Seismic Reflection Tomography with 3D RTM Angle Gathers

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SUMMARY

3D angle domain common image gathers (ADCIGs) from reverse time migration (RTM) provide accurate representation of residual moveout in complex media, especially in the presence of salt. Thus, tomography with residual moveout picked from RTM angle gathers allows us to build accurate models for seismic imaging. However, RTM angle gathers bring some challenges too. Among them are spatial under-sampling and insufficient angular sampling in deep parts of the image. In this paper, we present the approaches to overcome such problems and our complete work flow to build models with 3D RTM angle gathers.

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3D angle domain common image gathers (ADCIGs) from reverse time migration (RTM) provide accurate representation of residual moveout in complex media, especially in the presence of salt. Thus, tomography with residual moveout picked from RTM angle gathers allows us to build accurate models for seismic imaging. However, RTM angle gathers bring some challenges too. Among them are spatial under-sampling and coarse angular sampling in deep parts of the image. In this paper, we present the approaches to overcome such problems and our complete work flow to build models with 3D RTM angle gathers.

Introduction

The tomographic model building in angle domain follows roughly the same workflow as that in offset domain. For our angle domain tomography, we utilize 3D RTM gathers that are decomposed into azimuthal sectors and opening angles. In order to pick such information, we propose two picking strategies, curvature analysis (Gamma scanning) and the cross-correlation based picking, which are combined into one picking algorithm. For wide azimuthal (WAZ) or multiple azimuthal (MAZ) acquisition, angle gathers usually suffer from the spatial under-sampling problem, which requires proper gather conditioning. Another challenge is that the angular sampling in the deep region of a RTM angle gather is coarse. A solution to this is to refine sampling. However, this will further increase the oversampling in the shallow region, and dramatically increase the I/O and storage expense. A better approach to tackle this problem is to insert specular ray pairs between the picks during ray-tracing to properly set up equations for under-sampled events.

RTM angle gathers

Cross-correlation imaging condition could be used to produce stacked RTM image (Claerbout, 1985). Many methods have been formulated to get migrated pre-stack data in the form of angle gathers. We use the method presented by Crawley et al. (2012) that produces angle gathers directly from the migration based on mapping of the local wave-front directions. This also allows for the construction of azimuth sectored angle gathers, which is particularly useful when dealing with WAZ/MAZ surveys. The key component of those gathers – azimuthal variation of moveout - could be used in TTI/TORT model building. If source or/and receiver arrays are coarsely sampled, angular coverage within ADCIGs will be sparse, thus proper conditioning of gathers is needed before the model building stage.

Tomography

A key step of a tomographic model building process is residual moveout picking. Zhou et. al. (2012) proposed a volumetric curvature analysis for angle gathers that essentially scans γ in the provided range and picks the curve with the maximal semblance. To capture the azimuthal information that exists in 3D RTM angle gathers, such analysis is performed volumetrically on each azimuthal sector individually. This picking scheme is complemented by a more general picking algorithm that measures the moveout shift by a cross-correlation technique. This approach can be applied either on individual azimuthal sector or the whole gather.

To set up the equation for a picked residual moveout, a specular ray pair is traced to the surface to obtain the ray path information. As RTM angle gathers suffer from coarse angular sampling in the deep region, we trace specular ray pairs at a depth variant angle increment that is bigger in shallow but finer in deep. The corresponding residuals are calculated from the picked γ value in the case of curvature analysis or interpolated from the adjacent picked residuals in the case of cross-correlation based picking. Since more ray pairs are traced from the deep region, the ray coverage is better (Fig. 1) and the null space of tomographic operator is reduced.

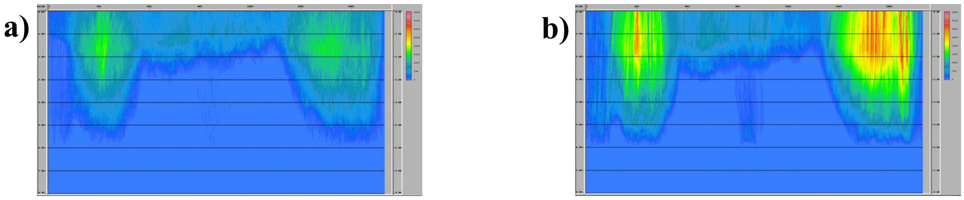

Figure 1 Ray coverage comparison: a) ray pairs are traced for each sampled angle; b) ray pairs are traced according to a depth variant angular sampling.

By tracing all specular rays, the tomography system can be set up with a smoothing regularization operator (Zhou et. al., 2009) as

$$\mathbf{S}\mathbf{S}^{\mathbf{T}}\mathbf{A}^{\mathbf{T}}\mathbf{A}\mathbf{x} + \tau\mathbf{x} = \mathbf{S}\mathbf{S}^{\mathbf{T}}\mathbf{A}^{\mathbf{T}}\mathbf{b}\,, \qquad (2)$$

where **x** is a vector of parameter perturbations; matrix **A** contains their coefficients obtained through ray tracing; and **b** is the data vector; **S** is the smoothing operator; **T** represents the transpose; and τ is the regularization factor. Iterative tomography gradually flattens the angle gathers (Fig. 2).

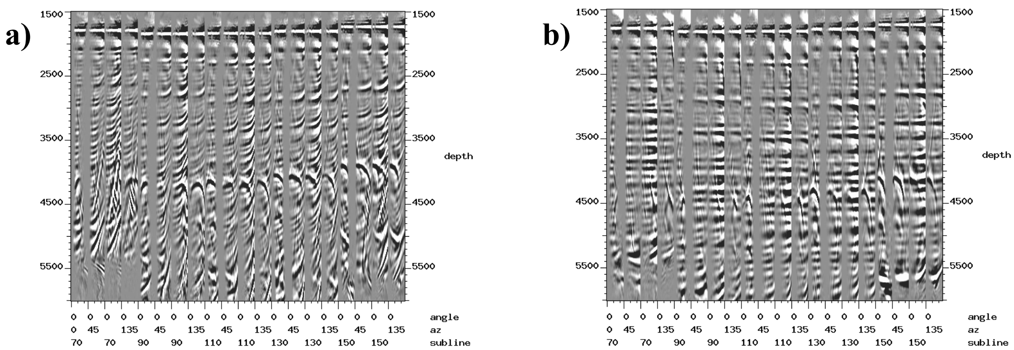

Figure 2 Angle gather comparison: a) migration with initial model; b) migration with final model. Each panel contains 4 azimuths (0,45,90,135) and angle gathers from 0 to 50 degrees.

Conclusions

RTM is used to produce accurate angle gathers that are subsequently used for tomographic velocity updating. We pick the residual moveout by using a combination of curvature-based, and cross-correlation based picking. The picks are incorporated in the tomography system of equations after using careful conditioning and depth variable angle sampling. The resulting solution enables us to successfully build models with 3D RTM angle gathers.

References

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