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TI Model Building through Geologically Regularized Tomography

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SUMMARY

A vast number of case histories have demonstrated that anisotropy cannot be neglected in several fields of interest: among others, the creation of a reliable seismic image, AVO analysis, AVO modeling and pore pressure prediction. The standard industrial tool for velocity model building is grid tomography: it is therefore straightforward to be interested in the extension of the tomographic techniques to manage anisotropic parameters at the same accuracy of the velocity field. A regularized approach to anisotropic multi-parameter tomography is proposed, exploiting the knowledge of geological models and geological data to reduce the ambiguity in tomographic inversion and thus improve achievable resolution and reliability of anisotropic tomography.

A depth-domain inversion technique, completely based on PSDM and on the classic CIG flattening principle, is proposed. It is based on a joint tomographic inversion of two anisotropic velocity volumes, which are able to properly account for the non-hyperbolic residual moveout of CIGs. The method is applied on a multi-azimuth dataset and on a marine dataset.

Introduction

Nowadays it is widely accepted that anisotropy cannot be neglected in the creation of a reliable seismic image, and accordingly anisotropy estimation has entered into the standard practice of industrial seismic imaging. In particular, anisotropy estimation allows obtaining at the same time a seismic volume which presents (reasonably) flat Common Image Gathers (CIGs) and which is calibrated to available well markers. Anisotropy is also of paramount importance for proper AVO/AVA analysis, which is more and more often being performed on depth migrated data.

As a consequence industry is interested in the extension of the tomographic techniques to estimate anisotropic parameters at the same degree of accuracy of the velocity field, and most importantly, using the residual moveout that can be measured directly in the post-migrated depth domain.

Therefore, a depth-domain estimation technique is pursued, which is completely based on PSDM and on the classic CIG flattening principle.

Nonetheless reflection tomography is well known to be an undetermined ill-posed inverse problem, and the solution of inversion is highly non-unique. The ill-conditioning of the tomographic problem is even worse in the anisotropic case, due to the increased number of degrees of freedom.

In order to stabilize anisotropic tomography it is desirable to fill in the null space with constraints that incorporate geological knowledge into tomographic inversion. A widespread approach is to regularize the velocity updates by using steering filters, trying to maximize the alignment of the velocity gradient along the perpendicular direction to geological structures (Clapp et al., 2004). Although geologically consistent, this regularization alone might not be enough to exploit all the information provided by geological models and geological data: well-markers and/or structural constraints on particular horizons (typically the flatness of the base of salt) can provide other means to reduce uncertainty.

To this purposes, new regularizers have been developed to address these specific problems. The joint application of geological regularizers to a multi-parameter anisotropic inversion can reduce the ambiguity and thus improve achievable resolution and reliability of anisotropic tomography.

Figure 1 CIGs before and after velocity analysis. Epsilon model in the central panel.

Method

VTI or TTI propagation velocity V_g can be described by three parameters V_V, V_N, V_H (V_V is the vertical velocity, V_N is the normal moveout velocity and V_H is the horizontal velocity). Two additional parameters are needed to define the TTI symmetry axis throughout the 3D space, and they are usually derived from an already available migrated image by estimating structure slopes, thus making the model a STI model (structurally conformable TI model), where the symmetry axis is assumed to be perpendicular to the reflectors at every point. The tomographic operator can be built starting from the linearization of V_g (V_V, V_N, V_H), whilst residual moveout is extracted from CIGs using automatic non-hyperbolic algorithms, to be able to adapt to the complexities of anisotropic propagation.

At every tomographic iteration, the complete tomographic operator to be inverted is:

$$\begin{bmatrix} \mathbf{G} \\ \mathbf{R} \end{bmatrix} \Delta \mathbf{m} = \begin{bmatrix} \Delta \mathbf{t} \\ -\mathbf{Rm} \end{bmatrix}$$

The tomographic operator $\mathbf{G}$ backprojects the residual traveltimes on the model parameters, here represented symbolically by $\mathbf{m}$; $\mathbf{R}$ is the regularization matrix that is applied to the updated model, and not on the inverted perturbations. Using only conventional regularization, it is common practice to invert for V_N and V_H perturbations only, since these are the two components of the velocity that directly influence residual moveout of migrated events.

Additional regularization terms are needed to constrain the vertical velocity V_V (which in the TTI case is measured along the symmetry axis); this parameter is mainly responsible for the depth positioning but has no direct influence on residual moveout. For instance by imposing geometrical constraints directly on the shape of target reflectors, it is possible to apply operators of the form

$$\mathbf{C}(\hat{\mathbf{z}} - \mathbf{z}) = \mathbf{C}\mathbf{H}_z\Delta\mathbf{m}$$

where $\mathbf{z}$ and $\mathbf{H}_z$ are the current reflector map and its zero offset rays tomographic operator respectively; $\hat{\mathbf{z}}$ may contain either well-markers or the desired reflector map subject to some smoothness or shaping constraint described by the 2D operator $\mathbf{C}$.

Figure 2 Marker based regularization. (left) original horizon, with highlighted marker misties (red lines); (right) horizon after regularization: the inverted velocity update is calculated in order to honour markers and to minimize distortions on the horizon's original shape.

Conclusions

By exploiting the link between the update of the velocity model and the update on the imaged reflector it is possible to design several different constraints which allow to reduce the null-space of tomographic velocity analysis. This is especially useful for anisotropic tomography, which exhibits strong ambiguities and non-uniqueness. The introduction of interpretation driven and geologically consistent information into the tomographic inversion should in any case obtain (or preserve) event flatness in common image gathers to ensure consistency with seismic data. Conversely, consistency with seismic data can be used as an indicator to validate the a priori geological model.

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References

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