

Tomography for Static Corrections and Prestack Depth Imaging

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Summary

Turning-ray tomography and tomostatics have been applied to areas with rugged topography and strongly variant near-surface geology. I review the methodology of turning-ray tomography and tomostatics, and show how the near-surface velocities estimated from turning-ray tomography are used for static correction, wave-equation datuming and prestack depth migration. Questions frequently asked will be highlighted to show 1) when and where tomostatics will work better than conventional refraction statics; 2) limitations of tomostatics; and 3) key steps to run tomostatics. Quality controls will be illustrated to ensure the robustness of turning-ray tomography and tomostatics. Synthetic and field data examples have shown that the resolution of estimating a near-surface velocity model is directly dependent upon the picked first arrivals. Picking the first arrivals via a virtual reality system significantly improves the consistency of input data for the subsequent velocity estimation.

Introduction

Applications of turning-ray tomography and tomostatics are being evolved from static correction to wave-equation datuming and prestack depth migration, and from 2D to 3D. Tomostatics have advantages over traditional refraction statics in regions where 1) no refractors can be easily identified (e.g. unconsolidated marine trench, gas cloud and thrust belt areas), and 2) high velocity materials (e.g. basalt and carbonates) overlay low velocity sediments immediately below the topography such that conventional refraction statics usually fail (Figure 1).

In turning-ray tomography, the medium to be imaged is generalized into a continuous medium, such that the first arrivals recorded at the surface are not necessary to be associated with refractors having strong velocity contrasts. Instead, turning waves will be generated as long as the medium has an overall positive velocity gradient with respect to depth, and the recording aperture is sufficient. Usually, the recording aperture (signed offsets) should be at least four times larger than the desired imaging depth (Zhu, et al., 1992; Stefani, 1995).

The velocities estimated from turning-ray tomography are usually most accurate immediately below the topography. This velocity field can be used for static corrections, assuming reflected rays are traveling vertically near the surface. If strong vertical and lateral velocity gradient components are present, the raypaths will not be vertical. Therefore, wave-equation datuming (e.g. Zhu, et al., 1998)

and prestack depth migration (e.g. Zhu et al., 2001) using velocities estimated from tomography should be considered.

Methods

Turning-ray tomography, also known as refraction tomography or diving-wave tomography, uses first-arrival traveltimes as input (Zhu and McMechan, 1989; Stefani, 1995). The solution involves minimization of the difference between the observed traveltimes and those predicted by ray tracing through an initial model. The solution is iterative and contains five steps: (1) picking of first arrivals, (2) ray tracing through an initial estimate of the velocity model, (3) segmenting raypaths into the portion contained in each cell of the velocity model, (4) computing the differences between the observed and predicted traveltimes for each ray, and (5) iteratively back projecting the time differences to produce velocity-model updates. Velocity updates are performed by a simultaneous iterative reconstruction technique (SIRT).

Tomostatics stands for turning-ray tomography followed by static corrections (Zhu, et al., 1992; Stefani, 1995). In static corrections, shot and receiver statics are calculated vertically from the surface topography to a downward continuation datum (or pseudo datum), using the near-surface velocity model computed by tomography.

The estimated near-surface velocities can be integrated into a velocity model for wave-equation datuming and prestack depth migration.

Frequently asked questions

Questions frequently asked in the production processing are as follows:

- 1) What is the limitation of tomostatics? As with refraction statics, tomostatics is most sensitive to the accuracy of the time picks. First arrivals should be consistently picked. Virtual reality systems provide such consistency (Zhu et al., 2001). Figure 2 shows the resolution of the velocity model dependent upon the first arrivals. If a high-velocity layer (e.g. basalt) is thick (Figure 2a), the refracted energy or the first arrivals are continuous (Figure 2b). If the thickness of the high-velocity layer is below the seismic resolution limit in terms of the wavelength, refracted or scattered energy will be "leaked" into deep formations and refracted back

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to the surface once it hits a deep refractor (Figure 2c). In this case, the first arrivals will be disconnected (Figure 2d). This should be considered in the first-arrival picking.

- 2) When should we use tomostatics? In general, tomostatics are applied when refraction statics do not work. Also, accurate near-surface velocity models are very useful for interpreting deep structures and for reducing exploration risks.
- 3) Is tomostatics always better than refraction statics? Not necessarily. If structures are relatively simple and the assumption for refraction statics is valid, then tomostatics will not be better than refraction statics. However, we rarely see examples where tomostatics are worse than refraction statics when the first arrivals are picked with equal quality.
- 4) Is tomostatics sensitive to an initial velocity model? No. Non-linear tomography is not sensitive to an initial velocity model. However, good initial velocity model improves the convergence rate.
- 5) Should we pick the first arrivals at all offsets? Yes, if we can. However, if the first arrivals are contaminated by noise at near or far offsets, we should eliminate those offsets.
- 6) What are the key steps to run tomostatics? The key steps are (a) picking the first arrivals consistently for turning-ray tomography; (b) removing any previously applied elevation and velocity statics before tomostatics; (c) re-picking NMO velocities after tomostatics; and (d) applying residual statics afterwards, as short-wavelength statics often remain because of errors in picking the first arrivals and smoothing in the tomography algorithm.

Quality control

Like refraction statics, tomostatics require quality controls to ensure the stability and robustness of the solutions. Typical QC plots in the production processing are: 1) Picked first arrivals; 2) Ray density; 3) Average time residual; 4) First arrival fitting; and 5) Stack responses. In this presentation, QC plots will be demonstrated with field data examples.

Discussions and Conclusions

Turning-ray tomography and tomostatics enhance interpretation and are applicable to areas where refraction statics often fail, such as marine trench, gas cloud, basalt outcrop and thrust belts. Although it does not always provide better-stacked images than those from refraction statics, tomostatics are at least as good as refraction statics. Interpreters often find the near-surface velocity profile very useful when they determine a drill site.

Like refraction statics, one of the challenges in applying tomostatics is how to pick the first arrivals in production processing. Picking the first arrivals using a virtual reality system has shown advantages of consistency and efficiency. In the future, a robust tomography with global optimization is expected to produce good shallow and deep velocity models (Figure 3) for depth migration from topography.

Acknowledgments

We thank Fusion Petroleum Technologies Inc. and PGS for permission to show the results.

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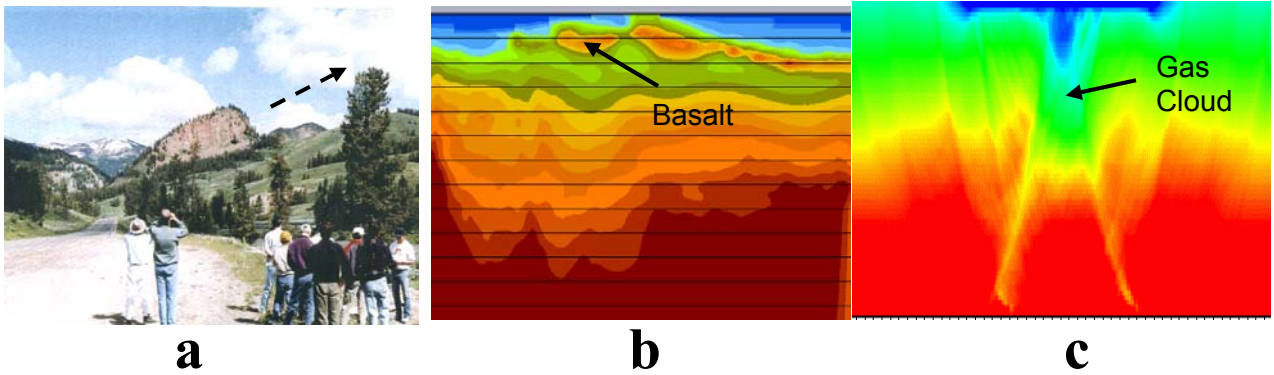


Figure 1. Difficult areas for conventional refraction statics. a) Thrust belt; b) basalt outcrop; c) gas cloud or marine trench. Velocities in b) and c) are estimated from field datasets using turning-ray tomography.

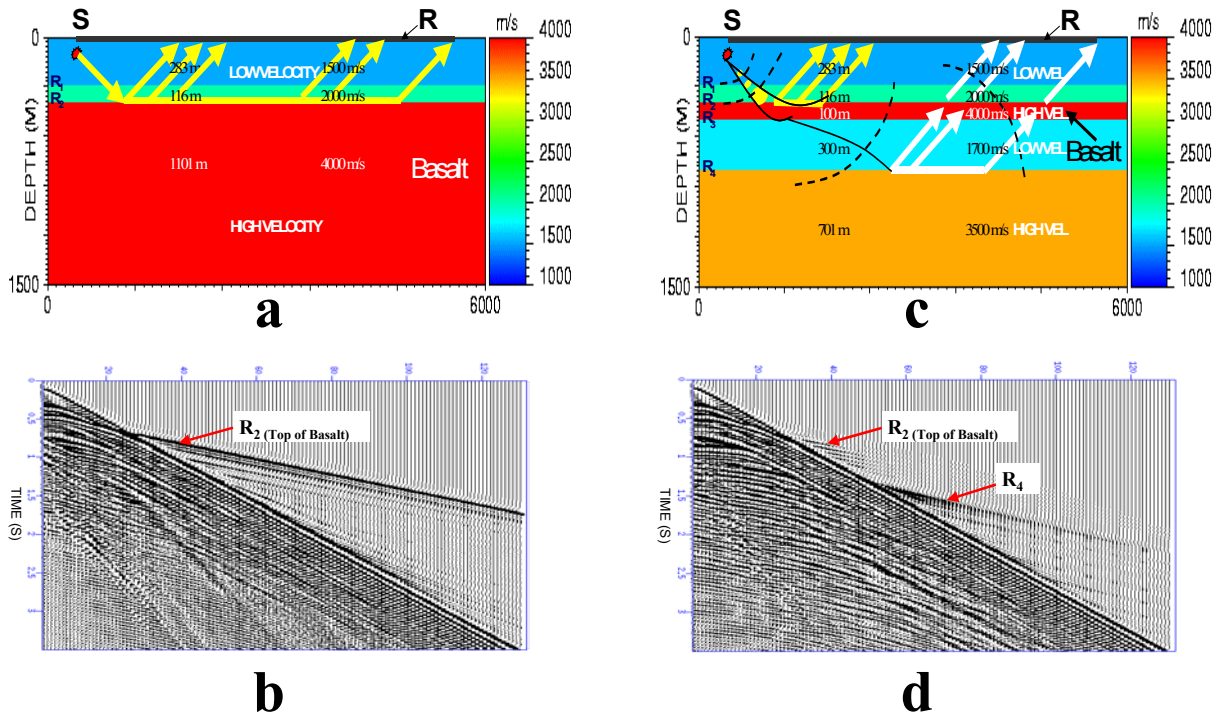


Figure 2. Velocity models and seismic responses showing the effect of high-velocity layer thickness on the first arrivals. a) Velocity model containing a thick high-velocity basalt layer; b) seismic responses of model a) generated by a finite-difference method; c) velocity model containing a thin basalt layer; d) seismic responses of model c). Refracted raypaths are sketched in a) and c). Refractions R2 and R4 in d) are generated from the top of the basalt and the interface R4 in c), respectively.

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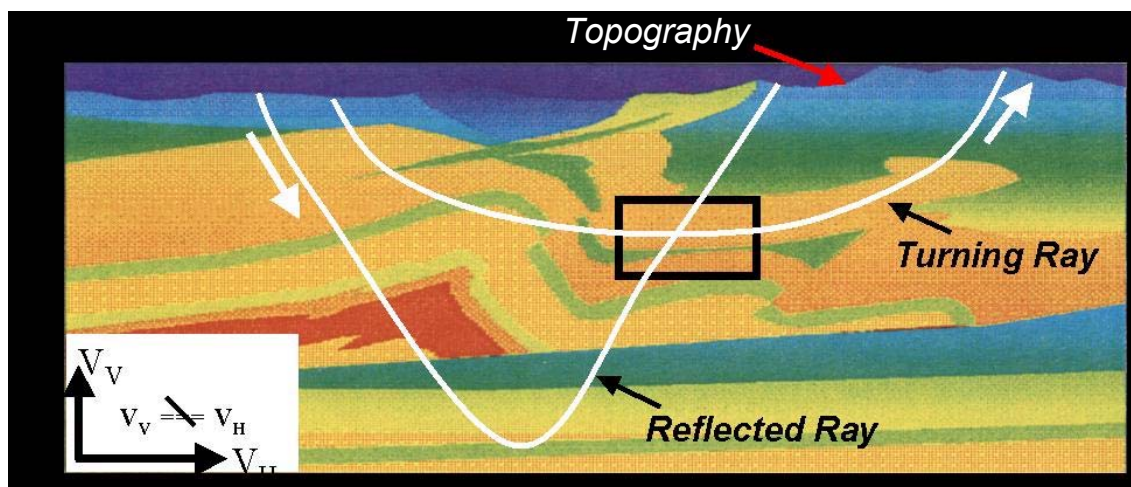


Figure 3. A sketch of joint tomography using reflected and turning rays.

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