Fast velocity model building using kinematic demigration and migration

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Summary

3-D prestack depth migration is the most time consuming part in velocity model building. To minimize the required iteration of depth migration, we first perform a demigration to the pick residual moveout (RMO) to get unmigrated time gathers, then zero-offset migration and two point ray tracing is performed iteratively to obtain the new traveltime through the updated velocity model at each iteration. There is no need for prestack depth migration at each iteration. The new approach is more rigorous than other conventional tomography approaches.

Introduction

With the target area becoming more and more complicated, prestack depth migration is already a route processing step for seismic imaging. The success of depth imaging depends on a good migration velocity model. The general step to get an accurate velocity model is based on flatting the common-imaging gathers (CIGs) after prestack depth migration. The prestack depth migration takes a significant amount of time, considering the huge data size of modern 3-d seismic data.

Tomography, based on the domain it is working can be classified into two categories: one is done in time domain (Bishop et al., 1985, Billette et al., 1999), and the other one is done in depth domain, which is also called post-migrated tomography (Stork, 1992). The advantage of time domain tomography is that the data needs to be picked once. However, when the geology structure is getting complicated, time domain picking is cumbersome and problematic. To solve the problem, Stork 1992 proposed tomography in post-migrated domain, which requires picking of CIGs after each prestack depth migration and the picking is much easier.

The conventional post-migrated tomography is based on the loop of full prestack depth migration and velocity model updating, which requires intensive computation time. To speed up the turnaround time of tomography, an efficient tomography algorithm should have a migration engine build in so that it can approximately predict the shape of CIGs after velocity model is updated. In this way, the full prestack depth migration can be reduced to minima. The most efficient and ideal tomography first demigrate the picked CIGs to find the specular ray path, the convert the depth residual into time domain to build up the tomographic matrix. A build-in migration engine is included in tomography to predict the trajectory of CIGs after the velocity model is updated. The most successful using of this idea is in paper by Guillaume et al., 2003 and Wang et al., 2005). The workflow of the tomography loop is shown in Figure 1.

Using the workflow in Figure 1, the external loop (prestack depth migration) is reduced into a minimum, instead of migrating the whole dataset at each iteration. The internal loop basically mimics a migration engine, which predicts what the CIGs will look like with the updated velocity model so that the full migration is not needed. Generally, the internal loop has some assumptions associated with it, such as small dip, hyperbolic moveout, etc. So, when internal loop is converged; we still need external loop to further update velocity. Compared with the scheme that requires depth migration at each iteration, the workflow is highly efficient. In this abstract, we proposed a new approach for internal loop which has no assumption with it, and is able to predict the time residual more accurately.

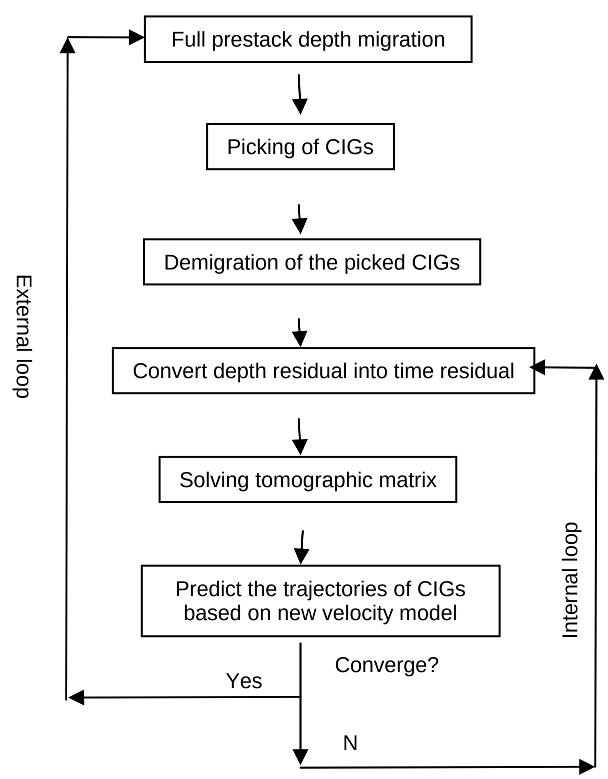

Figure 1. General workflow of tomography

Methodology

Since the internal loop of tomography is mimicking the depth migration, the input data to this internal loop should be in time domain, which means we should convert the picked CIGs back to time domain. This needs us to find the specular ray path of each event in the CIGs. The way to find specular ray path is shown in Chauris (b) et al, 2002 and Guillaume et al., 2003. This process is also called demigration (Guillaume et al., 2003; Wang et al., 2005). It can be considered a process that undoes the migration, so the time section after demigration can be considered to mimic the prestack seismic data, which is called time-independent data by Guillaume et al., 2003. Then after demigration, the goal of tomography is to produce a velocity model which can best explain the demigrated time section.

To get complete CIGs, we must migrate seismic data with different offset, which equivalent to a common-offset migration. According to Chauris et al., 2002, the focusing equation for a common-offset migration is:

$$t_s(s, x, z, v) + t_r(r, x, z, v) = t^*(m, h) \quad (1)$$

$$\frac{\partial(t_s + t_r)}{\partial m} = \frac{\partial t^*}{\partial m} \quad (2)$$

where t_s and t_r are one-way traveltime from s and r to imaging point (x, z); m, h are midpoint and offset, respectively; t^* is the seismic data traveltime.

For zero offset trace, we have

$$p_s = p_r \quad (3)$$

$$p_m = \frac{p_s + p_r}{2} \quad (4)$$

Sutstitue (3) and (4) into (2), we will have

$$2p_0 = p_0^* \quad (5)$$

where p_0 is zero-offset ray parameter. Equation (5) tells us that after demigration, the travetime derivative (p_0) is half of the ray parameter p_0^* measured on the zero-offset seismic data. Also, the zero-offset demigration time equals to half of the recording time on the seimic data.

By using p_0 and t_0, and the concept of parsimonious migration (Biaolong and MeMechan, 2001), we can migration the zero-offset spike using different velocities, which means we can build in a zero-offset migration engine into tomography to predict when the velocity model is updated, how the reflection point will move spatially.

So, the internal loop steps are summarized as followed:

1) Pick local consistent reflectors, estimate dip and azimuth (Figure 2a),
2) Find the specular ray paths of the picked CIGs (Figure 2b) based on the dip and azimuth to get the unmigrated time gather T (Figure 2c),
3) Zero-offset ray tracing according to the demigrated time and traveltime derivative (p_x, p_y) into the velocity model to get spatial position (x, y, z) (Figure 3a),
4) For non-zero-offset traces, do a two point ray tracing to the (x, y, z) and the corresponding source and receiver positions, and calculate the traveltime time T′= (Ts + Tr) (Figure 3b),
5) The traveltime difference between T′ and T will be the traveltime residual to update velocity (Figure 3c),
6) After doing steps 3-5 for all the picked CIGs, solving tomographic matrix to update velocity model,
7) Repeat step 3) to 6) until the internal loop is converged,
8) Return to external loop (full prestack depth migration), and repeat 1) to 7) until the whole tomography is converged.

In step (5), we calculate the traveltime residual based on ray tracing. The conventional way of converting depth residuals to time residuals is based on Stork, 1992, Bee Bednar, 1994, there are several assumptions associated with this depth-time conversion equation: 1) local constant velocity assumption; 2) It usually uses zero-offset depth as reference to get the depth residual, which is not accurate because when velocity model is wrong, the zero-offset depth is also wrong. As pointed out by Woodward et al., 1998, this approach leads to some loss of accuracy. To solve this problem, Van Trier (1990) and Zhou et al (2001), uses unmigrated normal ray from a given reflector as reference, which is kind of similar to our approach, both are using zero-offset traveltime as reference. Compared with other tomography method, our approach doesn't have assumptions such as small offset, small dip, or hyperbolic moveout etc. the idea of updating the layer (or reflection point) position using zero-offset traveltime and traveltime derivative can also be found in Sexton and Williamson, 1998, Fei and McMechan 2003.

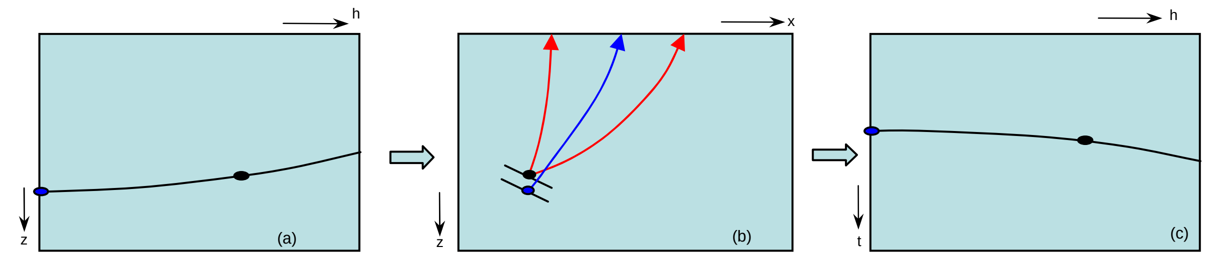

Figure 2. Sketch to show the process of getting unmigrated time section.

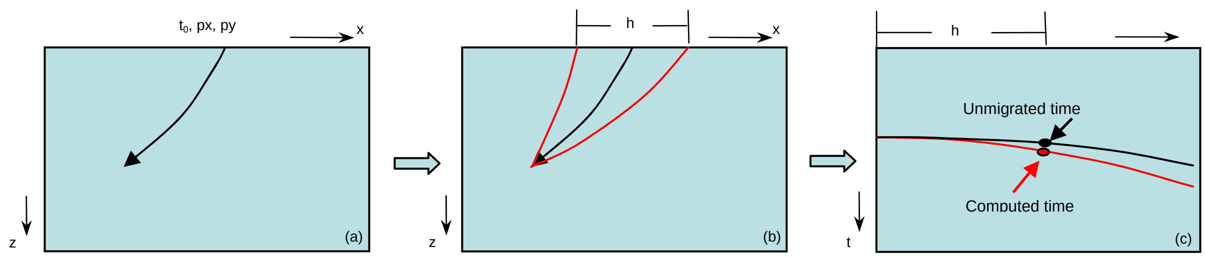

Figure 3. Sketch to show the procedure of getting traveltime residual.

Example

We present a simple example in this section to show this concept works.

A single layer velocity model with dip 30 degree and velocity 2000 m/s is designed, and common shot gathers are generated by a ray tracing modeling program. Then the velocity model is perturbed by 20% lower, and prestack depth migration using the perturbed model is performed to get the common-image gathers. Then following the tomographic steps shown in previous section, we got the unmigrated time gather for one picked image point. We overlayed the unmigrated time section onto the corresponding prestack seismic data (Figure 4), and it shows these two are matched quite well, which means we can use the unmigrated time gather as the reference time to update velocity model. The time obtained from zero-offset migration and two-point ray tracing is shown in Figure 5 (red line). Clearly, we can pick the traveltime residual to update the velocity model.

Conclusions

A fast and novel tomographic algorithm is proposed. This algorithm has no dip and offset limitation, and the traveltime residual is obtained from ray tracing instead of depth residual to time conversion. This scheme can reduce the required prestack Kirchhoff migration. A simple example shows this idea works.

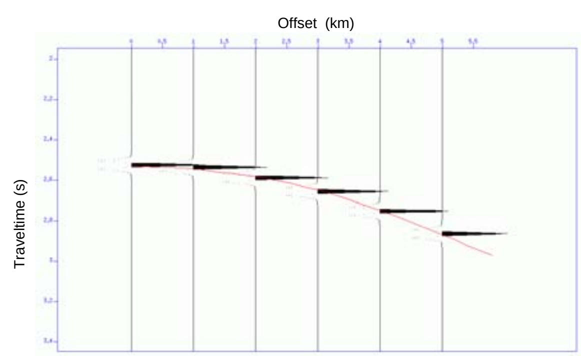

Figure 4. Superimpose the unmigrated time curve (red line) on the corresponding prestack traces.

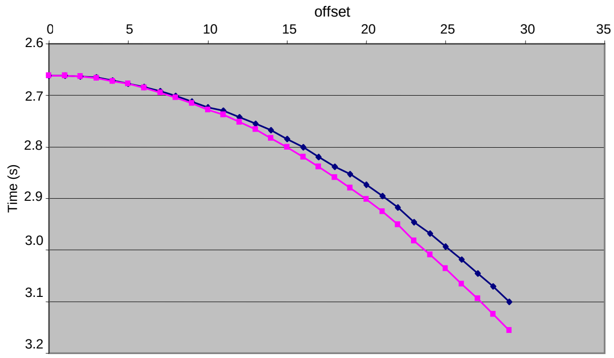

Figure 5. Overlay of the unmigrate time curve (purple) and the ray tracing time curve (blue). The difference between these two curves will be used to update velocity model.

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