Application of Joint Tomography to Tarim Basin Foothill Imaging

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Summary

One of the challenges for land seismic exploration in foothills is estimating velocities. This is because of the complexity in both near-surface and subsurface structures. This paper illustrates a robust approach of velocity-model building for both shallow and deep sections, using joint turning-ray and reflection tomography. First, turning-ray tomography is performed to derive a near-surface velocity-depth model. Second, we combine the near-surface model with an initial subsurface model as the starting model for reflection tomography. During reflection tomography, both near-surface and subsurface velocity-depth models are jointly updated. This method is practical and efficient for velocity model building and prestack depth imaging in foothill regions.

Introduction

The study area is located at Kelasu Thrust Belt between Tianshan Mountain to the North and the edge of Baicheng sag to the South. This area has favorable petroleum geology conditions with good cap rocks, reservoirs, and source rocks. The main target is the Bashijiqike Formation (Cretaceous) overlaid by a Paleogene gypsum rock. The depth of target area is quite deep (over 8000m in the deepest area) and usually has poor signal to noise ratio (S/N) due to strong absorption of top gypsum-salt cap rock. In addition, above the salt layers there are complex geological structures with steep dips and deformed composite gypsum-salt layers which vary in thickness from dozens to thousands of meters. Beneath the salt the over-thrusting structure is severe (Figure1).

One of the objectives of this study is to understand why the previously drilled well (K12) was dry. Because depth imaging is very sensitive to velocities, we developed and applied joint turning-ray and reflection tomography to improve the accuracy of velocity-depth model at both shallow and deep sections in the study area. After TTI anisotropic prestack depth migration from topography, using velocities estimated from the joint tomography, results have showed that the structural apex of the previously drilled dry hole is several hundreds of meters away from the newly imaged structural apex, suggesting that a new well location is to be considered.

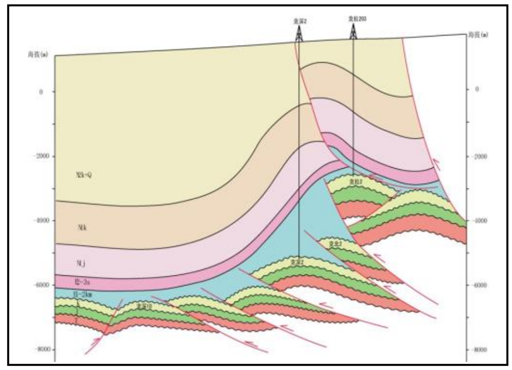

Figure 1: A Schematic geologic section.

Principle of joint tomography

Zhu et al. (2001, 2003) proposed a joint topography, combining both refraction or turning-ray tomography and reflection tomography to build an entire velocity model for depth migration. Turning-ray tomography has been conventionally used to calculate statics， which is also referred to as tomostatics (Zhu, et al., 1992). In turning-ray tomography, the medium to be imaged is generalized into a continuous medium, such that the first arrivals recorded at the surface need not be associated with refractors having strong velocity contrasts. Turning-ray tomography inverts for a velocity model by minimizing misfits between observed first-break times and calculated travel times from turning-rays. Since a continuous medium is assumed, the inversion results in grid-based model. Usually, generation of robust results requires that the recording aperture (signed offsets) be at least four times larger than the desired imaging depth. Therefore, we can use this model as a good estimation of near-surface model combined with reflection tomography. In practice, we need to select the maximum depths of reliable velocities based on the ray density from tomography.

Reflection tomography in the postmigration domain utilizes depth residuals among traces within a common image gather generated from prestack depth migration (Stork, C., 1992; Jiao, et al., 2010). The residuals are distributed along reflection rays. By minimizing the residuals, reflection tomography inverts for velocity perturbation and then updates velocity model according to the previous model. Reflection tomography is an iterative process of prestack depth migration and tomographic inversion until the residuals are minimized.

Since near-surface velocity-depth model derived from turning-ray tomography is more accurate and has higher resolution than that from reflection tomography beneath the surface, we keep the near-surface model unchanged during early stages of iterations in the joint tomography. To consider the errors associated with the picked first arrivals for turning-ray tomography and combine both models seamlessly, we allow reflection tomography to update both shallow and deep velocities simultaneously in the later stage of iterations.

Field data example from Tarim Basin

The near-surface morphology of the study area is known to have isolated high-velocity conglomerate rocks in the foreland basin surrounded by weathered sediments. The targeted zones are at depth of ~7 km underneath the conglomerate rocks. Therefore, the imaging fidelity of targeted zones strongly depends on the accuracy of near-surface velocity-depth models.

Figure 2 shows the near-surface velocity-depth model estimated from nonlinear turning-ray tomography. 10 non-linear iterations or ray tracings were performed, each containing 15 linear iterations. The maximum offset of the first-arrival traveltimes used was 7000 m, which produces a reliable depth (dashed line in Figure 2) approximately 1300 m below the topography and is much deeper than that from conventional refraction inversion. The marked high-velocity zone corresponds to conglomerate rocks and is consistent with geological background of the study area.

Figure 3 shows the combined model, where the shallow part is from turning-ray tomography, and the deep part is filled with the legacy model previously obtained. Slightly smoothing was applied to the suture zone to avoid abrupt changes.

During the first 3 iterations, we kept the near-surface model unchanged while we updated both models in the last two iterations. Figure 4 shows the initial and final velocity-depth models, respectively. The migrated results from the updated models using joint tomography is shown in Figure 5. This representative inline is overlaid with well K12. The new apex of the structure (blue line cutting through) is now on the right side of the previously drilled location (yellow dashed line), approximately 500 m apart. The well drilled previously missed the target, only water was discovered in the reservoir. A new well location along the blue line is recommended.

Conclusions

Prestack depth imaging in foothills of Tarim Basin is very sensitive to velocity models. The previously drilled dry hole (well K12) was mainly caused by the velocity errors.

We have successfully developed and applied joint turning-ray and reflection tomography to build a reliable velocity-depth model for prestack depth migration from topography. We first use turning-ray tomography to derive a near-surface velocity-depth model based on the first arrivals. Then, reflection tomography is applied to invert for the subsurface model with near-surface model masked at the first several iterations. During the later iterations, both near-surface and subsurface models are updated. We found that near-surface velocities are decreased slightly after joint inversion. The percentage of velocity reduction depends upon the degree of anisotropy near the surface.

Acknowledgements

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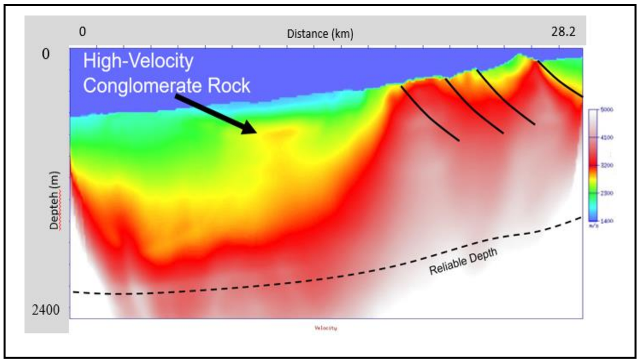

Figure 2: Near-surface model derived from Turning-ray Tomography. The maximum offset of the first-arrival traveltimes used is 7000 m.

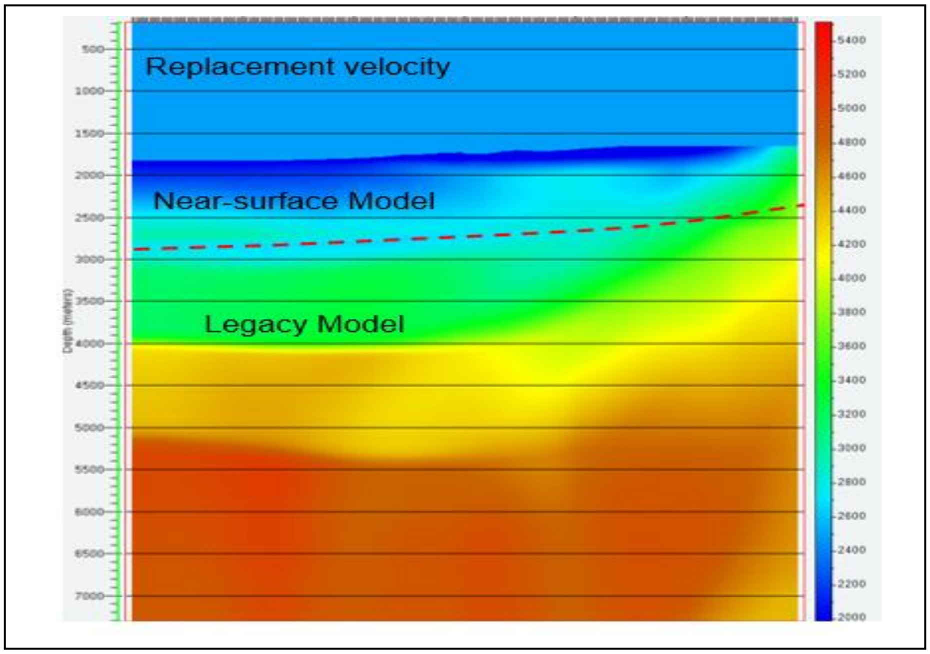

Figure 3. Initial model combining both near-surface model derived from turning-ray tomography and legacy model.

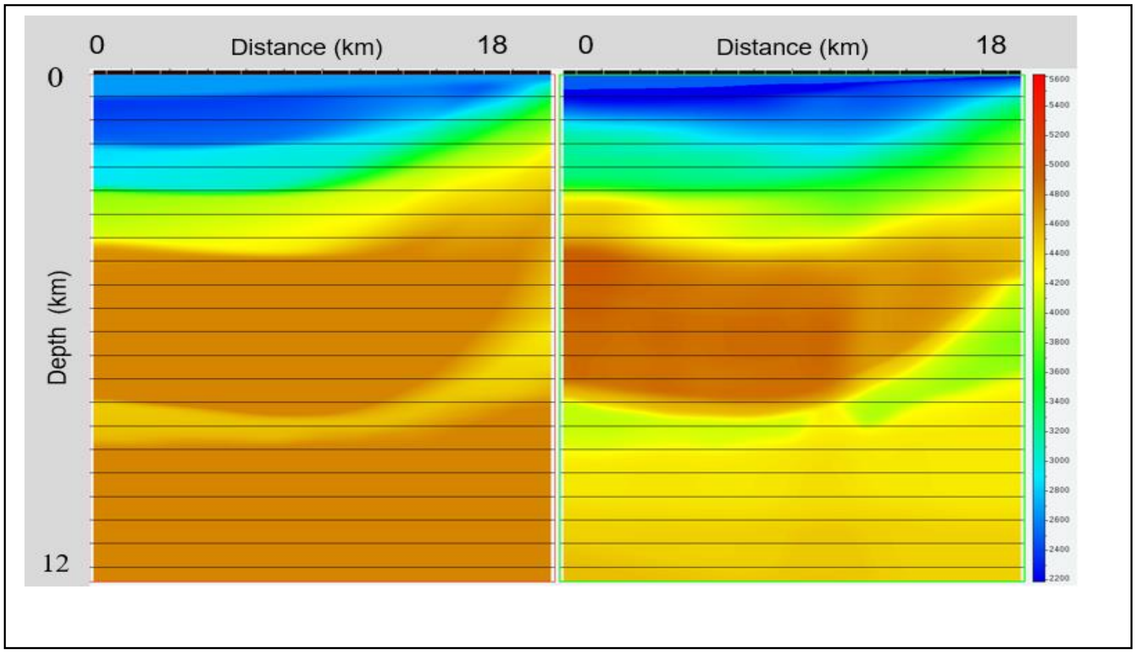

Figure 4. Velocity before (left) and after (right) joint tomography update. To show the details of shallow velocities, color bar used in Figure 3 is different from Figure 4.

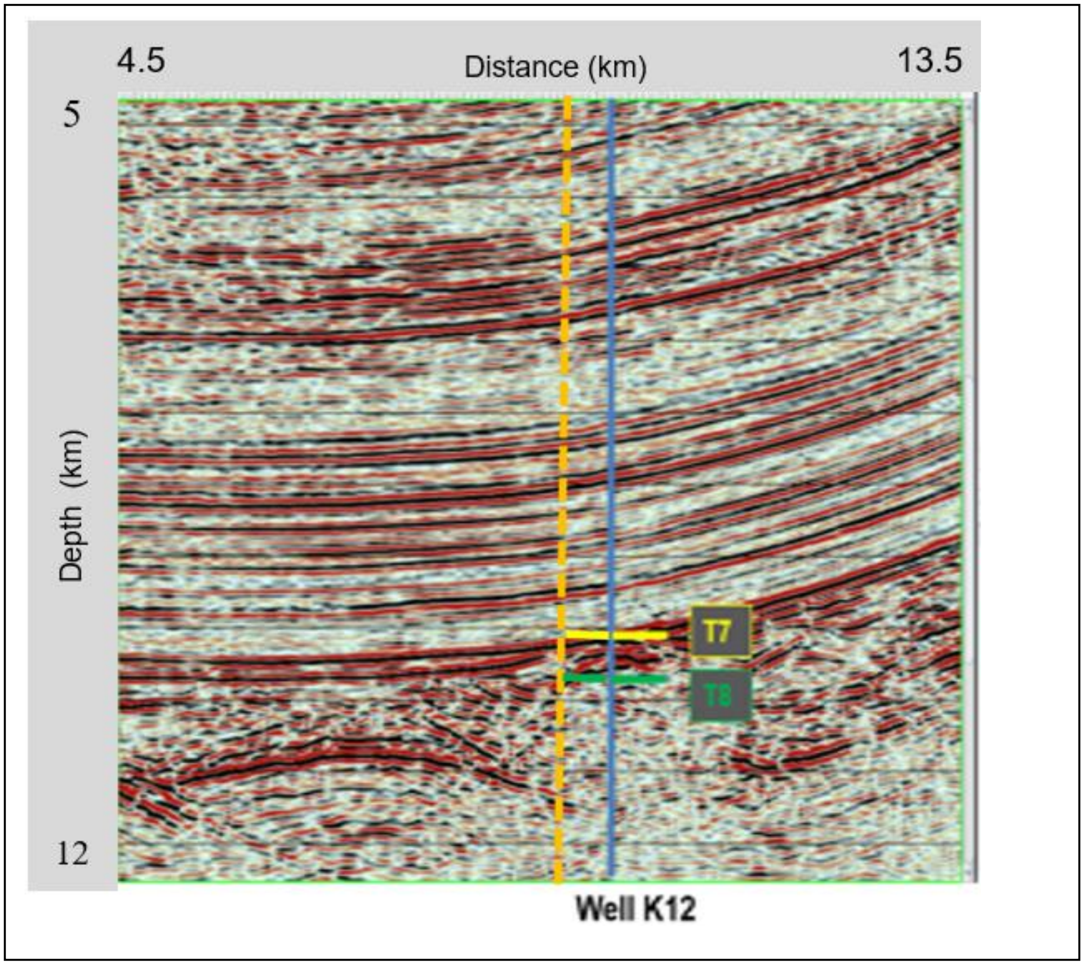

Figure 5. Location of Well K12 on a representative PSDM section. The new apex of the structure (blue line cutting through) is approximately 500 m away from the previously drilled location (yellow dashed line), suggesting a new well location. T7 and T8 are two geologic horizons.