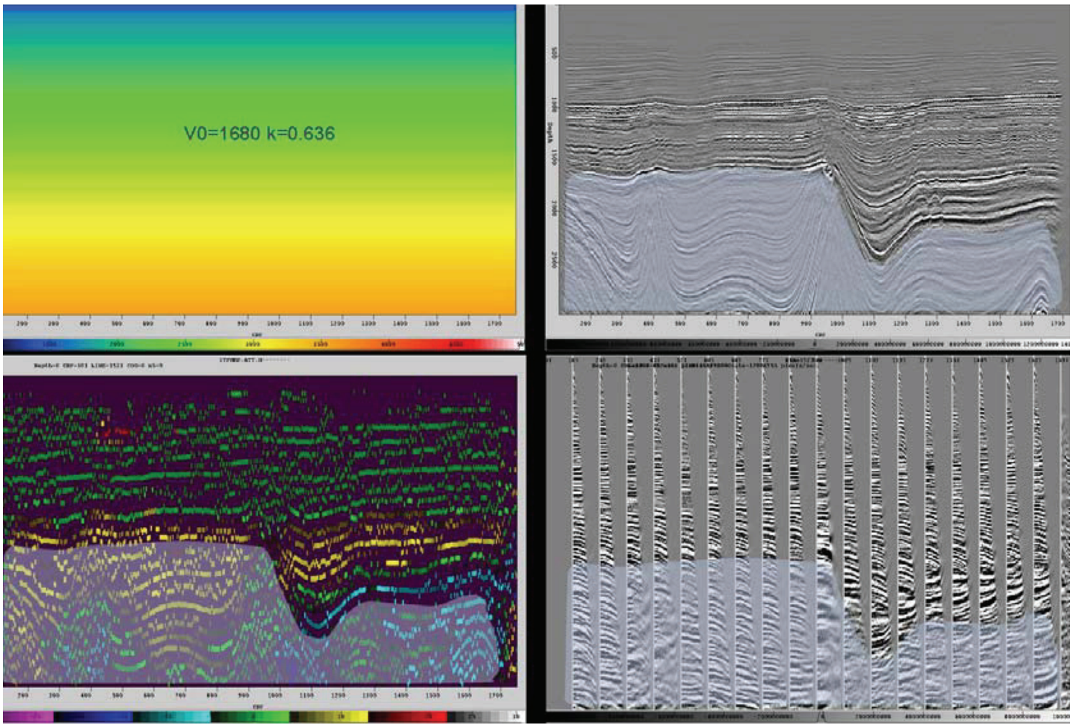

Figure 2: From upper left to bottom right : Initial migration 1D isotropic model, associated 3D PSDM images, Flatness index of migrated CIG associated to initial velocity model and finally migrated CIG showing residual moveout.

- Second, besides CPU cost considerations, operating with the two distinct velocity models adds a full flexibility for inversion parameters testing. One can tests different scenarios for model description (grid vs. blocky, number or distance between velocity nodes) or playing with inversion tuning parameters such as the trade-off between the data objective function and a priori information. All these tests can be done on the fly during tomographic inversion without having recourse to intermediate full PSDM runs and associated QC. As a consequence, processor can not only achieve a fast turnaround for the depth imaging project or achieve a better convergence to the true models, but also gain a better understanding of real geological model under study, thanks to the flexibility for testing several scenarii and predicting the associated residual moveout.

Wang et al (2006) apply a demigration of locally coherent depth migrated events in the migration model followed by exact 3D finite-offset map migration in the tomographic model. To our knowledge, this is another method which operates with two distinct models and allows non-linear iterations, while the fitting was defined on the basis of invariant data observed in pre-stack un-migrated domain.

Application

We applied our non-linear inversion method during a 3D depth imaging project. Figure 2 shows the initial optimized 1D isotropic velocity model. This initial model was used to run a full 3D PSDM and to measure the post-migration residual moveout in the gathers. The flattening index cube and migrated gathers indicate that 1D velocity model was too fast in the second layer and slower beneath.

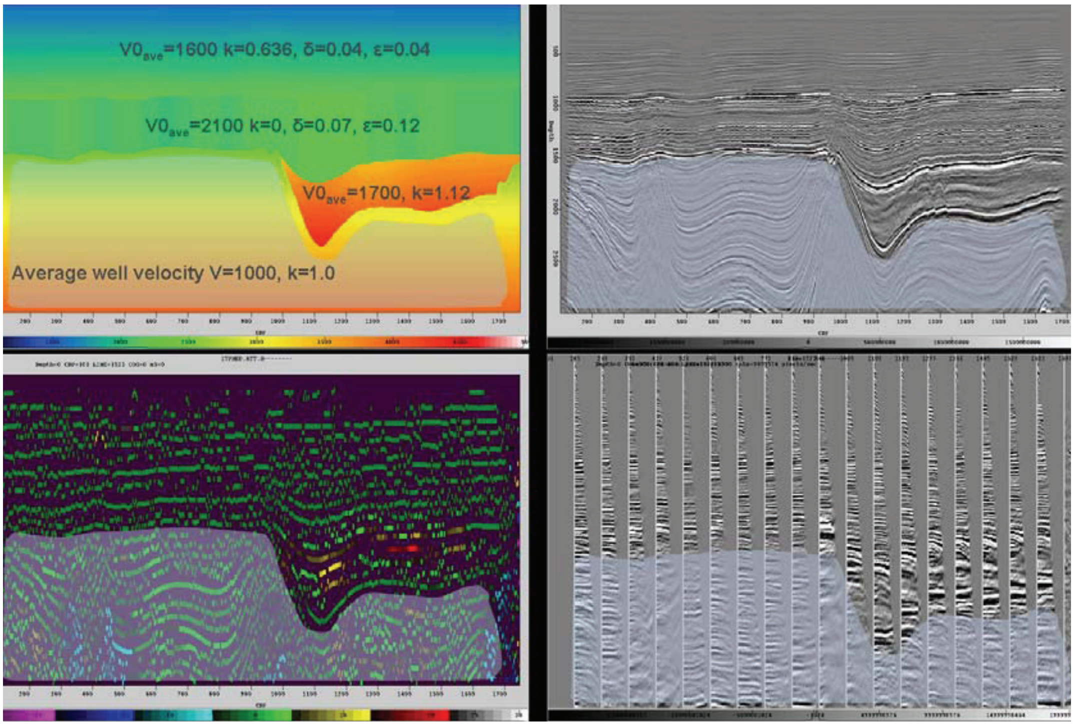

Figure 3: From upper left to bottom right : Optimized anisotropic model using the non-linear MVA approach, associated 3D PSDM images, Flatness index of migrated CIG corresponding to the optimized tomographic model and finally the corresponding migrated CIG.

Comparison with well marker shows also some keys horizons are too deep indicating that anisotropic description for associated layers is more suited. We could use for this imaging project the standard sequential iterative PSDM and tomography workflow. However, our new non-linear MVA inversion allows us to perform tens of iterations starting from the previous PSDM run. During these non-linear iterations, we were able to switch from isotropic to anisotropic description for specific layer under test, or to switch from global inversion to layer stripping approach and to test different options for model parameterisation and inversion regularisation without depth remigration of pre-stack data. Thanks to the non-linear inversion scheme and to the predicted residuals in the updated model. Figure 2 shows the results of the second full volume PSDM and associated QC map.

Conclusion

We presented a new non-linear tomographic approach with the novelty of using initial migrated depth position in PSDM gathers as invariant data to fit. This method reduces cycle number of the standard sequential full volume PSDM runs. It adds also a full flexibility for inversion parameters, a priori information or interpretations scenario testing.

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