Reducing the uncertainty in parameter estimation and data processing of PS converted waves

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Summary

We developed a simplified approach to reduce the uncertainty in parameter estimation and data processing of PS converted waves. This is archived by using a simplified PS-wave moveout. In this moveout, a combination parameter is used to replaced the vertical Vp/Vs ratio, effective Vp/Vs ratio and PS-wave anisotropy, and another combination of these parameters, a model parameter, is empirically set to a constant value. This simplified moveout is more accurate than the original moveout. Tools are developed to estimate these parameters and apply the parameters to moveout correction. Applying these tools to a real dataset shows that the new approach can reduce the uncertainty in parameter estimation and simplify the processing steps. The results obtained from the new approach are the same as that from the original method.
Introduction

PS converted waves in multi-component seismic data have been used increasingly in the oil industry due to their ability for imaging through gas clouds and lithology-fluid prediction. The moveout of PS converted waves plays a crucial role in imaging and velocity model estimation. Different formulae have been derived for the moveout of PS-converted waves with different kinds of parameterization (Alkhalifah, 1997; Cheret, et al, 2000; Li and Yuan, 2003; Thomsen, 1986, 1999; Tsvankin and Thomsen, 1994). Several formulae with three, four, or five parameters are used. Therefore different approaches and software need to be applied to PS-converted wave datasets. Unlike processing P- and S-waves, not all the parameters in these formulae can be reliably estimated from the PS-converted wave alone. This gives rise to some ambiguities in parameter estimation using PS-converted wave moveout. In order to simplify the approaches for processing PS-waves and overcome the problems in parameter estimation, Dai and Li (2005) proposed a simplified formula for the PS converted wave. In this paper, we show how to apply this formula in PS wave processing and discuss its advantages for data processing.

PS-converted wave moveout

In anisotropic media, the moveout of PS converted waves is written as (Dai and Li, 2005),

\[ t^2 = t_0^2 + \frac{x^2}{V_{ps}^2} - 2k_{eff} \frac{V_{ps}^2}{V_{ps}^2} \left( \gamma_0 V_{ps} + m \cdot x^2 \right), \] (1)

\[ k_{eff} = \frac{(\gamma_0 V_{eff} - 1)^2 + 8 \chi_{eff} (1 + \gamma_0)}{8 \gamma_0^2 (1 + \gamma_0)^2}, \] (2)

\[ m = 2k_{eff} \frac{(1 + \gamma_0) [(\gamma_0 - 1) \gamma_{eff}^2 + 2 \chi_{eff}]}{(\gamma_0 - 1) \gamma_{eff} (\gamma_0 V_{eff} - 1) + 2(1 + \gamma_0) \chi_{eff}}, \] (3)

Where, \( x \) is the offset, \( V_{ps} \) is the stacking velocity, \( \gamma_0 \) is the vertical velocity ratio, \( \gamma_{eff} \) is the effective velocity ratio, and \( \chi_{eff} \) is the anisotropic coefficient for PS-converted waves. \( k_{eff} \) and \( m \) are combinations of \( \gamma_0 \), \( \gamma_{eff} \), and \( \chi_{eff} \). Note that \( \gamma_0 \) is estimated by correlating events in the P-wave and PS converted wave images. Then \( V_{ps} \), \( \gamma_{eff} \) and \( \chi_{eff} \) need to be estimated from the PS-wave moveout (Equation 1). When using this formula to estimated the three parameters for the PS-wave moveout, the values of these parameters might not be unique and have ambiguities. Generally, an iteration procedure is needed to estimate the four parameters.

After binning the dataset into ACP gathers, \( V_{ps}, \gamma_{eff} \) and \( \chi_{eff} \) can be estimated with an initial value of \( \gamma_0 \). A NMO correction is applied to the ACP gathers based on these parameters and then gathers are stacked to form a stacked section. Based on the stacked section, new values of \( \gamma_0 \) can be estimated from registering events on the PP and PS wave sections. Because the new profile of \( \gamma_0 \) may be different from the initial values, \( V_{ps}, \gamma_{eff} \) and \( \chi_{eff} \) have to be re-estimated with the new values of \( \gamma_0 \). The NMO correction and stacking are performed again to obtain a new stacked section.

Actually, this iteration procedure is caused by the ambiguities in estimating \( V_{ps}, \gamma_{eff} \) and \( \chi_{eff} \), which also depend on the value of \( \gamma_0 \). In order to reduce the ambiguities and dependence, we found that \( k_{eff} \) and \( m \), instead of \( \gamma_{eff} \) and \( \chi_{eff} \), can be estimated. One of the
advantages of using $\kappa_{\text{eff}}$ and $m$ is that $m$ can be set a fixed value. This is because Equation (1) is an approximation equation and $m$ is also an approximation. The moveout calculated from Equation (1) based on the model parameters is not the same as the exact moveout which is calculated from a ray-tracing method. We have performed a numerical analysis for four multi-layer models: Model 1 is with strong velocity contrasts and larger anisotropy; Model 2 is its corresponding isotropic model; Model 3 is with moderate velocity contrasts and less anisotropy; and Model 4 is its corresponding isotropic model. The results show that when the calculated $m$ is larger than a certain value, the moveout is larger than the accurate one. When $m$ is less than the certain value, the moveout is less than the accurate one. It shows that $m$ can be empirically set to a constant value (roughly 3/7 for our test models). Equation 1 with a constant $m$ (=3/7) is more accurate than that with $m$ calculated from model parameters.

Since $m$ is constant in Equation (1), the non-hyperbolic feature of PS converted wave is controlled by $\kappa_{\text{eff}}$ only, not by $\gamma_0$, $\gamma_{\text{eff}}$ and $\chi_{\text{eff}}$ separately. Equation 1 actually has only two parameters ($V_{ps}$ and $\kappa_{\text{eff}}$). Estimating two parameters from one equation is simpler and less ambiguous than estimating three parameters. This provides an alternative approach to simply and efficiently estimate the PS-wave parameters and process the PS wave data. Note that we can calculate $\gamma_{\text{eff}}$ and $\chi_{\text{eff}}$ using Equations (2) and (3) with the estimated $\kappa_{\text{eff}}$, the constant $m$ (=3/7) and the estimated $\gamma_0$.

Processing flow

Figure 1 shows the flow chart of this alternative approach. In this approach, the estimation of the parameters is decoupled into separate steps. $\gamma_0$ is estimated from the event registration of P and PS wave data. $V_{ps}$ and $\kappa_{\text{eff}}$ are estimated from the PS-wave moveout. The advantage of this decoupling is that estimation of $V_{ps}$ and $\kappa_{\text{eff}}$ is independent of $\gamma_0$. The normal moveout (NMO) correction uses $V_{ps}$ and $\kappa_{\text{eff}}$ only. It will make the processing flow for the PS converted wave simpler. After binning the data into ACP gather, we can directly estimate $V_{ps}$ and $\kappa_{\text{eff}}$, then perform NMO correction for the ACP gathers and stack them to obtain the stacked section without knowing $\gamma_0$. $\gamma_0$ is estimated by event registration of PP and PS wave sections afterward. This is no need to re-estimate $\gamma_0$, and then $V_{ps}$ and $\kappa_{\text{eff}}$. Instead, we can use $\kappa_{\text{eff}}$ and $\gamma_0$ to directly calculate $\gamma_{\text{eff}}$ and $\chi_{\text{eff}}$ using Equations (2) and (3). Based on the above analysis, we developed a new GUI tool to estimate $V_{ps}$ and $\kappa_{\text{eff}}$ and a tool to apply NMO using $V_{ps}$ and $\kappa_{\text{eff}}$. Note that this approach still have four parameters, $\gamma_0$, $V_{ps}$, $\kappa_{\text{eff}}$ and $m$ (which is fixed to a constant value). These four parameters need to be converted to $\gamma_0$, $V_{ps}$, $\gamma_{\text{eff}}$ and $\chi_{\text{eff}}$ for other processing steps, such as pre-stack time migration.
Data Example.

The data used to test this approach is from a 3D-4C marine dataset acquired in August 2001 (Courtesy of Kerr-McGee North Sea UK Ltd). This is a North Sea survey which was centred on a domed structure which is obscured by a gas chimney. Faulting is thought to be present beneath the summit of the dome. Since the P-waves are attenuated by gas clouds, the P-wave image of the structure beneath the gas chimney is dimmed, but PS converted waves can image that structure (Dai, et al 2007). Here we compare the results obtained using the original approach and the new approach.

Figure 2 shows the velocity analysis results for an ACP gather with two or four parameters. Both approaches can flatten the events in this ACP gather. However, using the four parameters, we need to carefully to adjust $V_{ps}$, $\gamma_{eff}$ and $\kappa_{eff}$ several times to flatten the events, and some times, we also need to adjust $\gamma_0$. Note that for the events between 1s and 2s, we find that it is difficult to flatten them at the far offset. But, using the two parameters, we only need to adjust $V_{ps}$ and $\kappa_{eff}$. It is easy to flatten the events at the far offset. We can observe a little difference between Figure 2a and 2b. The event between 1s and 2s in the negative far offset is more flattened in Figure 2a than Figure 2b.

Figure 3 shows the final stacked results. Both two approaches give similar results. In the shallow part of the section, it seems the new approach with two parameters has a slightly better image, for example, the image at times in between 1s and 3s and at CDP between 200 and 400.

Discussion and Conclusions

A simplified PS-wave moveout is used to propose a new approach to estimate PS wave velocity model and process PS-waves. This moveout controlled by $V_{ps}$ and $\kappa_{eff}$ with a
constant $m (=3/7)$ is more accurate than that with $m$ calculated from model parameters. In this approach, the estimation of the parameters is decoupled into separate steps. These separated steps are independent to each other. Estimating $V_{ps}$ and $\kappa_{eff}$ is easier than estimating $V_{ps}$, $\gamma_{eff}$ and $\chi_{eff}$. Results obtained by applying the two approaches to process a real dataset have the similar accuracy. But the new approach can reduce the uncertainty in parameter estimation and simplify the processing step.

![Figure 3. Stacking sections obtained using (a) two parameters and (b) four parameters](image)

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**References**