
Analysis of Factors Affecting Residual Moveout Picking and Solutions

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Abstract: Reflection tomography on the base of common image gathers (CIGs) in offset domain or angle domain is the powerful and mostly used tool for velocity inversion. There are many factors that affect the accuracy and resolution of reflection tomography, in which RMO picking is a quite important one that can't be ignored. Residual moveout Auto Picking on common image gathers is the most important step in tomography velocity inversion, the reliability of residual moveout picking decides the accuracy of tomography velocity inversion. Based on a case study of field data, the paper give a full discussions and experiences analysis of factors such as grid step, input data quality, geological structure, picking parameter, which affect residual moveout picking greatly. Furthermore, the paper also put forward corresponding suggestions and solutions to reduce or eliminate the impact of these factors on residual moveout picking. At last we implement a structure controlled residual moveout picking method with horizon constraint to a field data residual moveout picking. The proposed picking method refines the global picking though utilizing horizon constraint in vertical orientation and structure subdividing in lateral orientation. It effectively improves residual moveout quality and enhances inversion reliability, and also helps tomography inversion to update a velocity model with high resolution. The final prestack depth migration shows a good imaging of complex structures and faults, which demonstrates how important of the role that the fine residual moveout picking method plays in tomography inversion.

Keywords: Residual Moveout, Horizon Constraint, Prestack Depth Migration, Tomography, Velocity Inversion

1. Introduction

Velocity is the key factor which affects imaging quality of pre-stack depth migration (PSDM). A good depth interval velocity helps pre-stack depth migration (PSDM) obtain good quality image than pre-stack time migration in complex structures. When internal velocity is inaccurate or incorrect, PSDM will cause big deviation with drilling well and mislead well placement. Therefore, building an accurate interval velocity is quite important for pre-stack depth migration.

Reflection tomography on the base of common image gathers (CIGs) in offset domain [1-6] or angle domain [7-10] is the powerful and mostly used tool for velocity inversion. Stoke (1992) [1] first proposed reflection tomography velocity inversion method on post-migrated domain by picking residual moveout (RMO) automatically. The main approaches of velocity inversion by reflection tomography involve iteration [11-13]. During this process, many factors affect reflection tomography, in which RMO picking is a quite

important one that can't be ignored [14-17]. Many papers researched inversion problems and methods for addressing them [18-23].

In this paper, we don't further to working on methods or algorithms to compute the travel time derivation. We will give some discussions and analysis of several factors, such as grid step, input data quality, geological structure, picking parameter, which affect RMO picking greatly. Furthermore, we also put forward corresponding suggestions and solutions to reduce or eliminate the impact of these factors on RMO picking. At last we implement a structure controlled RMO picking method with horizon constraint to a field data RMO picking. It refines the global picking though utilizing horizon constraint in vertical orientation and structure subdividing in lateral orientation. It effectively improves RMO quality and enhances inversion reliability, and the field data test demonstrates a good result of velocity inversion.

2. Principle of Tomography Velocity Inversion

The theoretical basis of reflection tomography is Radon transform, in reflection tomography formulation, the travel time derivation of an arrival between observed data and reference model can be written by the linear integration of slow residual along the ray path [2], which is

$$\Delta t = \int_r \Delta s dr \quad (1)$$

Where, Δt is the travel deviation, dr is the length of ray segment along the ray path, Δs is the slowness deviation between the true model and reference model along the ray path.

By discretizing the slowness field Δs using rectangular grids, the matrix equation of the collection of all the ray paths can be written as equation 2

$$L\Delta s = \Delta t \quad (2)$$

Where, L is the sensitivity matrix of the segment lengths of a given ray in a given grid, Δs is the slowness derivations, Δt is travel time derivations. The tomographic inverse problem is always ill-posed, thus other restrain information is required to regularize inverse problem. Since pure mathematics regularization constraints may cause a false target judgment in inversion. Here the paper use a geological structural conformed regularization, which is stable in inversion and velocity variety is natural, reasonable and consistent with the change of geological structure.

$$\begin{bmatrix} L \\ \lambda D \end{bmatrix} [\Delta s] = \begin{bmatrix} \Delta t \\ 0 \end{bmatrix} \quad (3)$$

Where, D is regularization matrix to stabilize the tomographic inversion, λ is regularization weight.

3. Quality Analysis of Global Automatic Picked RMO

The key part in the theory of tomography velocity inversion is to obtain accurate travel time derivations form picking the RMO on CIGs. Therefore, the picking quality of RMO on CIGs directly affects inversion accuracy. Next, we will demonstrate studies on effects of factors affect RMO picking on CIGs.

3.1. Effect of Grid Step on RMO Picking

Autopicking residual moveouts on CIGs is a huge workload. So chose an appropriate grid step along inline and crossline orientation between consecutive autopicked seed points helps it to be more economic, as well as less migration areas of the PSDM which offers CIGs for RMO picking. Small values result in more seed points, which mean an increase in accuracy, but a substantial increase in computation time and memory requirements. Large values result in less seed points, which reduce computation time but also reduce accuracy for both

PSDM and tomography inversion.

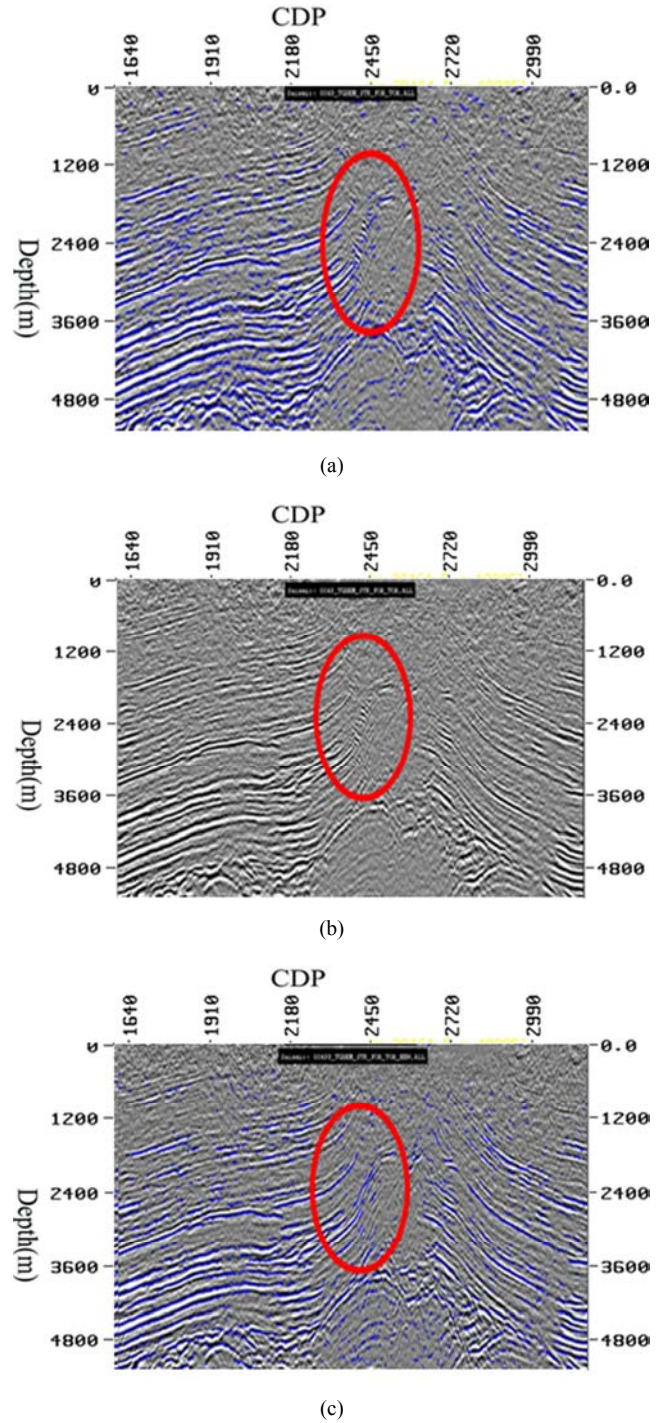


Figure 1. PSDM sections with different grid steps. (a) PSDM section with 4 times grid steps of surface survey. (b) PSDM section with 2 times grid steps of surface survey interpolated by PSDM data shown in 1a. (c) PSDM section with 2 times grid steps of surface survey.

We demonstrate a land acquisition data in China as an example, and its bin size is 25m. We use 4 times grid step of surface survey for pre-stack depth migration and RMO pick, which is less than the default value of 200m in most commercial software. The result displayed in Figure 1a appears serious dispersion, due to an insufficient sampling for

high and steep structure areas. The dispersion shown in image caused an incorrect autopicked RMO values.

We interpolate the PSDM image into 2 times grid step of surface survey, as shown in Figure 1b, the dispersion still exists. This shows that grid step of surface survey selection is very important for initial migration. Distortions of final image

would bring artifact, it's hard to be addressed by normal technique measures because of insufficient sampling.

We do migration of the same data using 2 times grid step of surface survey. The result shown in Figure 1c has no dispersion and artifacts, so we can ensure that the result is real and RMO picks is reliable.

3.2. Effect of Noise on RMO Picking

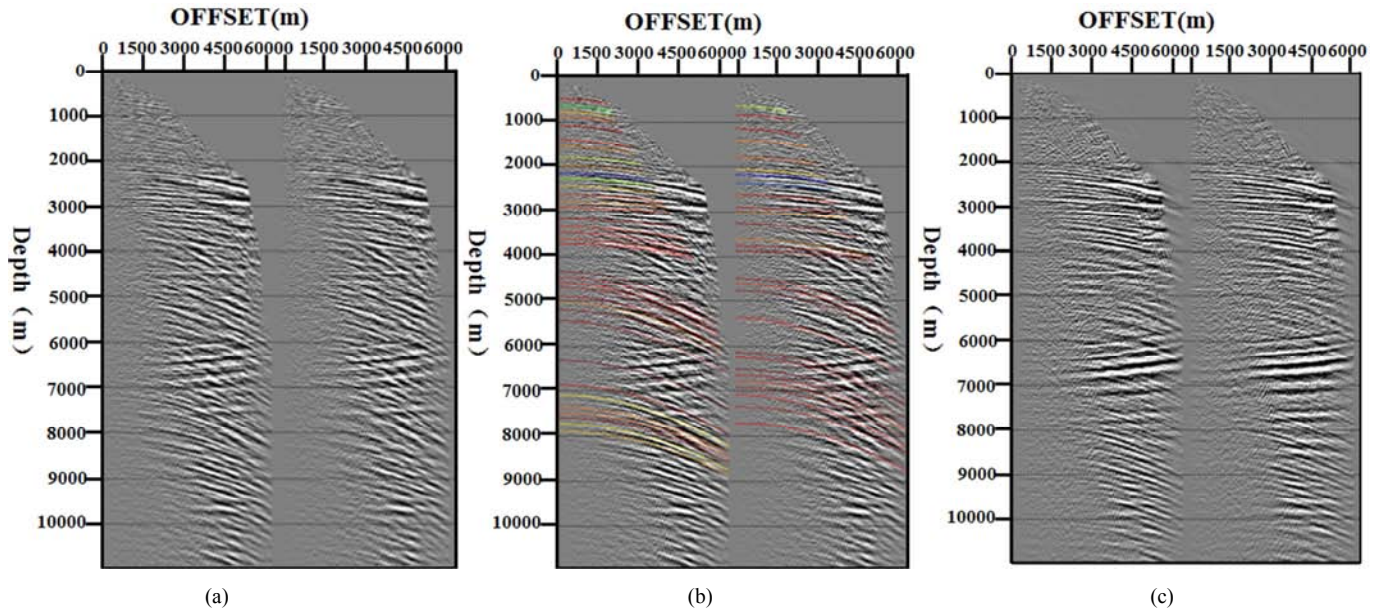


Figure 2. (a) Raw CIGs with multiples. (b) RMO picking of raw CIGs. (c) The CIGs after multiple suppression.

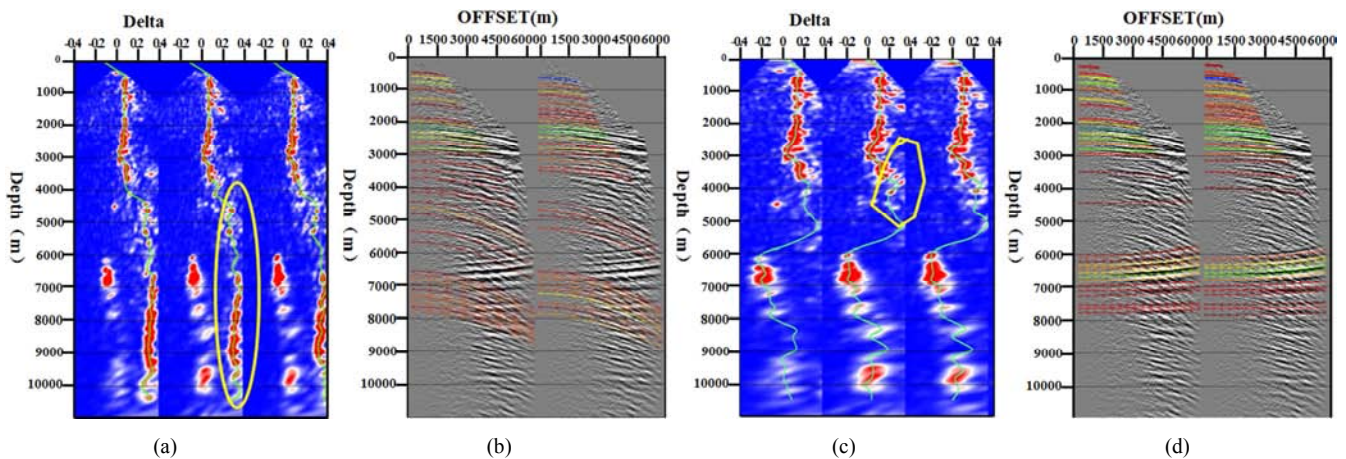


Figure 3. (a) Semblance of raw CIGs with multiple waves. (b) RMO picking of raw CIGs. (c) Edited semblance of raw CIGs (d) RMO picking of raw CIGs based on edited semblance.

Residual noises after prestack data preconditioning degrades the quality of CIGs and further affect RMO picking. Figure 2a displays CIGs with multiple which mess up and distorted reflection events, and lead to wrong picking of residual curvature (Figure 2b). Some kinds of multiple suppress methods are indispensable, however the current multiple suppression methods can't completely clear CIGs (Figure 2c). In particular, in the shown field data, it is difficult to identify multiples from either shot gathers or offset gathers in the pre-migrated domain.

In this paper we used the semblance-based RMO picking method [24] to deal with multiple. We note that multiples have relatively low velocity, and in the semblance it is clearly showing the range of multiples (yellow part of Figure 3a) distinguished with primary reflections. So we can do edits on this part of semblance. For multiples have the similar velocity range to primary reflections (yellow part of Figure 3c), it is much easier to find multiples on semblance than on CIGs, and then we can avoid picking at these parts by select suitable picking parameters. Figure 3d shows RMO picking of raw

CIGs based on edited semblance, compared with RMO picking of raw CIGs without any edit (Figure 3b), we can see that figure 3d perfectly avoid the effects of multiples and obtain reliable RMOs.

3.3. Effect of Single-to-Noise Level on RMO Picking

Picking RMO on CIGs deemed needs PSDM results are not low single-to-noise level, in which reflection events are difficult to be described in an automated manner. On the depth migration section (Figure 4), the global section has different single-to-noise levels of different strata, which associates with

depositional environment. H1, H2, H3, H4, H5 define base horizons of several layers. From shallow to H1 are continued terrestrial deposition strata, which have relatively continues beds and PSDM data has a high single-to-noise level. H1 to H2 are transition strata of terrestrial deposition to marine deposition, and the bottom layer of H2 contains a large amount of gypsum sediment, so the interval velocity is higher than surrounding layers. PSDM data has a low single-to-noise level and bad depth imaging quality because of the change of sediment source and physical processes.

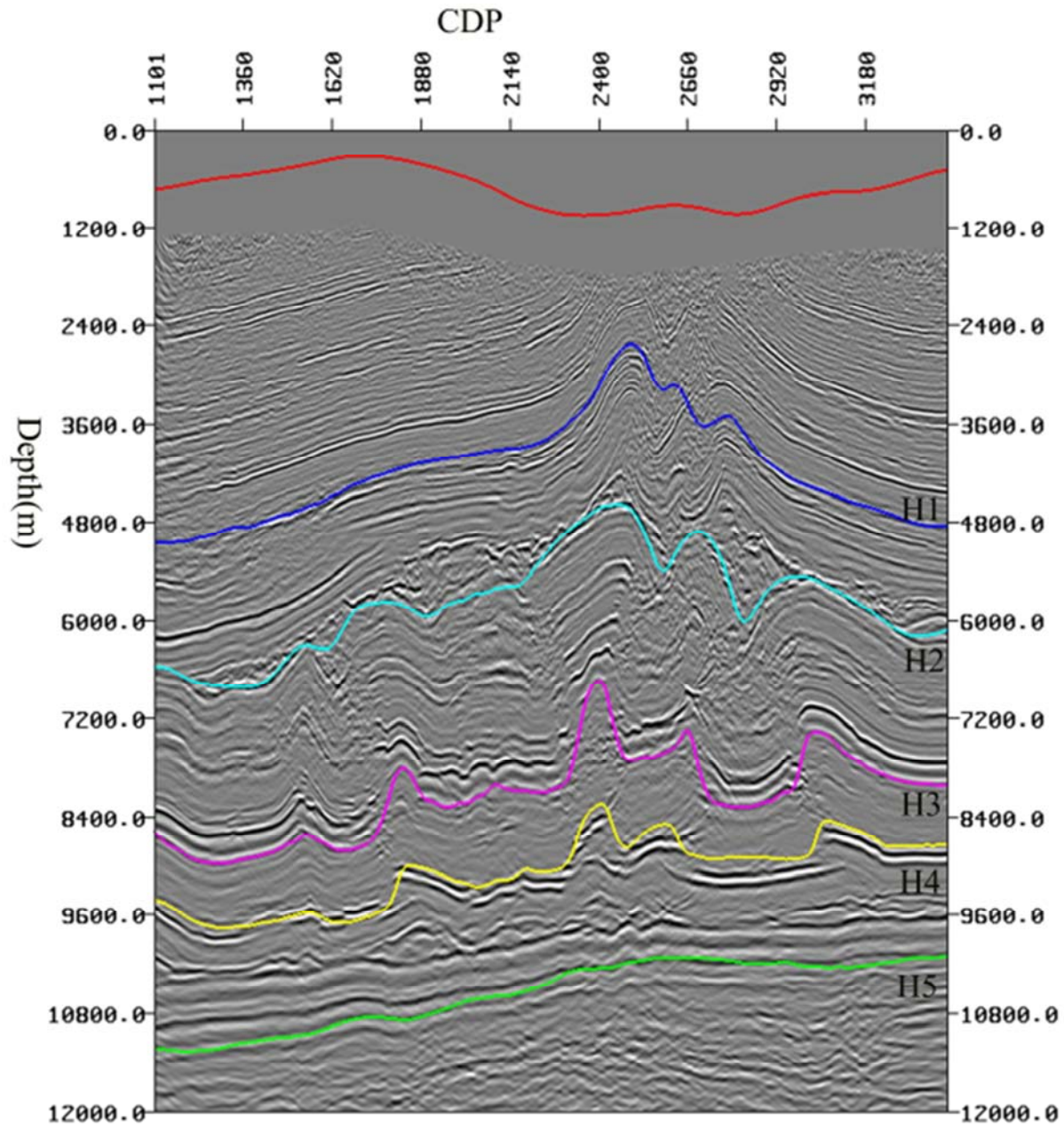


Figure 4. Interpret Horizons.

H2 to H3 are the continued marine deposition strata, with a relatively high single-to-noise level of PSDM data. However, strata at the top half of H2 to H3 have different sediment rock

types with that of the bottom half of H2 to H3, so they shows different data quality. Strata at the top half part have continuous layers but week amplitude energy, strata at the

bottom half part have strong amplitude energy but discontinuous layers.

H3 to H4 are transition strata of marine terrestrial deposition to terrestrial deposition, which also have low single-to-noise level of PSDM data as H1 to H2 do. Below H4 the layers are deep than 8000m, they have low single-to-noise level of PSDM data and low resolution.

The change of single-to-noise level greatly influences the global RMO auto picking on CIGs when using the same picking parameters from shallow to deep. In practice, this phenomenon always exists because single-to-noise level is a serious problem affecting seismic data quality on land acquisition. We perform a layer-by-layer RMO picking with

horizon constraint to give different picking parameters for CIGs with different single-to-noise levels from shallow to deep.

RMO picking with horizon constraint consists of three steps: first, interpret several horizons as constraint which can divide velocity model into different parts by taking single-to-noise levels on associate PSDM sections as a reference. Second, use different picking parameters at divided model parts according to amplitude energy and event continuity (as shown as figure 5). At this step, Δt in equation 2 can be seen as $[\Delta t_{H1}, \Delta t_{H2}, \Delta t_{H3}, \Delta t_{H4}, \dots]$. Finally, we can perform global inversion though merging CIG picks all together.

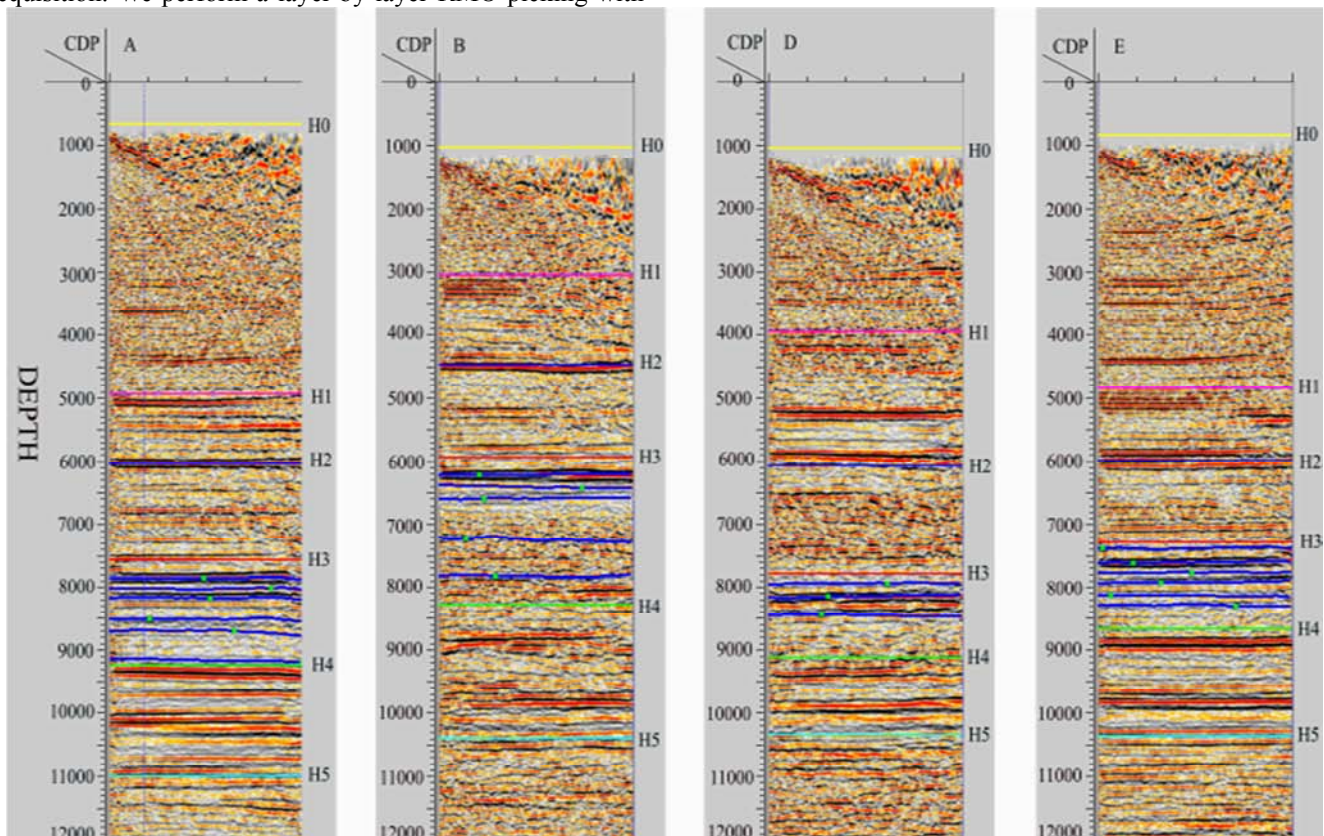


Figure 5. Residual moveout picking with horizon constraints.

3.4. Effect of Subsurface Structure on RMO Picking

Usually we can't clearly distinguish the extent of each factor as they are associated with each other, and RMO picking problem possibly caused by cooperation of several reasons. For the example data we discussed in the paper, deformation of subsurface structure has significant impact on RMO picking.

Strata between H2 to H3 in 3.3, not only have different single-to-noise levels in vertical orientation, but also have different complex structures. We divided strata between H2 to H3 into 5 parts laterally. Figure 6 shows that A has mild anticline and small scale wave-like fold and faults. B, C and D have sharp folds with pairs of anticlines and synclines, and overthrust faults. E has flat layers.

The developed multiple lateral structures produce amount

of diffractions, scattered waves, crossing arrivals and interference. A to D parts are especially complex, wavefields distorted and interfered mutually. These brought difficulties to PSDM and velocity inversion. PSDM based on ray-tracing or one way wave equation can't handle multi-wavefiled imaging, and velocity inversion using ray-tracing in the tomography can't deal with multipath problems. Poor behavior of PSDM makes reflection events on CIGs and hard to track. Figure 7 shows picks on three CIGs located at A, B and E, respectively.

CIGs located at A and B show poor quality than CIGs located at E. The disadvantage of method we proposed using horizon constraint to perform layer-by-layer RMO picking is that the same picking parameter in the same layer can't adapt to energy strength variation and continuity change of CIGs caused by lateral structures.

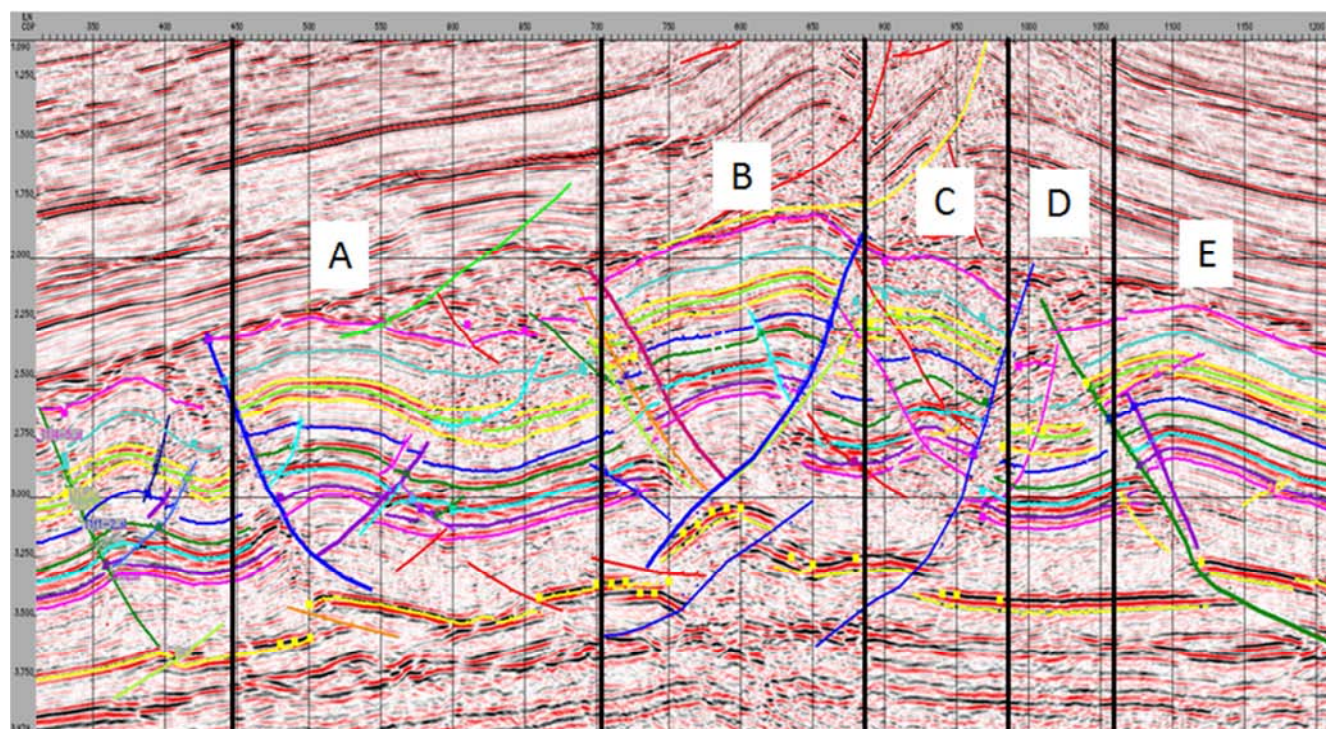


Figure 6. PSDM result of an example data.

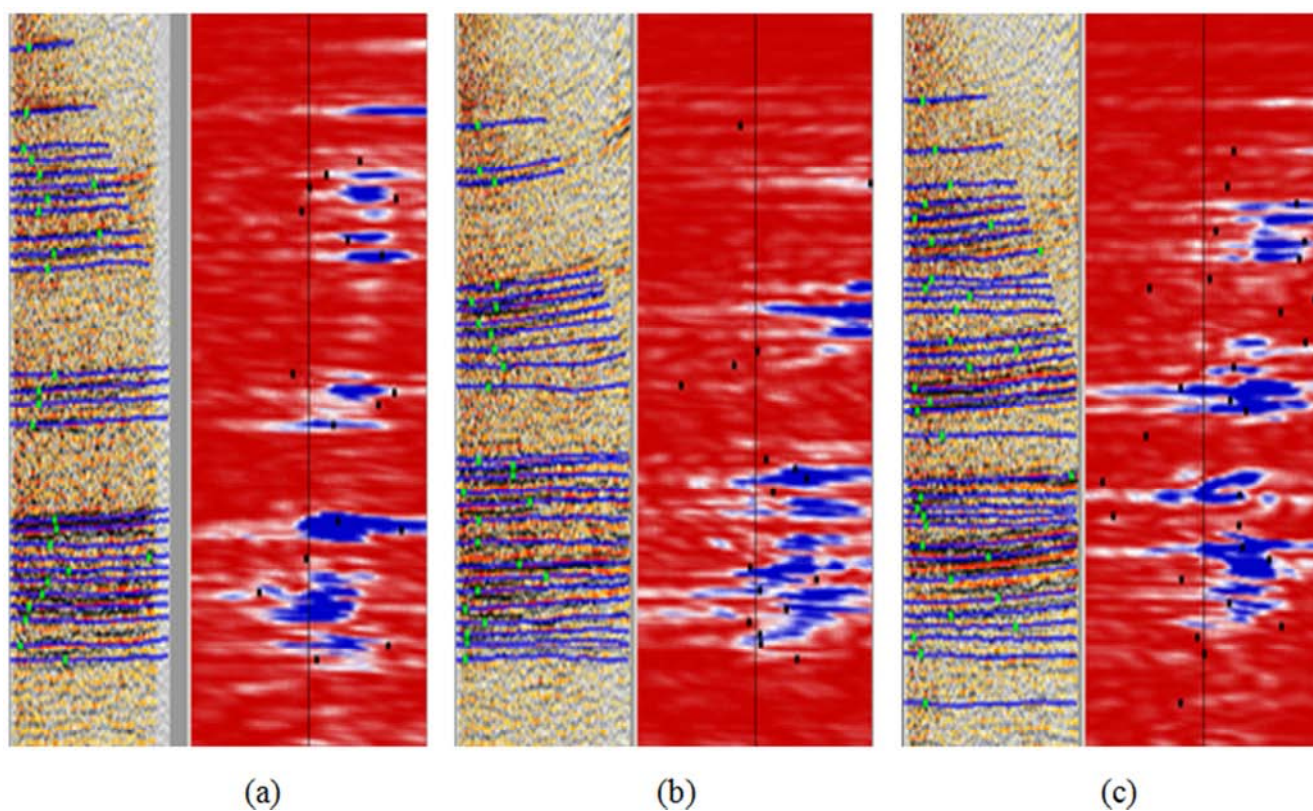


Figure 7. Residual curvature pick of gathers at different structures. (a) CIG gather locating at A. (b) CIG gather locating at B. (c) CIG gather locating at E.

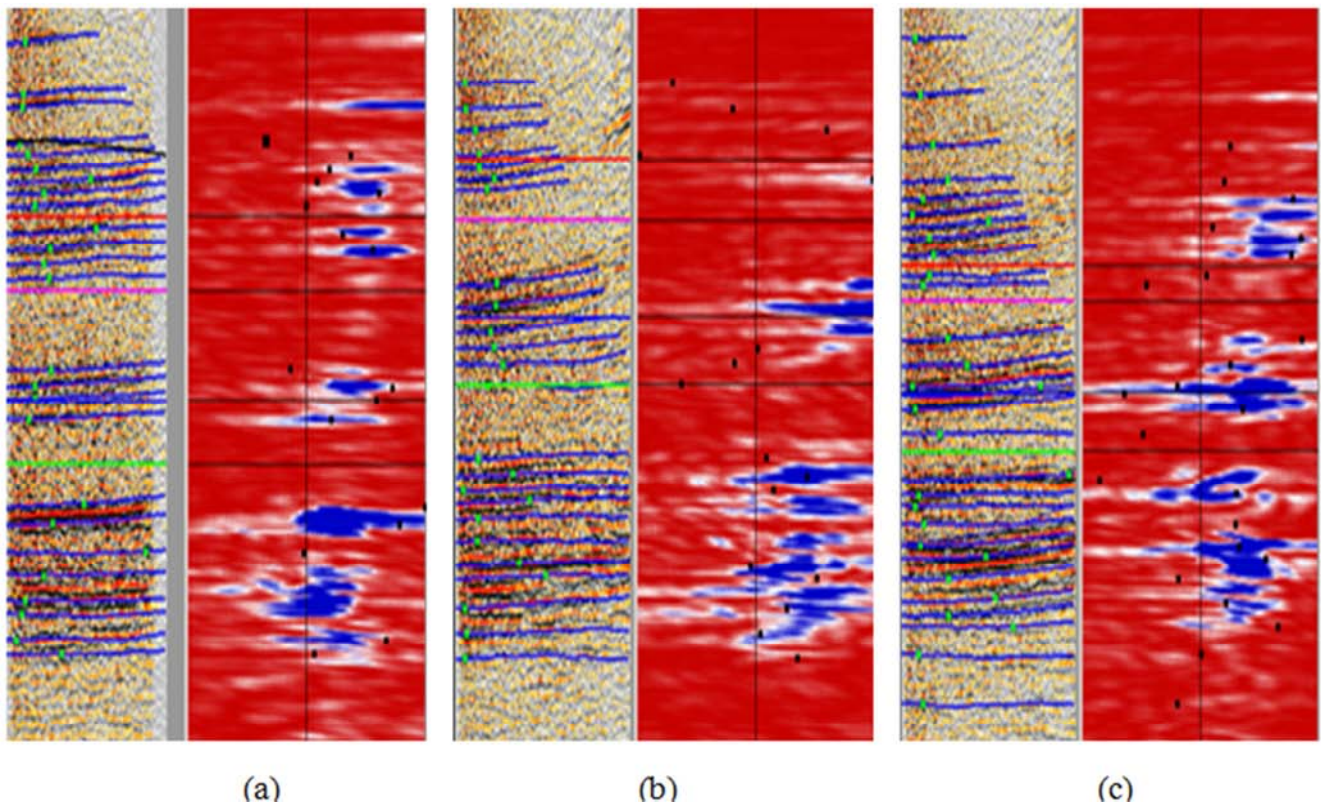
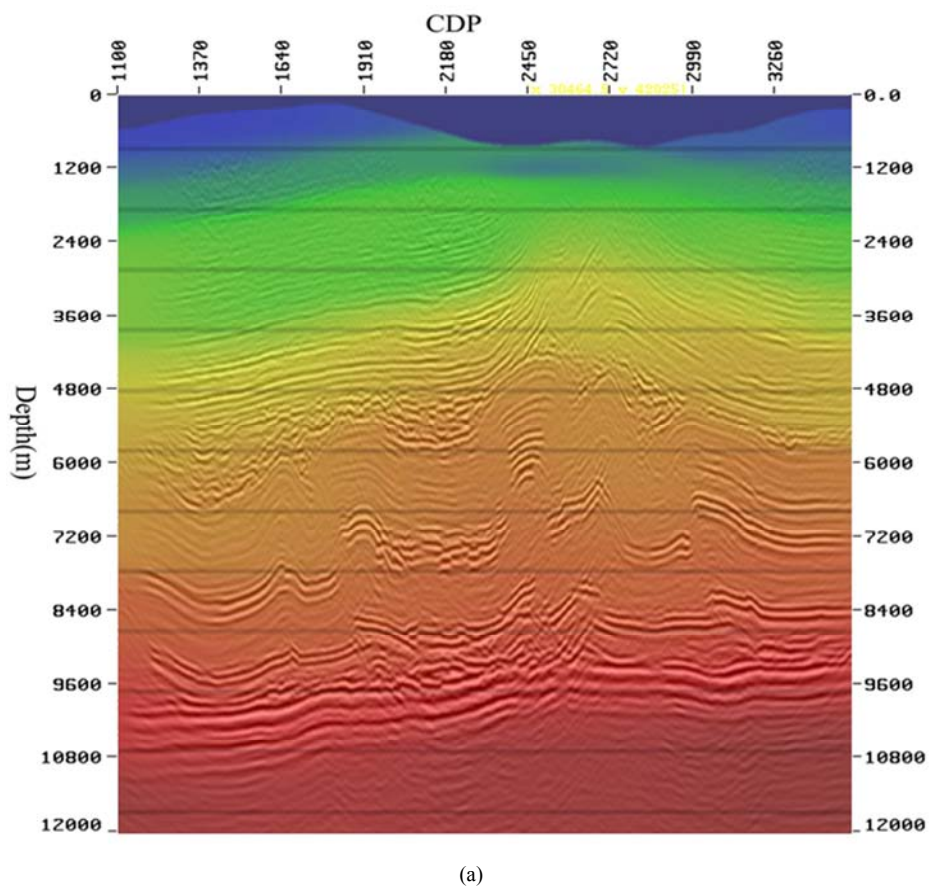


Figure 8. RMO pick of gathers at different structures using horizon constraint. (a) CIG gather locating at A. (b) CIG gather locating at B. (c) CIG gather locating at E.



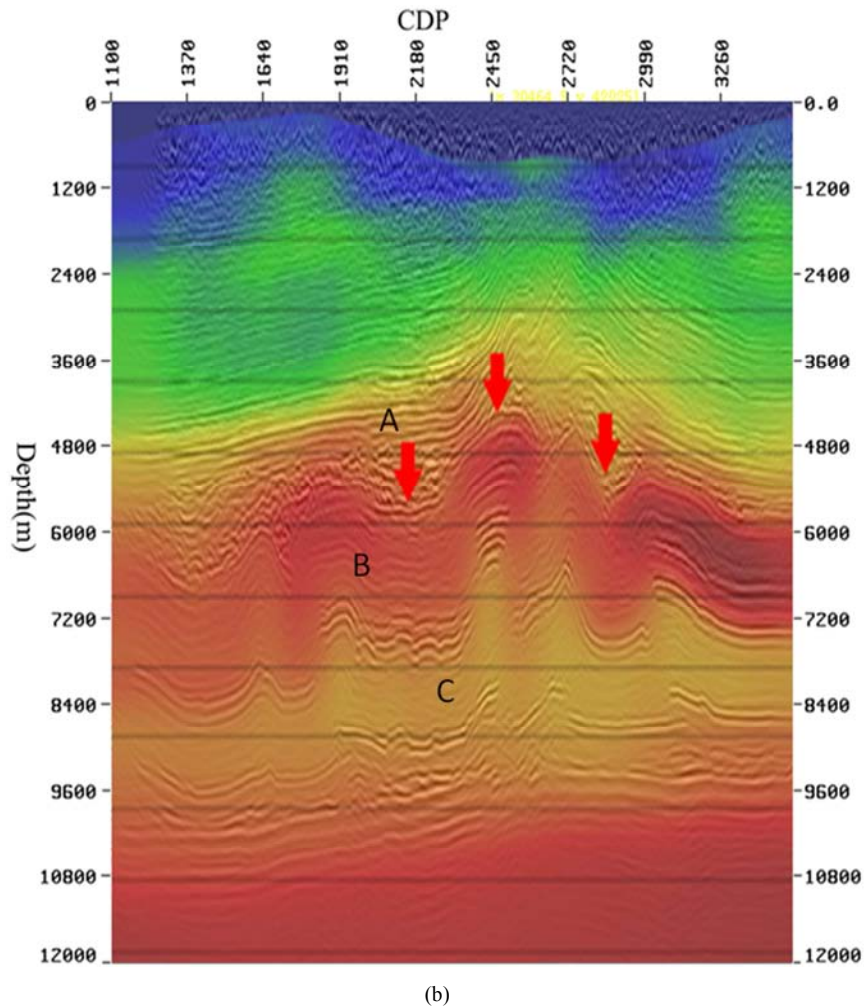


Figure 9. Comparison of velocity models before and after tomography inversion. (a) Initial velocity used for tomography inversion. (b) Final velocity after three times iteration.

4. The Application to the Field Data

We used the proposed ideas for RMO picking on the field data that we analyzed in the paper. Figure 9a is the overlay display of initial velocity model and associate PSDM image. After three times iterate of velocity inversion, we obtained final velocity and associate PSDM image (Figure 9b).

Initial velocity is simple and smooth which obtained though time migration velocity. Compared with initial velocity, the final velocity matches geological knowledge very well. First, the bottom of gypsum layer is clear and easy to interpret as shown by red arrows in figure 9b. Second, the rapid increases in velocity at depth A indicates the interface of terrestrial deposition to marine deposition, high velocity layer at depth B corresponds a stable marine deposition process. Third, it appears velocity reversal at depth C, which reflects the change of marine deposition to terrestrial deposition as we analyzed before.

PSDM result using final velocity shows a good imaging of complex structures, faults imaging is clear-cut, the bottom of gypsum layer is clearly portrayed and easy to interpret. The weak reflection layers which have low single-to-noise levels

below gypsum layer have been improved.

5. Conclusions

The paper analyzed aspects of input data quality, geological structure, single-to-noise level and quality control which affect RMO picking. Through field data implementation we proposed a structure-controlled RMO picking method with horizon constraint to improve residual move out picking quality hence to raise inversion reliability.

- (1) There are many factors influence automatic RMO picking, such as single-to-noise level of input data, quality of common-image gathers, subsurface structure, depth migration method, picking parameters. Processors should pay attention to quality control of RMO picking in field data process and under the guidance of geological knowledge using geological constraint to improve the quality of RMO picking.
- (2) After picking up accurate and reliable RMO, tomography inversion can obtain accurate velocity matching with geological knowledge and PSDM image with high quality.

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