MULTI-COMPONENT DECONVOLUTION OF VSP DATA FOR SHEAR-WAVE SPLITTING

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SUMMARY

Most multi-component VSP data for shear-wave splitting analysis show that the wave properties of the near-surface layers and source behaviour affect the anisotropic interpretation of a subsurface target zone. In this paper, based on a vector convolutional model for shear-wave splitting, we develop a multi-component deconvolution algorithm for VSP data, which removes these effects so that we may estimate local polarization and time-delay. Applying this deconvolution can also be used to directly concentrate on the target zone. This deconvolution is applied to a field data set for three wells from the Romashkino reservoir, Russia, and demonstrates that previous inconsistencies in the polarization and time-delay are removed. The polarization directions in the reservoir zone are slightly different for the two wells (N139°E for well 15037 and N119°E for well 15548). Both wells display a similar shear-wave anisotropy of about 6-8%. No evidence of anisotropy is found for the third well (17598) in the reservoir zone. These results suggest a positive correlation between the shear-wave anisotropy and production of reservoir.

INTRODUCTION

Over recent years, multicomponent data acquired using vertically and horizontally polarized sources and three-component receivers, have been used to provide detailed information about the internal stress and crack-geometry within a reservoir by interpreting the anisotropy (Crampin and Lovell, 1991). However, most multi-component VSP data for shear-wave splitting analysis show a large amount of time-delay between fast and slow shear-waves built up in the near-surface. This will affect the anisotropic interpretation of a subsurface target zone. It has been common to correct for this in shear-wave data by assuming a uniform anisotropic layer (Winterstein and Meadows, 1991). This correction relies upon the unitary assumption for the downgoing transmission response for the overburden. Therefore, which M, (u) for which M, (v)M, (u) is a unit matrix. Here v represents the temporal frequency, with the \* symbol representing complex conjugate, and the superscript T a transpose matrix. It is unlikely this assumption will be generally applicable to the complicated near-surface layer. This problem may be resolved for near-offset VSPs by using a deconvolution designed for the downgoing wavefield, which renders the overburden response unitary. This deconvolution is applied to a VSP data set from the Romashkino, Russia, to show how this algorithm can improve our understanding of the target zone.

DESIGN OF DECONVOLUTION OPERATOR

It is assumed that after transmission through the overburden, the wave field propagates through an anisotropic subsurface containing the target zone. The anisotropic operator D,(v) which connects closely spaced geophone levels is unitary, and the ith recorded data matrix D,i(v) (group of displacements from several source motions) may be expressed by (D,(v))M,, (v). A group of VSP levels for determining the overburden response can now be chosen using the unitary product:

\[ D_i(v) = M_i(v)^{-1}M_0(v); \] (1)

which is independent of the depth for suitable recordings. An estimate of the overburden operator is determined from the shallowest group of these recordings. First, a least-squares estimate is obtained for the local transfer function D,(v) and then M,(v) is obtained by minimizing the error between the recorded data matrices D,(v) and the estimates (D,(v))M,(v). Deconvolution can now be applied by post-multiplying the recorded data matrix with the inverse overburden operator.

CASE STUDY FROM FOUR-COMPONENT VSPS

DATA ACQUISITION: The data sets to be discussed here are from multicomponent VSPs recorded at three wells (well 13037, 15548, and 17598). The details of data acquisition were described in Clet et al. (1991). There is a significant difference in production levels between wells 15548 (14m³/day) and 15037 (3m³/day). However, well 17598 has not yet entered production at the levels considered by this survey. Although the data were recorded in a large range of depth, with both P-sources and S-sources, in this paper we will consider only the shear-waves data recorded in the target zone, which is a 70m layer started from the depth of about 509m (sea level). For well 15037, data from three source polarizations (A=N47°E, B=N137°E, and C=N91°E) were recorded, but only the recordings from sources A and B were in the reservoir zone. Data from well 15548 was also collected from three source polarizations (A=192°E, B=N280°E, and C=N226°E). Well 17598 was recorded with four source polarizations with sources A (N122°E) and B (N212°E) have a similar strength but were less powerful than sources C (N77°E) and D (N167°E), which were again of similar strength. All the data were recorded at 5m intervals with the sampling intervals of 2m, and at the reservoir zone all incident angles are less than 40°. The pre-processing of the data includes a mild high-cut filter to eliminate the high frequency noise and a f-k filter to separate the down going wave and up going wave. Here we consider only the down going wave in the design.
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METHODS OF ANALYSIS: Many techniques have been developed for analyzing shear-wave splitting (see Li et al., 1993 for details). The techniques we have used here are the algebraic processing techniques developed by Zeng and MacBeth (1992). The cumulative rotation technique (DCT) is used to determine the polarization direction ($\theta$) and time delay. This technique calculates the polarization direction of $qSI$ by minimizing the total energy in the off-diagonal components of four component matrix by synchronous rotation of source and geophone angles. Another algebraic technique, the independent source/geophone rotation technique (DIT) is used to detect the asymmetry of the data matrix by singular value decomposition.

RESULTS: Figure 1 shows the original data matrix for sources A and B at well 15548. Figure 2 gives the polarization direction and time-delay from DCT by using different combination of sources. Although both the polarization direction and time-delay are consistent with each other for different source combinations. It is clear that this source dependent polarization direction is not the true polarization of the shear-wave in the region. In fact, the DIT results (Figure 3) show two estimated angles $\theta_1$ and $\theta_2$ are far apart, suggesting that the data matrix is asymmetric and the condition of uniform anisotropy in the upper reservoir is not correct (MacBeth et al., 1993).

To solve this problem, we applied the multi-component deconvolution algorithm to this data designed on the shallowest few traces. Figure 4 shows the deconvolved data matrix. Now that the effects of the near-surface have been removed, we have essentially moved the sources to a new reference level with the source polarizations aligned along the two new axes. Figure 5 and 6 gives the results of DCT and DIT applied to the deconvolved data. Three important improvements have been achieved for these results: First, $\theta_1$ and $\theta_2$ from DIT come together and agree with value of $\theta$ estimated from DCT (Figure 5). The results of DCT are now independent of the source combinations and consistent with those of DIT. Any combinations of the three sources gives nearly the same results (Figure 6). The result now represents the true degree of shear-wave splitting in the reservoir zone. The time-delay from the deconvolved data has been recovered, and vanged from 0 at the first geophone increasing to about 2 ms at the bottom of the reservoir zone. Overall the results show that there is an anisotropy in the reservoir zone and surrounding rocks for well 15548. The $qSI$ polarization is $N115^\circE$ with an error of $\pm 7.5^\circ$. The corresponding degree of the shear-wave anisotropy in this zone is about 6-8%.

The procedure has been applied to the data sets from well 15037 and well 17598. Figure 7 shows the DCT result for well 15037. It gives the $qSI$ polarization direction on $N138^\circE$ with an error of $\pm 2^\circ$. The increase of time-delay in the reservoir zone is about 2.2 ms, which also corresponds to a shear-wave anisotropy of about 6-8%. In Figure 8, we present the DCT result for well 17598 for both sources A+B and C+D. The $qSI$ polarization direction is almost $N90^\circE$, and the time-delay over the reservoir zone is nearly zero. These together suggest that the reservoir zone in this well is effectively isotropic.

CONCLUSIONS

Multi-component deconvolution technique offers the possibility of a satisfactory correction for the seismic wave properties of the near-surface or overburden in multi-component VSP data. We suggest that this procedure is particularly useful for analyses where we seek to correlate target zone birefringence with fractures and production rates. The case study of the Romashkino field by using this technique shows that the presence of the shear-wave splitting in this area, with the polarization direction changing from $N138^\circE$ (well 15037) to $N115^\circE$ (well 15548). Both wells have the similar degree of shear-wave anisotropy of about 6-8%. On the other hand for the well 17598, there is no evidence of anisotropy within the reservoir zone. The results are in positive agreement with the reservoir production figures.

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REFERENCES


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Figure 1. Original data matrix of well 15548 for sources A and B. XX and XY are the two horizontal geophone components from in-line source (A) and YY and YX are that from cross-line source (B).

Figure 2. Results for well 15548 by applying DCT directly to the original data matrix, where A+B means using the combination of source A and B.

Figure 3. Results for well 15548 by applying both DCT and DIT directly to the original data of A+B.

Figure 4. Data matrix for sources A and B of well 15548 after applying the deconvolution. For the clarity of display, a 200ms time shift was used.
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Figure 5. Results from the deconvolved data of well 15548 by using DCT and DIT for sources A+B.

Figure 6. Results from the deconvolved data of well 15548 by using DCT for different sources combinations.

Figure 7. DCT results for well 15037 after applying the deconvolution.

Figure 8. DCT results for well 17598 for both combinations of sources A+B and C+D.