A velocity analysis procedure for multicomponent data with topographic variations

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Summary

We have modified the normal-moveout (NMO) equation for both P-wave and converted-wave (C-wave) data to handle surface elevation changes, and we have implemented this equation in our velocity analysis and NMO correction programs. For the C-wave case, we have also developed a new velocity analysis method that combines NMO correction and common conversion point (CCP) binning with a set of trial γ (Vp/Vs) values, thereby reducing errors introduced by the approximate asymptotic conversion point (ACP) binning method. This procedure has been successfully applied to P-wave and C-wave field data from western Canada and the Colombian Foothills. The benefits are both prestack and poststack. Stacked sections from synthetic and field data that have been processed using these modified equations show better focusing and event continuity. Furthermore, since the events on the moveout-corrected gathers are flatter, longer offsets can be retained for AVO analysis. The improved gathers also enable a more robust residual statics calculation.

Introduction

Multicomponent seismic data can provide richer interpretational potential than conventional P-wave-only datasets by allowing analysis of the different physical interactions of the propagating P and S modes with the host medium. To realize this potential, events on the P- and C-wave sections need to be correlated prior to performing techniques such as joint inversion. Furthermore, to minimize the inherent uncertainties of event correlation, especially in the absence of well data, it is important that the P- and C-wave data be processed in as similar a manner as possible. Since the correlation is most naturally performed in depth, accurate estimates of the P and S velocity fields must first be obtained. Also, drift and residual statics must be computed and applied in a manner that results in P- and C-wave sections referenced to a common datum. Finally, in cases of land data recorded in areas of topographic variations, velocity analysis and surface consistent statics must be calculated and applied from a common floating datum (a smooth version of the true topographic surface) in order to be compatible with subsequent prestack imaging.

C-wave data processing presents unique challenges relative to conventional P-wave processing. In particular, kinematic effects due to anisotropy, the near surface and topography are exaggerated on C-wave data. Furthermore, while the common midpoint for P-wave data is determined geometrically and is independent of velocity, this is not true for C-wave data where the conversion point becomes a function of source-receiver offset, depth and the P-wave to S-wave velocity ratio, γ. CMP binning is therefore not applicable for the C-wave case and other binning methods, namely asymptotic conversion point (ACP) or common conversion point (CCP), must be used. C-wave velocity analysis can be performed either by estimating the C-wave moveout velocity Vc_2 (Thomsen, 1999), or by directly determining the velocity ratio γ using a previously-estimated P-wave velocity function. While the former approach has the advantage of not having to compute the conversion point location, the latter facilitates processing from topography.

The DSR moveout equation

The conventional P-wave NMO equation assumes that all shot-receiver pairs for traces within a midpoint gather are at the same elevation. Data are typically processed to meet this assumption by the application of statics. While this method is applicable in areas of minimal topography, it progressively breaks down in areas where topographical variations exceed a few tens of meters, making accurate velocity analysis difficult. In order to account for elevation differences between the shot, receiver and common midpoint (CMP), the paths from shot to the CMP and from the CMP to receiver have to be considered separately (Figure 1).

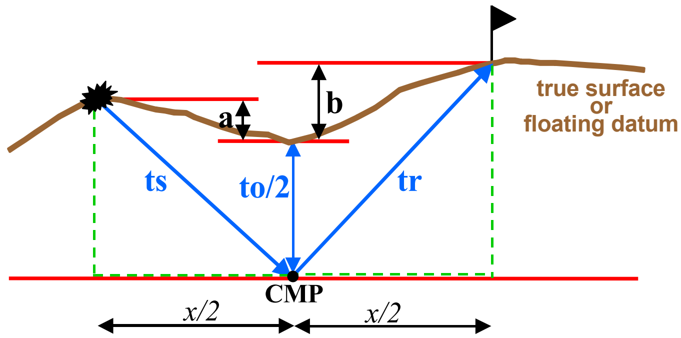

Figure 1. *Schematic illustration for the derivation of NMO with the double square root equation. 'ts' is the travel time from shot to CMP, 'tr' is the travel time from CMP to receiver, 'to' the two-way zero offset time, and 'x' the source-receiver offset.*

The conventional P-wave single square root NMO equation can then be modified to include the elevation differences as follows. If 'a' is the difference between shot and CMP elevation, and 'b' is the difference between receiver and CMP elevation, as illustrated in Figure 1, and v is the RMS velocity, the total travel time from the source to the receiver is described by the following double square root (DSR) equation, which is similar to that commonly used in prestack imaging:

$$t = \sqrt{\left(\frac{to}{2}+\frac{a}{v}\right)^2+\left(\frac{x}{2}\right)^2\left(\frac{1}{v^2}\right)} + \sqrt{\left(\frac{to}{2}+\frac{b}{v}\right)^2+\left(\frac{x}{2}\right)^2\left(\frac{1}{v^2}\right)}\,. \qquad (1)$$

In practice, because of the presence of the near-surface low-velocity or weathering layer, drift static corrections have to be computed first. These can be done in a surface-consistent way to a floating datum, and NMO with the DSR equation can follow. Velocity analysis is performed by scanning a cube of constant velocity stacks, or by other techniques. A temporally and laterally varying velocity function is interactively picked and applied to the gathers using Equation 1. Such a flow is also compatible with prestack time and depth migration surface-consistency requirements.

Problems caused by the assumption of a flat surface are more pronounced on C-wave data because of the larger travel time effects in the near surface due to lower shear-wave velocities. Hence, we have also modified the PS-NMO equation as with the P-wave case to take account of elevation changes between shot, receiver and the CCP. This form of the DSR equation is also convenient for handling the differences in velocity between the downgoing P-wave and upgoing S-wave ray paths. We used this modified equation to NMO correct the gathers prior to CCP binning. This enables velocity analysis and NMO correction to be performed from the true topographic surface or a floating datum.

P-wave data example

Figure 2 shows part of a stacked section from the Colombian Foothills that has rapidly-varying elevation changes along the line. Figure 2a shows the stack obtained after velocity analysis and NMO correction using CMP-consistent statics and NMO with the single square root equation (the conventional approach). Figure 2b shows the corresponding result using surface consistent statics and NMO from a floating datum with the new DSR equation. Improved reflection continuity and focusing can be observed in Figure 2b, particularly in the highlighted areas.

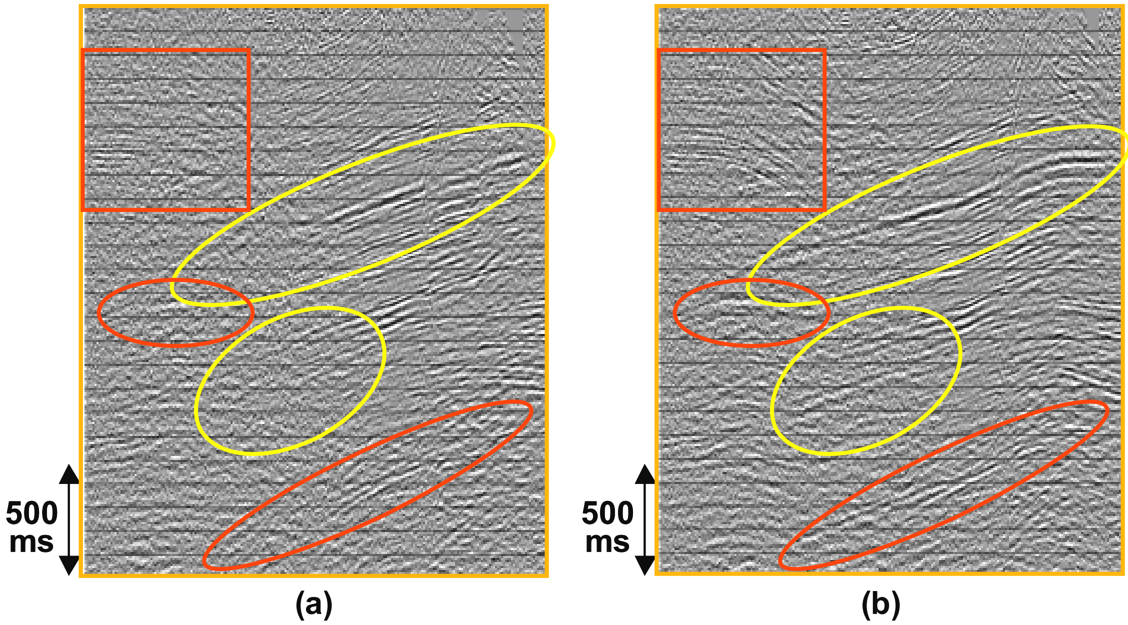

Figure 2. *Comparison of stacked sections from the Colombian Foothills with severe topography. (a) Stack obtained after CMP-consistent statics and conventional NMO, (b) stack obtained after surface- consistent statics and NMO from topography.*

C-wave velocity analysis from topography using CCP γ-scanning

As mentioned earlier, two binning methods are used for C-wave data: ACP binning and CCP binning. ACP binning, which uses a single γ value, is similar to CMP binning but with the midpoint shifted towards the receivers. It is least accurate in the shallower part of the section where the difference between the assumed fixed conversion point and the true conversion point is largest. Consequently, the stack quality is degraded in the shallower section, making P- and C-wave event correlation and hence the estimation of the vertical γ_0 more difficult. CCP binning is more accurate, and uses a depth-variant γ function. It is a data-mapping operation where different parts of a trace are put in different bins depending on the γ value and depth. Thus, while we need to bin the data before velocity analysis, we also need a velocity function to bin the data properly. To overcome this problem, we developed the CCP γ-cube scanning method illustrated in Figure 3. Each panel (CCP stack) in the cube (Figure 3) is created by combining the C-wave DSR moveout correction and CCP mapping using a trial γ value. We then pick a time- and CCP-variant γ by performing γ-scanning on the CCP stacks in a fashion similar to P-wave constant velocity stack analysis. Hence, the binning and picked γ values are treated as γ_2 (the short-spread ratio of moveout velocities) at this stage. While not exact compared with the ideal value for binning, $\gamma_{eff} \equiv \gamma_2^2/\gamma_0$ (Thomsen, 1999), the value obtained is much better than from the ACP assumption used for the initial iteration. γ_{eff} can be subsequently computed after P- and C-wave event correlation.

Figure 4 compares CCP stacks for radial-component data from the Weyburn field, Saskatchewan, Canada. In Figure 4a, the γ_2 function was picked on ACP-binned gathers. The gathers were NMO corrected using the conventional PS-NMO equation, which does not account for topographic variations. In Figure 4b, the γ_2 function was obtained using the new γ-scanning approach described above. The gathers were NMO corrected with the modified PS-NMO equation to account for surface elevation changes. Figure 4b clearly shows how the continuity of events has been increased, particularly in the highlighted areas. In this example topographic variations were minimal, so much of the improvement is attributed to the new γ-scanning method.

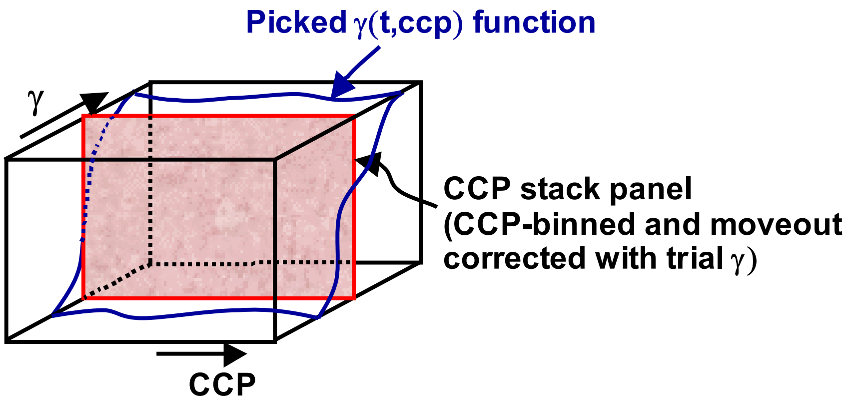

Figure 3. Schematic representation of the CCP γ-scanning technique. Each CCP stack panel has been PS-NMO corrected and CCP binned with a trial γ. A time- and CCP-variant γ_2 function is picked by scanning through the panels.

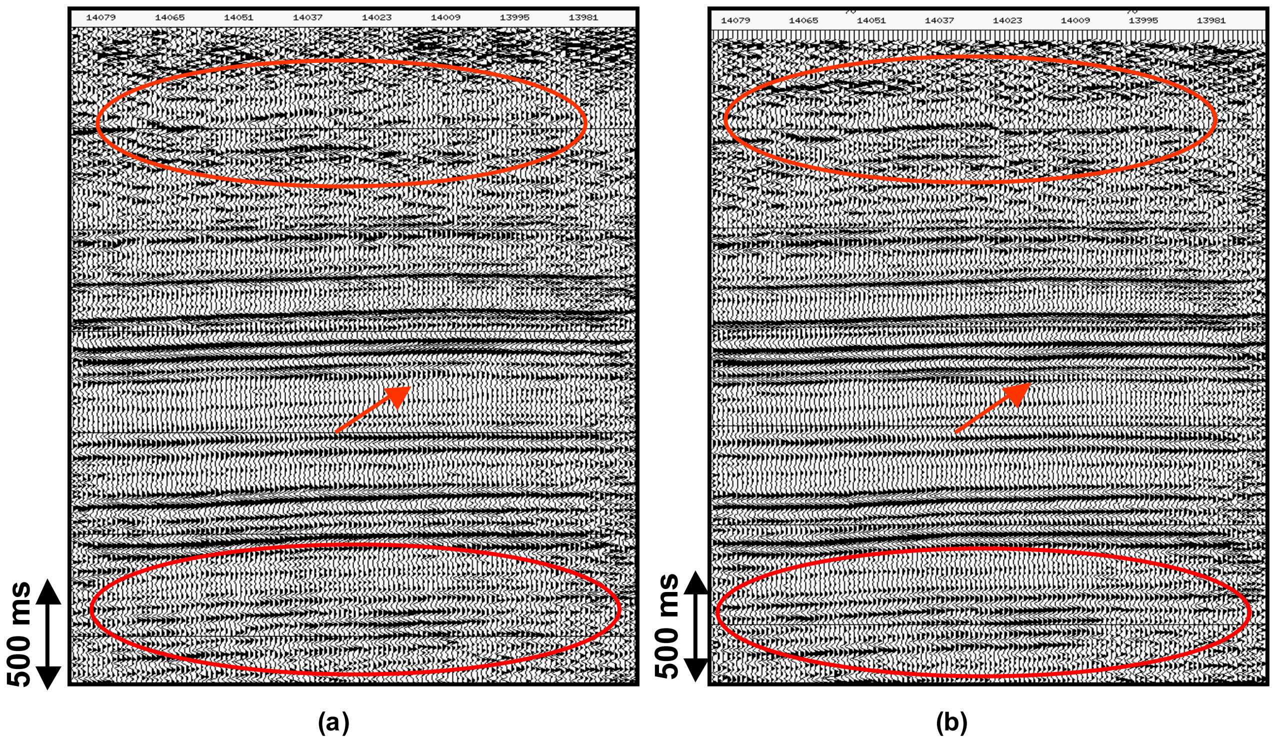

Figure 4. *A comparison of radial-component CCP stacks from the Weyburn field in Saskatchewan. (a) The γ_2 function was picked on ACP binned gathers, (b) the γ_2 was picked using the γ-scanning technique. Highlighted areas illustrate improvements in (b).*

Conclusions

Surface consistent drift statics and NMO correction using a DSR equation that accounts for topographic variations results in better focusing of events on stack sections when compared to those obtained after application of CMP-consistent drift statics and conventional NMO. The use of the DSR equation also makes the method more compatible with prestack time migration. A new method for C-wave velocity analysis which combines NMO correction from topography and CCP-binning with the same trial γ value led to improved CCP stacked sections. An extension of this approach to take account of anisotropy is currently under development.

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Reference

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