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Velocity Updating for Converted-Wave Prestack Time Migration

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Abstract

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 Vp 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 (γ_{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 γ_{eff} and anisotropy parameter χ_{eff} estimates can only be corrected by a trial-and-error method. This can cause difficulties in flattening the image gathers since γ_{eff} and χ_{eff} affect the intermediate- and far-offset data.

I propose a method to remove the effects of initial γ_{eff} and χ_{eff} in the HMO-MCMP gathers by inverting the moveout related to the initial γ_{eff} and χ_{eff}. This enables a full non-hyperbolic velocity analysis to be conducted in order to update not only V_c but also γ_{eff} and χ_{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 an 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 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 γ_0 to convert V_s to the two-way Swave time. Since both V_p and V_s contribute to the first order moveout in the C-wave travel time, γ_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 γ_0 is not easy. Well logs can only provide γ_0 in a few locations. Errors in V_p and γ_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 γ_{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; γ_0 and γ_{eff} are less sensitive. When γ_0 is known, velocity updating is completely independent of P-wave processing. For polar anisotropic (vertical transversely isotropic (VTI)) media, only one anisotropy parameter χ_{eff} needs to be estimated. Here χ_{eff} is a function of the P-wave anisotropy parameter η_{eff} and the S-wave anisotropy parameter ζ_{eff}. For isotropic media, setting χ_{eff} to zero reduces velocity updating to two parameters, V_c and γ_{eff}. In this abstract, I will discuss only the anisotropic case.

C-Wave Time Migration Using V_c, γ_{eff} and χ_{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 η_{eff} and ζ_{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, γ_0 and γ_{eff}:

$$v_p^2 = \frac{(1+\gamma_0)\gamma_{eff}}{(1+\gamma_{eff})} v_c^2$$

and

$$v_s^2 = \frac{(1+\gamma_0)}{(1+\gamma_{eff})\gamma_{eff}} v_c^2$$

Similarly, the anisotropy parameters η_{eff} and ζ_{eff} can be derived from χ_{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, γ_{eff} and χ_{eff} should be sufficient for updating V_p, V_s, η_{eff} and ζ_{eff}. As mentioned earlier, γ_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)),

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

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. γ_{eff} contributes to the second and higher order moveout and χ_{eff} only affects the higher order moveout. The V_c estimation is most important, and the other two parameters along with γ_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 γ_{eff} and χ_{eff} in C-wave travel time cannot be ignored, especially for γ_{eff}, which affects intermediate- and far-offset moveouts. To be able to update γ_{eff} and χ_{eff}, I propose to invert the moveout related to γ_{eff} and χ_{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, γ_{eff} and χ_{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}, γ_{eff} and χ_{eff}) picked from the NHMO-CIG gather shown in the third panel. The black line represents χ_{eff}, the blue line is V_c, and the green line is γ_{eff}. For convenience of display, γ_{eff} is scaled by 1000. We can switch parameter picking among V_c, γ_{eff} and χ_{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 γ_{eff} and χ_{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 γ_{eff} and χ_{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 γ_{eff} and χ_{eff}. Figure 2 shows velocity analysis panels. On the left are the semblance spectra of the updated γ_{eff} (the first panel) and the corresponding moveout corrected gather (the second panel). The semblance spectra of the updated χ_{eff} are shown in the third panel, and its corresponding gather after moveout corrections is shown in the fourth panel.

The resolution of γ_{eff} and χ_{eff} are not as good as V_c. However, after applying moveout corrections using repicked γ_{eff}, the reflection events in the intermediate- and far-offsets become flatter when compared with the fourth panel in Figure 1. The effect of χ_{eff} is not as large as γ_{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 χ_{eff} picks can be converted to η_{eff}, so that simultaneous PP and PS anisotropic parameter analysis becomes possible. After velocity updating for V_c, γ_{eff} and χ_{eff}, the migrated events are better focused. The final migrated results will be shown in the presentation. This way, the effect of initial γ_{eff} and χ_{eff} only affects the binning to create imaging gathers. After a couple of iterations, the velocity estimation should converge quickly.

Conclusions

Estimating V_c, γ_{eff} and χ_{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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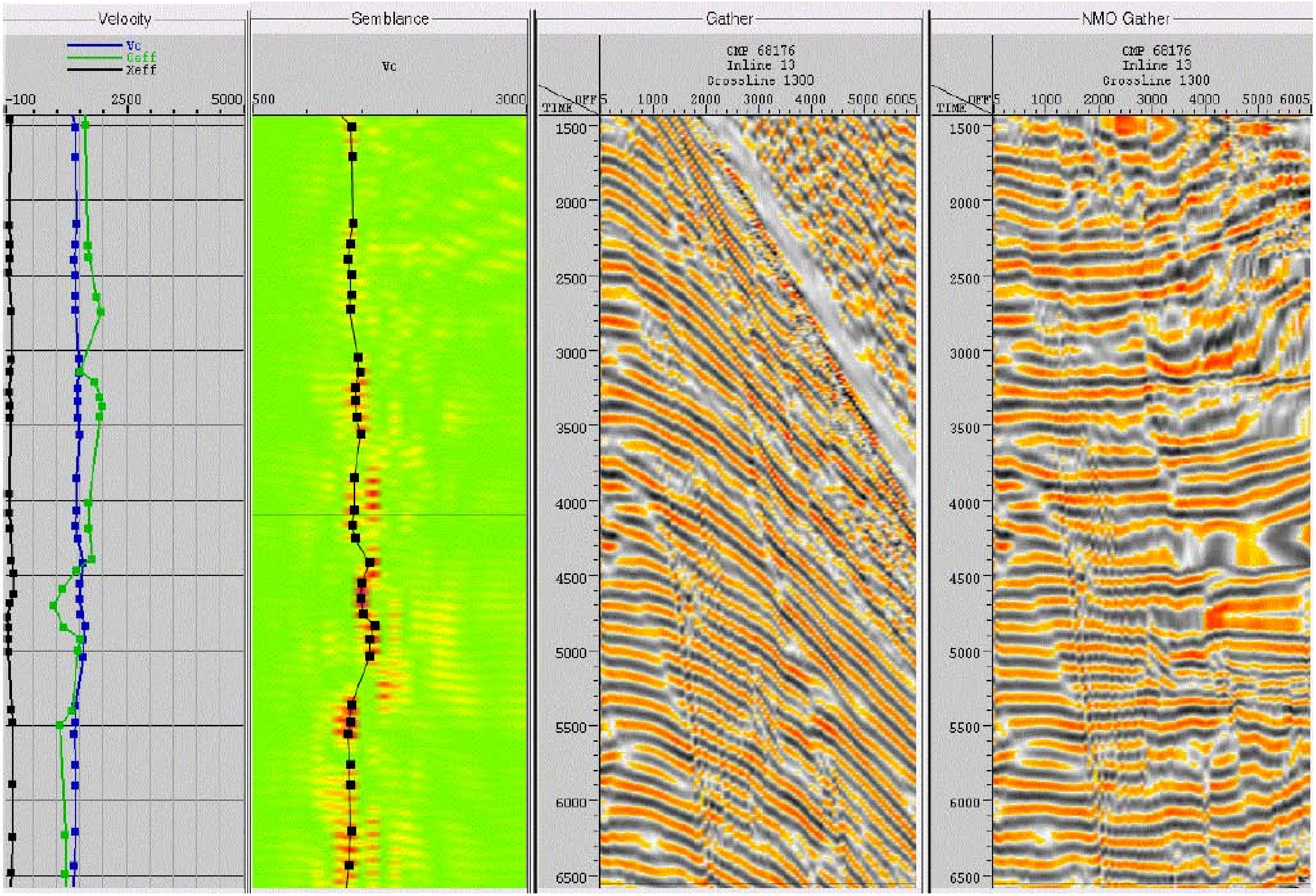

Figure 1. Migration velocity analysis panels. From left to right, the first panel is the picked velocity parameters V_c, γ_{eff} and χ_{eff}, the second panel is the V_c semblance, the third panel is the NHMO-CIG gather at #68176, on the right is the moveout corrected gather using updated V_c and initial γ_{eff} and χ_{eff}.

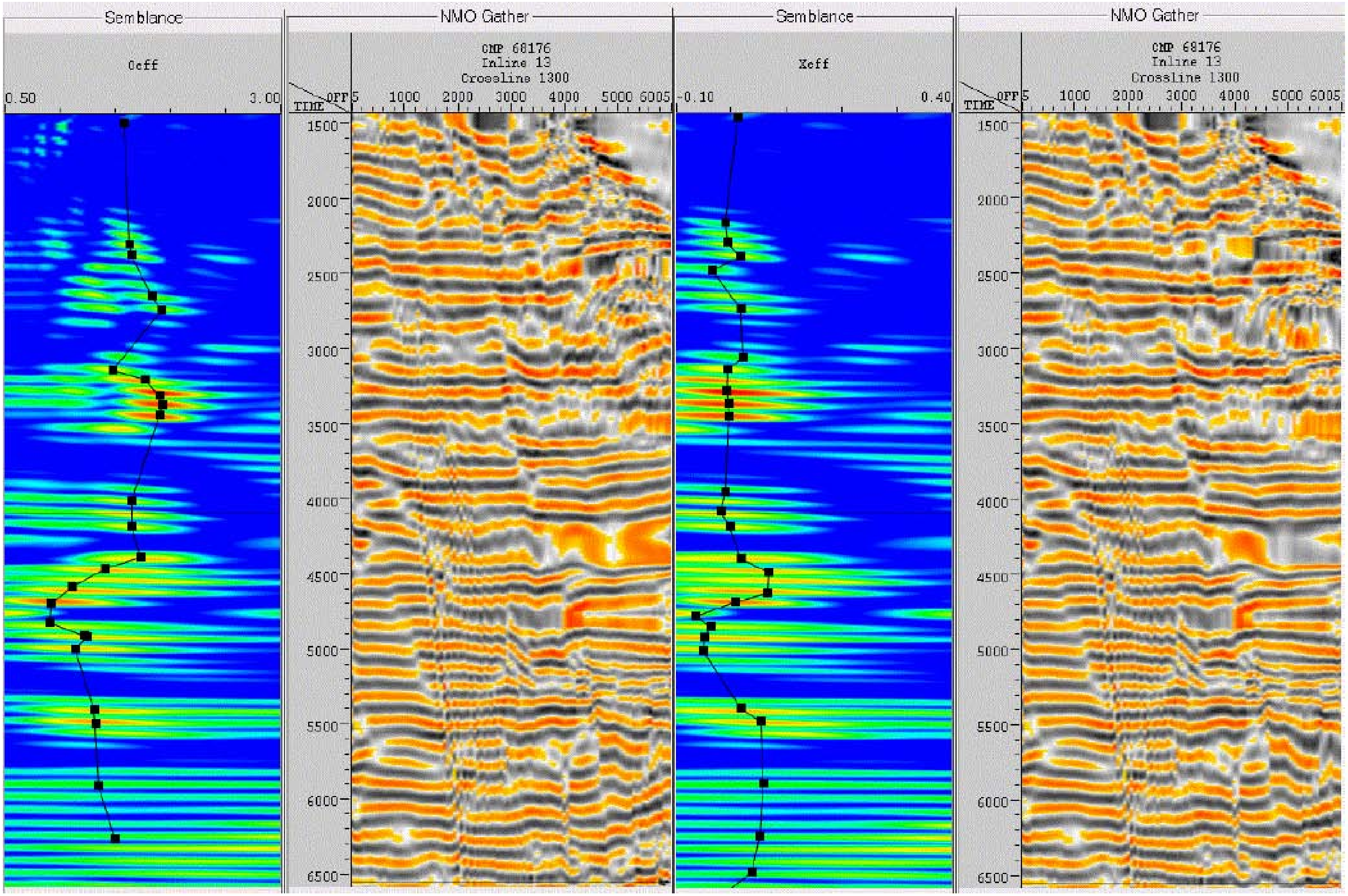

Figure 2. Velocity analyses for parameters γ_{eff} and χ_{eff}. On the left is the semblance spectrum of γ_{eff}. The second panel is the moveout corrected image gather using updated V_c and γ_{eff} but initial χ_{eff}. The third panel is the semblance spectrum of χ_{eff}. The fourth panel is the moveout corrected image gather using updated V_c, γ_{eff} and χ_{eff}.

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