C034

Gulf of Mexico Case Study of Localized Anisotropic Tomography with Checkshot

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SUMMARY

Reliably deriving parameters for anisotropic depth models requires use of borehole information. Localized tomographic inversion attempts to streamline and automate this process by directly incorporating the available well data into conventional reflection tomography. We present a case study from Gulf of Mexico where we conduct local VTI anisotropic tomography using a joint dataset consisting of seismic and checkshot data. Because this area has low structural dip, the results can be compared with more traditional manual 1D layer-stripping inversion. Tomographic inversion for three VTI parameters produces a smooth velocity model that both fits the checkshot traveltimes and flattens all seismic gathers. To regularize tomographic inversion, we apply smoothing operators that are oriented along predominant dips of seismic event and have large lateral extent. The anisotropic profiles derived by tomography and 1D inversion have similar low-frequency components, but differ in finer details. Borehole data require careful conditioning before joint inversion because of potential difference in water velocity between seismic and well surveys. The workflow we present can be applied to calibrating anisotropic parameters in the more general case of 3D models with structural dip and borehole data from deviated wells.

Introduction

While anisotropic depth imaging continues to gain popularity, estimation of anisotropic parameters remains the most challenging and ambiguous part of the velocity model building process. The available automated methods suffer from at least two serious restrictions. First, many of them rely on inverting seismic signatures that are hard to estimate, such as pre-stack traveltimes. Second, they are applicable to certain types of models only (1D, homogeneous layers, layers with gradients etc). Manual trial-and-error inversion may be applied to more complex cases, but the lack of automation makes the process highly tedious and the final result subjective. As a result, none of the available methods receive widespread approval and use in the oil and gas industry, where most of the velocity model building is performed with ray-based post-migration hybrid gridded tomography (Woodward et al., 2008). These types of tomography make no assumptions about the model type and can generally handle both "hard" geology (with highly contrasting properties) as well as "soft" geology (compaction-driven velocity regimes). Therefore, from a practical standpoint, it may be useful to adapt existing reflection tomography for anisotropic inversions by supplementing it with the appropriate well data. Such an approach was suggested by Bakulin et al. (2009) and demonstrated on synthetic data. Here, we present a case study of localized anisotropic tomography using real data from the Gulf of Mexico.

Gulf of Mexico case study

An initial vertically transversely isotropic (VTI) model was build without well control from a wide-azimuth survey for a large portion of Green Canyon, Gulf of Mexico. We extract a subset of these data around a well of interest that has a checkshot survey (Figure 1). The aim of the study is to build a local anisotropic model that is consistent with both seismic and well data. Out of the large initial model, we cut a sub-volume 50,000 by 50,000 by 20,000 ft, that will be used for localized inversion (Figure 1). We select 1,700 common-image point (CIP) gathers in the 3,000 by 3,000 ft area centered at the well. The stacked image shows very little structural dip; however, we observe some lateral velocity variation in the initial model. The vertical velocity in the initial model is too fast, which is manifested by residuals of up to 60 ms between measured checkshot times and traveltimes ray traced in the initial model (Figure 2a).

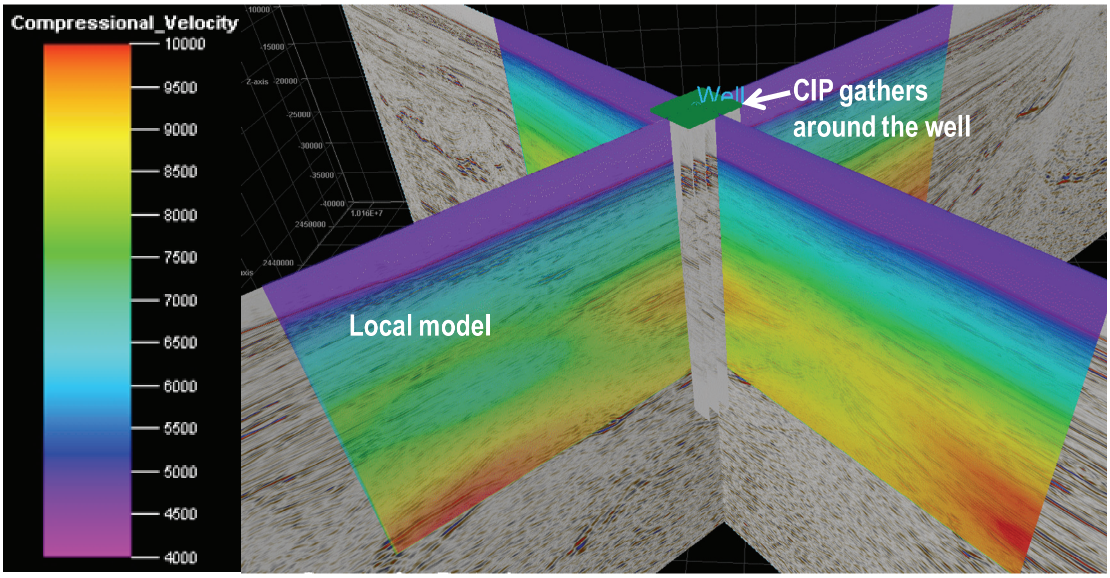

Figure 1 *Subvolume of velocity model around a well used for localized tomography. The green box shows the extent of CIP gathers used for inversion.*

We simultaneously invert for three parameters: vertical velocity V_{P0} and Thomsen parameters ε and δ. To avoid non-uniqueness, we invert only for a smooth model. In addition, we steer all parameter updates along the horizontal layers using smoothing operators in reflection tomography (Woodward et al., 2008). In a nutshell, we acknowledge that independent inversion for three parameters at each grid cell is highly non-unique, and therefore, unfeasible. We apply preconditioning and smoothing that both propagates well information (checkshot velocity) away from the well and prevents uncontrolled lateral variation of anisotropic parameters that would make the inverse problem highly unstable. The drawback to this approach is that we essentially restrict parameter updates to be laterally invariant; whereas, the initial model is laterally heterogeneous.

Preliminary analysis showed that well data must be conditioned because the water velocity was different for the seismic and checkshot surveys (Carvill, 2009). We shift all checkshot traveltimes by 8 ms to make seismic and well data consistent before joint inversion. We proceed with two different tomography scenarios that use distinct initial models: in the first case, the initial model is further from the final solution as compared to the second case.

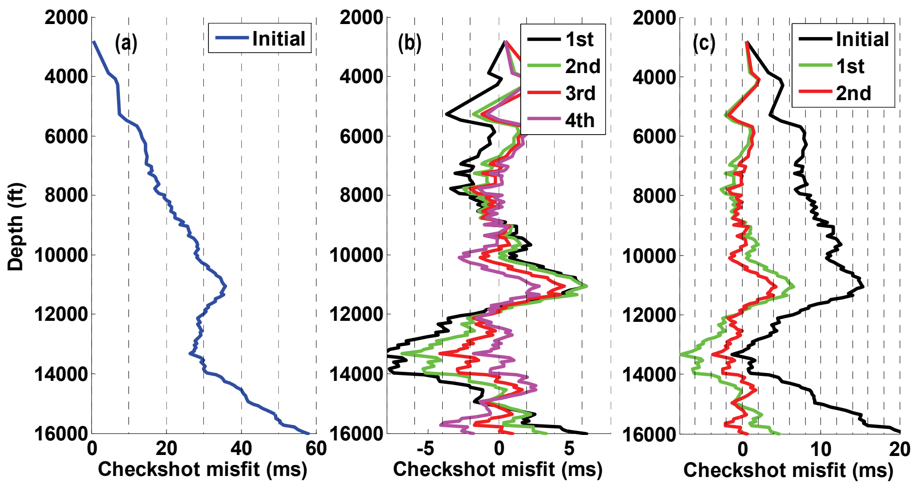

Figure 2 *Misfit in checkshot traveltimes during the first tomographic scenario (Figure 3) shown for initial model (a) and all subsequent iterations (b). Misfit is computed as a difference between measured and predicted traveltimes. Likewise, misfit for the second tomographic scenario (Figure 4) is shown in (c).*

In the first scenario, we use the available seismic velocity as an initial model. Because the seismic vertical velocity is too fast (Figure 2a), tomography slows down the velocity to fit the checkshot data (Figure 3a). At the same time, it increases Thomsen's parameters (Figure 3b,c) to compensate for these velocity changes and preserve the flatness of the image gathers (Figure 5a,b). The first two iterations of tomography are performed with a large vertical smoothing scale of 8000 ft; therefore, relocating velocity and anisotropy trends to a new position (Figure 3). The last two iterations are performed with a smaller vertical scale of 2000 ft; thus, allowing a better fit of checkshot traveltimes as well as revealing some finer details of anisotropy profiles. Because our checkshot data have no points in the first few thousand feet below water bottom, tomography tends to generate jumps in anisotropic parameters across the water bottom (Figure 3), which are not geologically plausible. To reduce these jumps, after a second iteration, we performed model editing by linearly tapering anisotropic parameters to zero near the water-bottom interface. Nevertheless, the remaining two iterations still generated similar, but smaller in magnitude, jumps (Figure 3). These artifacts can be reduced by either acquiring complete checkshots starting immediately from the water bottom, or by introducing additional rock physics constraints into the tomography.

In the second scenario, we start with a better initial model that has a regional profile with larger magnitudes of anisotropy, albeit without any vertical details. This new initial model is derived from an original model using the following simplistic process. First, we hang revised (larger) anisotropy profiles from the water bottom. Second, we scaled the velocity down according to the simple 1D equation $V_{P0}^{new} = V_{P0}^{old} \sqrt{\frac{(1+2\delta^{old})}{(1+2\delta^{new})}}$ that preserves gather flatness and is expected to reduce the subsequent tomographic workload.

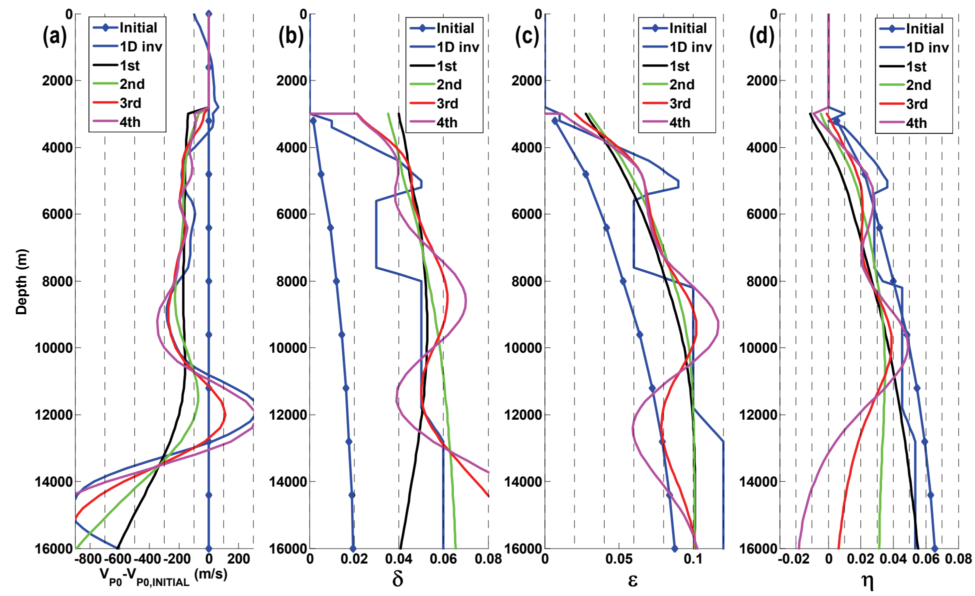

Figure 3 *Profiles of model parameters along the vertical well after each iteration of a three-parameter (V_{P0}, ε, and δ) VTI tomographic inversion of joint seismic and checkshot data for the first scenario: (a) velocity; (b) δ; (c) ε; (d) η. Velocity is shown as a difference between the current velocity in each iteration and the initial velocity. Curves labelled "1D inv" refer to smoothed velocity estimated from checkshot traveltimes and an anisotropic parameters derived by manual 1D layer-stripping inversion of a single depth gather.*

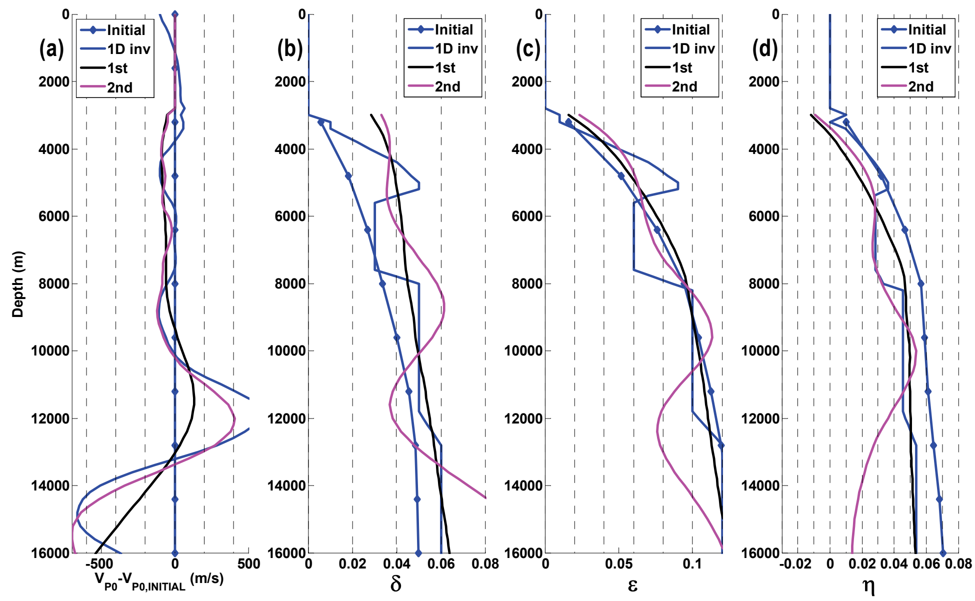

Figure 4 *Same as Figure 3, but for the second tomographic scenario.*

In all cases, we perform remigration with Rapid Beam Migration instead of full-blown migration with a new model to obtain quick feedback on the local tomographic inversion and reduce turnaround time. In this case, the initial model has smaller checkshot misfits (Figure 2c) and we only need two iterations to arrive at a similar solution to the one that took four iterations in the previous scenario.

Note that peaks and troughs as well as the magnitudes of anisotropic profiles are in agreement between these two tomographic scenarios (Figures 3 and 4); therefore, validating the stability of local multiparameter tomography with well data. Note that there are a few shallow events around 4,000 ft that can only be completely flattened using a substantially finer vertical scale (Figure 5d).

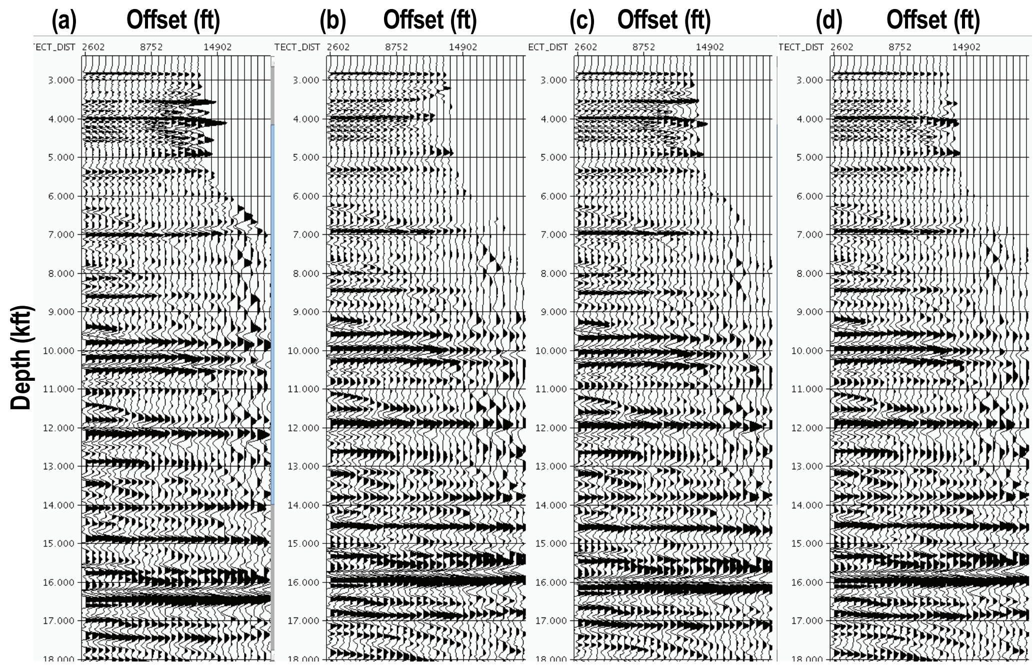

Figure 5 *Common-image point gather near the well: (a) initial model for first inversion; (b) final model after first inversion; (c) initial model for second inversion; (d) final model for second inversion.*

Conclusions

We have presented a case study of local anisotropic tomography with well data. In addition to a set of image gathers near the well tomography directly matched checkshot traveltimes measured in a vertical well. Tomography slowed down velocity near the well to fit the checkshot; whereas, use of laterally long smoothing operators along the dip of seismic events propagated such updates into the entire local volume. Simultaneously with updating vertical velocity, tomography also increases values of anisotropic parameters to make image gathers flat. Gradual reduction of the vertical height of the smoothing operator allowed recovery of finer vertical details of anisotropic profiles. Our tomographic results are generally consistent with manual 1D layer-stripping inversion, but are likely to be more accurate because they account for structural dip and lateral variation of the velocity model parameters. We believe that the workflow is also applicable to calibrating more general tilted transversely isotropic models using data from deviated wells.

Acknowledgements

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References

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