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Converted-wave Time Imaging – Nuts and Bolts

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Summary

In this paper, an alternative approach is proposed to include different kinds of anisotropy into the travel time calculation for converted-wave pre-stack time imaging. For areas with strong velocity gradients and strong intrinsic VTI anisotropy, it is especially important to treat them separately. Using similar approaches as PP PSTM and velocity information from PP processing for the down-going P-wave in PS time imaging is desirable for joint PP and PS pre-stack inversion of petro-physical parameters. The real data example, which shows strong ray bending, intrinsic VTI anisotropy and deep target, demonstrates that the new approach can yield comparable imaging of converted-wave data with that of PP data.

Introduction

Pre-stack time migration (PSTM) is routinely used in time processing with gentle lateral velocity variation and moderate subsurface structure. It is especially favorable for converted-wave (PS) time imaging, because PS PSTM naturally handles the time-variant and offset-dependent common conversion points (CCP) binning.

PP and PS pre-stack joint inversion has been becoming an important tool to extract petro-physics parameters from seismic data. To obtain comparable PS imaging with that from PP data and preserve AVO and AVAZ integrity for PS data, it is required to take into account the same types of anisotropy as the PP time imaging.

For PP time imaging, different kinds of anisotropy have already been incorporated into the time processing. Ver West and Wilkinson (2003) separated the vertical transverse isotropy (VTI) anisotropy into effective VTI anisotropy as the result of ray bending due to vertical variations in the interval velocity, and intrinsic VTI anisotropy caused by fine layering of the sediment. If there are vertical fractures embedded in a VTI medium, then VTI anisotropy and horizontal transverse isotropic (HTI) anisotropy were incorporated in the PP PSTM (Jenner, 2011). Recently, Wang and Wilkinson (2012) proposed a method to simultaneously estimate six parameters for orthorhombic velocity models, in which VTI anisotropy and HTI anisotropy are the special cases, and used the orthorhombic velocity for PP PSTM.

PS data are often more influenced by anisotropy in a medium than PP data (Cary, 2010). The azimuthal anisotropy causes shear-wave splitting of the PS wave field into separated PS1 and PS2 fields. Both wave fields (PS1 and PS2) are moreover affected by VTI anisotropy.

Migration velocity updating for PS PSTM is more complicated, because there are more velocity fields to be updated and it is more complicated to form gathers for velocity analysis prior to PS PSTM. A practical and efficient way for PS PSTM velocity analysis was proposed by Thomsen (1999), Li and Dai (2004), Miao and Zuk (2007).

Theory and Method

For converted-wave time imaging, if there is strong ray bending (effective anisotropy) and intrinsic VTI anisotropy, it is very important to treat both effects separately. By extending the work of Ver West and Wilkinson (2003) to the double-square root (DSR) equation for converted-wave travel time proposed by Li et al. (2004) and Miao et al (2007), we get:

$$t_{ps} = \sqrt{\tau_{p0}^2 + \frac{X_p^2}{v_p^2} - \frac{2\eta_{vp}X_p^4}{\tau_{p0}^2 v_p^4} - \frac{2\eta X_p^4}{v_p^2[\tau_{p0}^2 v_p^2 + (1+2\eta)X_p^2]}} + \sqrt{\tau_{s0}^2 + \frac{X_s^2}{v_s^2} - \frac{2\eta_{vs}X_s^4}{\tau_{s0}^2 v_s^4} + \frac{2\xi X_s^4}{v_s^2[\tau_{s0}^2 v_s^2 + X_s^2]}} \quad (1)$$

Where $\tau_{p0} = \tau_{ps0}/(1+\gamma_0)$ and $\tau_{s0} = \tau_{ps0} * \gamma_0/(1+\gamma_0)$ are the one way imaging time of down-going P-wave and up-going S-wave respectively. τ_{ps0} is the two way imaging time for PS wave. γ_0 is the vertical velocity ratio of P-wave and S-wave. v_p and v_s are the P-wave and S-wave RMS velocity respectively, which are the function of converted-wave RMS velocity v_c, γ_0 and effective velocity ratio γ_{eff}. X_p and X_s are the distance from source and receiver to the surface location of the imaging point respectively.

In each square root of the DSR equation, the first two terms are the conventional isotropic terms. The third terms are the high-order terms which correct the travel time error due to ray bending caused by varying vertical velocity. η_{vp} and η_{vs} are the effective anisotropy for P-wave and S-wave respectively, which are the function of the velocity gradient of P-wave and S-wave interval velocities. If there is strong ray bending and the target is deep, these terms become more important.

The travel time error due to intrinsic VTI anisotropy is corrected by the fourth terms in the DSR equation. η is the intrinsic anisotropy for P-waves and ξ is the intrinsic anisotropy for S-waves, which is related to η and γ_{eff} by $\xi = \eta * \gamma_{eff}^2$. The fourth term for up-going S-wave has different sign from that for down-going P-wave, because the polarization of down-going P-wave is along the ray direction while that of up-going S-wave is perpendicular to the ray path. This is why it is important to separate the effective anisotropy and intrinsic anisotropy for travel time calculation for PS time imaging.

Example

The new method was applied to an unconventional shale oil/gas data set. This dataset shows very strong effective VTI anisotropy (ray bending) and intrinsic VTI anisotropy. The target is relatively deep.

PS velocity analysis follows the procedure proposed by Miao et al (2007) and Li et al (2004). The initial converted-wave velocity v_c is calculated from final P-wave migration velocity, γ_0 and $\gamma_{eff} = \gamma_{nmo}^2/\gamma_0$, in which γ_{nmo} is the converted-wave NMO velocity and γ_0 is calculated by events registration from PP PSTM stack and PS post-stack migration section.

The comparison of PP pre-stack migrated stack (Left), PS pre-stack migrated stack (Middle) and PS post-stack migration is shown in Figure 1. The post-stack migration shows smeared structure, because CCP stacking may map the samples to the incorrect common conversion points due to lateral velocity variation. Pre-stack migration using the approach proposed in this paper yields very similar structure as that from PP PSTM.

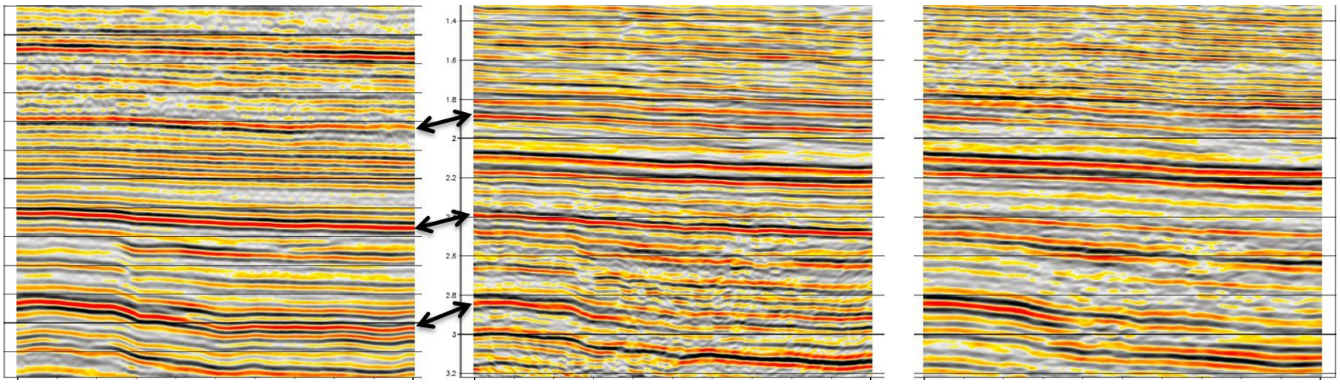

Figure 1: PP PSTM in PP time (Left, displayed in different vertical scale), PS PSTM in PS time (Middle) and PS Post-Stack Migration in PS time (Right).

Conclusions

Pre-stack time migration (PSTM) for converted-wave (PS) is very favorable for imaging PS data with moderate lateral velocity variation and subsurface structure. Besides all the benefits of PP PSTM, PS PSTM naturally handles the time-variant and offset-dependent CCP binning. Using similar approaches as PP PSTM and velocity information from PP processing for the down-going P-wave in PS time imaging is desirable for joint PP and PS pre-stack inversion of petro-physical parameters. For areas with strong velocity gradient and intrinsic VTI anisotropy, it is very important to treat the effective anisotropy and intrinsic VTI anisotropy separately. The real data example shows that the new approach can yield comparable imaging of converted-wave data with that of PP data.

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References

Cary, P.W., and Zhang, C., 2010, Optimizing converted-wave prestack time migration: GeoCanada 2010, CSEG, Extended Abstracts.

Dai, H. C. , and X. Y. Li, 2006, The effects of migration velocity errors on travel time accuracy in prestack Kirchhoff time migration and the image of PS converted waves: Geophysics, **71**, no. 2, S73–S83.

Grechka, V., and I. Tsvankin, 1999a, 3-D moveout velocity analysis and parameter estimation for orthorhombic media: Geophysics, **64**, 820 – 837.

Grechka, V., and I. Tsvankin, 1999b, 3-D moveout inversion in azimuthally anisotropic media with laterally velocity variation: Theory and a case study: Geophysics, **64**, 1202 – 1218.

Jenner, E., 2011, Combining VTI and HTI anisotropy in prestack time migration: Workflow and data examples: The Leading Edge, **30**, No. 7, 732-739.

Li, X. Y. , and Dai, H, 2004, Converted-wave imaging in anisotropic media: An overview: 74th Annual Conference and Exhibition, SEG, Extended Abstracts.

Thomsen, L., 1999, Converted-wave reflection seismology over inhomogeneous, anisotropic media: Geophysics, **64**, 678–690.

Tsvankin, I., and L. Thomsen, 1994, Nonhyperbolic moveout in anisotropic media: Geophysics, **59**, 1290–1304.

Wang, S., and D. Wilkinson, 2012, Imaging for unconventional resource plays using an orthorhombic velocity model: 82th Annual International Meeting, SEG, Expanded Abstracts.

Ver West, B., P. Hilton, and D. Wilkinson, 2003, The importance of anisotropy for prestack imaging of extensional fault systems: 65th Annual Conference and Exhibition, EAGE, Extended Abstracts, 0133.

Miao X., and T. Zuk, 2007, Anisotropic velocity updating for converted-wave prestack time migration: Geophysics, **72**, D29–D32.