# Velocity Updating for Converted-Wave Prestack Time Migration

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**Abstract**

Summary

The conventional method to estimate velocities for converted-wave (C-wave) time migration is an awkward procedure, because the P-wave velocity ($V_p$) comes from P-wave processing, the velocity ratio gamma ($V_p/V_s$) is estimated from C-wave data, and the S-wave velocity ($V_s$) is then derived from $V_p$ and gamma. Therefore, errors in $V_p$ estimation will be carried over to $V_s$. Instead, by using the C-wave velocity ($V_c$) and effective gamma ($\gamma_{eff}$) for converted-wave time migration, velocity updating becomes straightforward and is independent of P-wave processing.

To update $V_c$ for converted-wave time migration, Dai and Li (2004) proposed to create hyperbolic moveout migrated common midpoint (HMO-MCMP) gathers and carry out hyperbolic velocity analysis on these gathers. Because only $V_c$ can be updated by the HMO-MCMP gathers, the errors in initial $\gamma_{eff}$ and anisotropy parameter $\chi_{eff}$ estimates can only be corrected by a trial-and-error method. This can cause difficulties in flattening the image gathers since $\gamma_{eff}$ and $\chi_{eff}$ affect the intermediate- and far-offset data.

I propose a method to remove the effects of initial $\gamma_{eff}$ and $\chi_{eff}$ in the HMO-MCMP gathers by inverting the moveout related to the initial $\gamma_{eff}$ and $\chi_{eff}$. This enables a full non-hyperbolic velocity analysis to be conducted in order to update not only $V_c$ but also $\gamma_{eff}$ and $\chi_{eff}$. Then the errors in initial velocity can affect only the binning in creating the HMO-MCMP image gathers, and these binning errors can be reduced by iterations of velocity analysis. The method is tested with data and shows consistent improvement in estimating C-wave migration velocity.

Introduction

The PS converted wave travels as a P-wave down and a S-wave up. It is natural to use the P-wave velocity $V_p$ from P-wave processing and estimate the S-wave velocity $V_s$ from C-wave data for converted-wave prestack migration. However, is this an efficient and reliable way to update velocity for converted–wave migration? For depth migration, the answer is yes, but for time migration this is not really true: because the data used for $V_s$ analysis is converted-wave data in C-wave time, and $V_p$ is in two-way P-wave time. We need the vertical velocity ratio $\gamma_0$ to convert $V_s$ to the two-way S-wave time. Since both $V_p$ and $V_s$ contribute to the first order moveout in the C-wave travel time, $\gamma_0$ becomes sensitive in estimating $V_s$. Moreover, often when multicomponent data are acquired, there are problems in the P-wave data, for example lack of PP impedance contrast or presence of gas clouds in the survey area. As a result registration of PP/PS events to obtain $\gamma_0$ isn't easy. Well logs can only provide $\gamma_0$ in a few locations. Errors in $V_p$ and $\gamma_0$ estimates are carried over to $V_s$, which can cause difficulties in producing an optimized prestack image.

Alternatively, by using C-wave velocity and effective gamma for converted-wave time migration, velocity updating becomes straightforward and more reliable, since both $V_c$ and $\gamma_{eff}$ refer to the C-wave travel time. In addition, $V_c$ is the only parameter affecting the first order moveout in the C-wave travel time; $\gamma_0$ and $\gamma_{eff}$ are less sensitive. When $\gamma_0$ is known, velocity updating is completely independent of P-wave processing. For polar anisotropic (vertical transversely isotropic (VTI)) media, only one anisotropy parameter $\chi_{eff}$ needs to be estimated. Here $\chi_{eff}$ is a function of the P-wave anisotropy parameter $\eta_{eff}$ and the S-wave anisotropy parameter $\zeta_{eff}$. For isotropic media, setting $\chi_{eff}$ to zero reduces velocity updating to two parameters, $V_c$ and $\gamma_{eff}$. In this abstract, I will discuss only the anisotropic case.

C-wave time migration using $V_c$, $\gamma_{eff}$ and $\chi_{eff}$

The C-wave travel time calculation for prestack migration in a VTI medium can be expressed as

$$t_c = \sqrt{\frac{t_{c0}^2}{(1+\gamma_0)^2} + \frac{x_p^2}{v_p^2} - 2\eta_{eff}\Delta t_p^2} + \sqrt{\frac{t_{c0}^2\gamma_0^2}{(1+\gamma_0)^2} + \frac{x_s^2}{v_s^2} + 2\zeta_{eff}\Delta t_s^2}, \qquad (1)$$

where $t_c$ is the C-wave travel time, $t_{c0}$ is the C-wave vertical travel time, $V_p$ and $V_s$ are the P-wave and S-wave moveout velocities respectively, $x_p$ is the offset from source to the image point, $x_s$ is the offset from receiver to the image point, and $\eta_{eff}$ and $\zeta_{eff}$ are the anisotropy parameters for P-waves and S-waves respectively. The last terms in the above two square roots represent residual moveout related to anisotropy, which will be dropped for isotropic media. Relationships exist for $V_p$ and $V_s$ with moveout velocity $V_c$, $\gamma_0$ and $\gamma_{eff}$:

$$v_p^2 = \frac{(1+\gamma_0)\gamma_{eff}}{(1+\gamma_{eff})} v_c^2, \quad \text{and} \quad v_s^2 = \frac{(1+\gamma_0)}{(1+\gamma_{eff})\gamma_{eff}} v_c^2.$$

Similarly, the anisotropy parameters $\eta_{eff}$ and $\zeta_{eff}$ can be derived from $\chi_{eff}$ by $\eta_{eff} = \frac{\chi_{eff}}{(\gamma_0 - 1)\gamma_{eff}^2}$ and $\zeta_{eff} = \frac{\chi_{eff}}{(\gamma_0 - 1)}$. Therefore carrying out velocity analysis for $V_c$, $\gamma_{eff}$ and $\chi_{eff}$ should be sufficient for updating $V_p$, $V_s$, $\eta_{eff}$ and $\zeta_{eff}$. As mentioned earlier, $\gamma_0$ can be obtained from well log information or initial PP/PS event registration.

On the other hand, in a VTI medium the C-wave moveout can also be approximated by (Thomsen (1999), Li (2003)),

$$t_c^2 = t_{c0}^2 + \frac{x^2}{v_c^2} + \frac{A_4 x^4}{1 + A_5 x^2} \quad , \qquad (2)$$

where

$$A_4 = \frac{-1}{(1+\gamma_{eff})^2}\left[\frac{(\gamma_0\gamma_{eff}-1)^2 + 8(1+\gamma_0)\chi_{eff}}{4t_{c0}^2 v_c^2 \gamma_0 (1+\gamma_{eff})^2}\right], \quad A_5 = \frac{A_4 v_c^2 \ (1+\gamma_0)\gamma_{eff}\left[(\gamma_0 - 1)\gamma_{eff}^2 + 2\chi_{eff}\right]}{(1-\gamma_0\gamma_{eff})(\gamma_0 - 1)\gamma_{eff}^2 - 2(1+\gamma_0)\gamma_{eff}\chi_{eff}}.$$

The first two terms in (2) describe a hyperbolic moveout controlled by $V_c$; thus $V_c$ affects the first order travel time. $\gamma_{eff}$ contributes to the second and higher order moveout and $\chi_{eff}$ only affects the higher order moveout. The $V_c$ estimation is most important, and the other two parameters along with $\gamma_0$ are less sensitive to the travel time calculation (Li 2003).

Velocity updating

Dai and Li (2003) proposed to create HMO-CMIP gathers for velocity updating. A HMO-MCMP gather can be constructed by migrating data using initial velocities from NMO analysis or from previous migration velocity analysis, and partially shifting energy along diffraction curves with hyperbolic moveout retained. $V_c$ then can be estimated through a hyperbolic velocity analysis for the HMO-CMIP gathers.

However, the effect of $\gamma_{eff}$ and $\chi_{eff}$ in C-wave travel time cannot be ignored, especially for $\gamma_{eff}$, which affects intermediate- and far-offset moveouts. To be able to update $\gamma_{eff}$ and $\chi_{eff}$, I propose to invert the moveout related to $\gamma_{eff}$ and $\chi_{eff}$ in creating the HMO-MCMP gathers. Then the image gathers created for velocity analysis retain full non-hyperbolic moveout. I shall call them non-hyperbolic-moveout common imaging gathers (NHMO-CIG). The NHMO-CIG gathers created by migration are migrated to the output datum (with topographic variations taken into account) and equation (2) can be used to update $V_c$, $\gamma_{eff}$ and $\chi_{eff}$.

Data example

Figure 1 shows an example of velocity updating for C-wave prestack time migration. This example is from BP's Valhall synthetic data set. On the left are the parameters ($V_{c2}$, $\gamma_{eff}$ and $\chi_{eff}$ ) picked from the NHMO-CIG gather shown in the third panel. The black line represents $\chi_{eff}$, the blue line is $V_c$, and the green line is $\gamma_{eff}$. For convenience of display, $\gamma_{eff}$ is scaled by 1000. We can switch parameter picking among $V_c$, $\gamma_{eff}$ and $\chi_{eff}$. The semblance plot in the second panel corresponds to the semblance spectra of the currently picked parameter, which is $V_c$. As mentioned earlier, $V_c$ affects the first order moveout in the diffraction curves, thus it is very sensitive. Fortunately, the semblance spectra of $V_c$ have very high resolution, which makes $V_c$ picking very easy. After applying updated $V_c$ and initial $\gamma_{eff}$ and $\chi_{eff}$ to the gather, the gather is almost flat (see the fourth panel in Figure 1), except at the intermediate- and far-offsets, where some residual moveout can still be observed, even though all the $V_c$ picks are in the centers of the semblance maxima. Here the offset range is 0-6000m. This means the initial $\gamma_{eff}$ and $\chi_{eff}$ are not optimized and they need to be updated.

Since all the non-hyperbolic moveouts are retained in the image gather, we can re-pick $\gamma_{eff}$ and $\chi_{eff}$. Figure 2 shows velocity analysis panels. On the left are the semblance spectra of the updated $\gamma_{eff}$ (the first panel) and the corresponding moveout corrected gather (the second panel). The semblance spectra of the updated $\chi_{eff}$ are shown in the third panel, and its corresponding gather after moveout corrections is shown in the fourth panel.

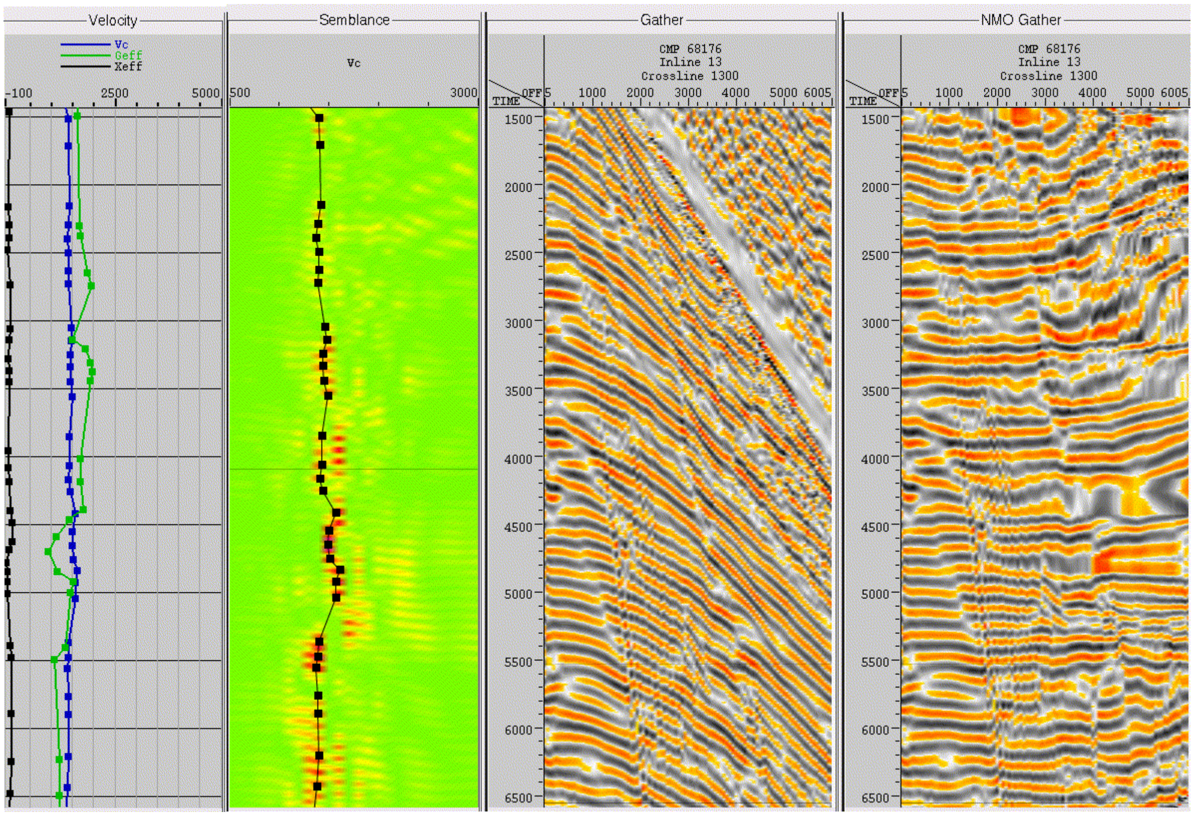


**Figure 1. Migration velocity analysis panels. From left to right, the 1st panel are the picked velocity parameters $V_c$, $\gamma_{eff}$ and $\chi_{eff}$, the 2nd panel is the $V_c$ semblance, the 3rd panel is the NHMO-CIG gather at #68176, on the right is the moveout corrected gather using updated $V_c$ and initial $\gamma_{eff}$ and $\chi_{eff}$.**

The resolution of $\gamma_{eff}$ and $\chi_{eff}$ are not as good as $V_c$. But after applying moveout corrections using re-picked $\gamma_{eff}$, the reflection events in the intermediate- and far-offsets become flatter when compared with the fourth panel in Figure 1. The effect of $\chi_{eff}$ is not as large as $\gamma_{eff}$, however, we can still observe changes in the far offsets, especially for the events in the shallow part (see panel 4 in Figure 2). These $\chi_{eff}$ picks can be converted to $\eta_{eff}$, so that simultaneous PP and PS anisotropic parameter analysis becomes possible. After velocity updating for $V_c$, $\gamma_{eff}$ and $\chi_{eff}$, the migrated events are better focused. The final migrated results will be shown in the presentation. This way, the effect of initial $\gamma_{eff}$ and $\chi_{eff}$ only affects the binning to create imaging gathers. After a couple of iterations, the velocity estimation should converge quickly.

## Conclusions

Estimating $V_c$, $\gamma_{eff}$ and $\chi_{eff}$ from non-hyperbolic moveout retained image gathers is an efficient way to update velocities for C-wave prestack time migration. The test data shows better flattened gathers and more focused migration results after applying this method.

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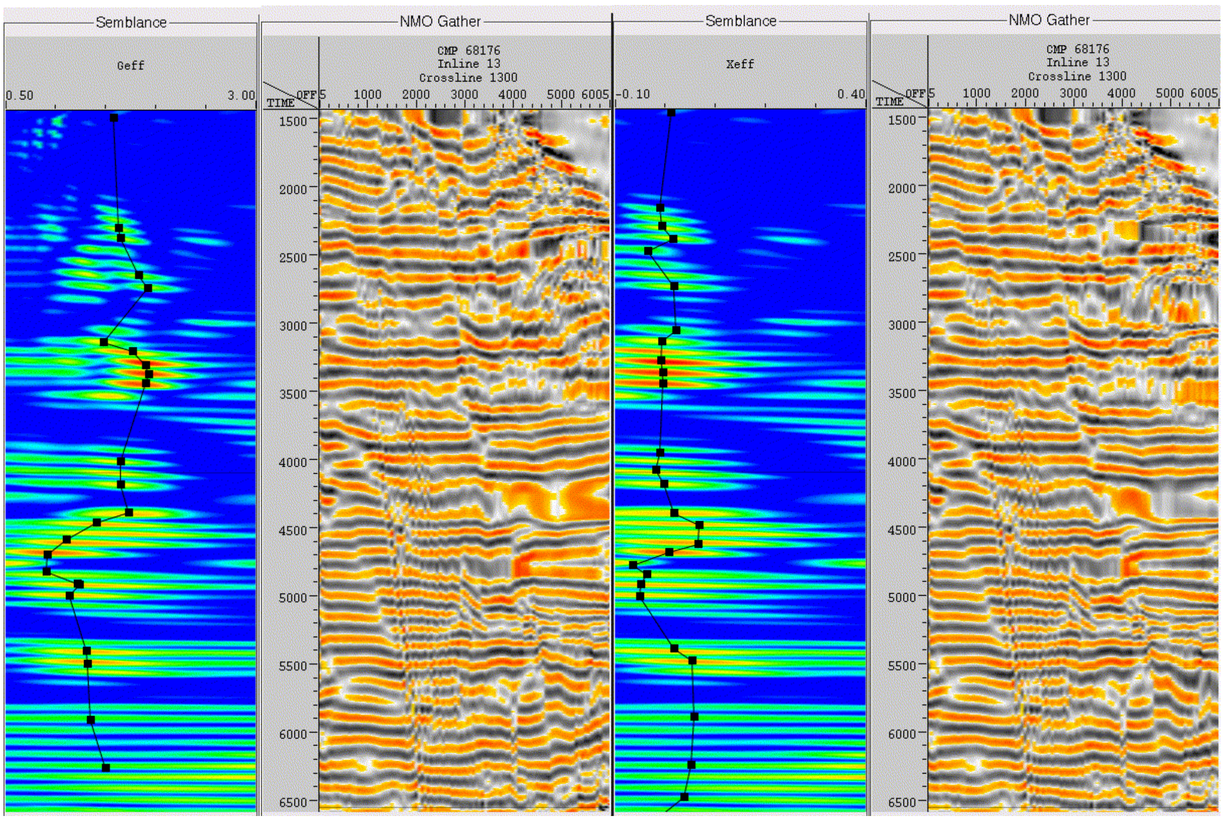


**Figure 2. Velocity analyses for parameters $\gamma_{eff}$ and $\chi_{eff.}$ On the left is the semblance spectrum of $\gamma_{eff.}$ The $2^{nd}$ panel is the moveout corrected image gather using updated $V_c$ and $\gamma_{eff}$ but initial $\chi_{eff.}$ The 3rd panel is the semblance spectrum of $\chi_{eff}$. The $4^{th}$ panel is the moveout corrected image gather using updated $V_c$, $\gamma_{eff}$ and $\chi_{eff.}$**

References

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