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Simplified processing of converted wave data

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Summary

A significant amount of converted wave (P-S) data is acquired, but not processed. There are numerous reasons, typically relating to the perceived expense of the processing. In addition, the quality of processing lead to questioning the added value that P-S data can contribute to an interpretation. These concerns are reduced with simple prestack migration processing that provides accurate velocities, especially the shallow areas, where the velocities that can be one third to one fifth the value of the conventional P-P data. This process is described and examples given.

Introduction

Much of the data acquired for converted wave processing remains unprocessed because of:

- the expence of processing,
- the perceived limited added value of the converted wave data,
- the complexity of processing P-S data,
- the desire for a depth migration rather than a time migration,
- the requirement of processing P-S data in parallel with the P-P data to align or register events,
- and the requirement of special personnel to do the processing.

Contrary to those opinions, converted wave data can be processed economically, independent of P-P data, with simplified flows that match those for P-P data, and return quality data for interpretation.

Conventional processing of P-P data forms common midpoint (CMP) gathers for estimating processing velocities, noise attenuation, and estimating statics. P-S data inherited this approach, however the converted wave data do not have symmetry about the midpoint, so the data were gathered about an asymptote formed from the reflection point location from deep horizontal layers. Statics could be estimated and the processing continued similar to P-P data. However, the shallow data suffered from the asymptotic assumption and produced inferior results.

A more accurate processing sequence follows a prestack Kirchhoff approach that assumes a vertical column of scatter points, and all input traces contain energy returned from those scatterpoints. This prestack energy in aligned in prestack migration gathers referred to as common scatterpoint (CSP) gathers (Bancroft, et al. 1996, 1998). A scatterpoint, which returns energy that is converted from P mode to S mode, is referred to as a conversion point. Converted wave data may also be collected in a similar manner to form common conversion-point (CCP) gathers (Guirigay and Bancroft 2012a-d). This completely eliminates the asymptotic assumption to produce a migrated section that is optimal for all depths.

The traveltime to a vertical array of conversion points, defined in depth, can be computed with conventional methods such as ray tracing, wavefront propagation, or wavefield propagation, with the downgoing times from a source using P velocities and the upgoing times to a receiver using S velocities. The resulting prestack depth migration requires reasonably accurate interval velocities, especially above and area under analysis.

A majority of the seismic projects that acquired converted wave data are located in sedimentary basins where the geology tends to be horizontal, allowing the simpler time migrations to produce accurate imaging of the subsurface. A vertical column of conversion points can be defined in time to create a prestack time migration. The velocity field of the subsurface is now defined with stacking or RMS type velocities. These velocities are much less sensitive that the interval velocities required for a depth migration. In addition, the time migration velocities are independent of the velocities above the conversion point and may be picked using traditional semblance plots.

Theory and/or Method

The converted wave data can be partially processed with a single velocity referred to as the converted wave velocity V_c. Once estimated, it can apply moveout correction to prestack gathers that can then be stacked to complete the prestack migration. Forming the prestack migration gathers requires the S velocities that are estimated from the known P velocities V_p, and initial estimates of V_c.

An initial estimate of the converted wave velocity $V_{c\text{-}1}$ is obtained from prestack migration gathers using a short range of surface displacements distances from the midpoint to a vertical array of scatterpoints similar to a super CMP gather. (Refinement can be made to these gathers based on the converted wave geometry.) The converted reflection data in these gathers tend to be hyperbolic and velocity analysis provides the initial estimate $V_{c\text{-}1}$.

Only a few of these gathers are formed across the span of the recorded data, which are then

combined with P velocities V_p (obtained from P-P processing) to obtain an estimate of S velocities V_s using

$$V_s = \frac{V_p V_c}{2V_p - V_c} \tag{1}$$

Using these initial RMS type velocities, the source and receiver traveltimes can be computed for all source or receiver locations using the hyperbolic assumption, and are combined to form the double square-root equation to give the total traveltime T using

$$T = \sqrt{\frac{T_{0-P}^2}{4} + \frac{h_s^2}{V_P^2}} + \sqrt{\frac{T_{0-S}^2}{4} + \frac{h_r^2}{V_S^2}}\ , \tag{2}$$

where the T_0's are vertical two-way traveltimes for the respective modes in the medium, h_s is the surface distance from the source to the vertical array, and h_r is the surface distance from the receiver to the vertical array. The location of the scatterpoint is defined at a pseudo depth, which is computed using the RMS velocities to approximate those of the Average velocities.

All input traces within the migration aperture are combined into each CCG using the travel time T and the equivalent offset h_e estimated from

$$h_e = \frac{V_c}{2}\sqrt{T^2 - T_{0-C}^2}\ , \tag{3}$$

where $T_{0\text{-}C}$ is the vertical two-way time to the scatter point using V_c.

A second velocity analysis, at a few locations, provides an accurate velocity field $V_{c\text{-}2}$ for all gathers. Moveout correction, amplitude scaling, and stacking complete the prestack migration of the P-S data.

Alignment of this P-S data with the corresponding P-P data is made using the pseudo depths. The pseudo depths for each mode, (P, S, and "C"), are used to align the velocities in equation 1, and 2. The errors in this assumption are minimal as we are actually using the ratios of the RMS and Average velocities (Guirigay and Bancroft 2012c).

In summary:

1. Create a few short displacement CCP gather.
2. Pick an initial $V_{c\text{-}1}$ velocities from these gathers.
3. Compute initial V_s velocities from V_p and $V_{c\text{-}1}$.
4. Form all full offset CCP gather using all the input data using V_p and $V_{c\text{-}1}$.
5. Pick final $V_{c\text{-}2}$ velocities from a few of the full CCP gathers to build the velocity model.
6. Apply moveout correction, amplitude scaling, and then stack the CCP gather to complete the prestack migration.

Alternative methods exist for estimating the initial converted wave velocity $V_{c\text{-}1}$ such as test gathers using the P velocities and various values for the Vp-Vs ratio γ.

Examples

The following figure shows three groups of panels of stacked data, formed from limited range gathers that were acquired in the Hussar area of Alberta. Each panel contains eighteen stacked traces from equally spaced locations along the line, with the range of displacement in meters shown at the top, used when forming the CCP gathers. The very short displacement ranges tend to zero amplitudes in accordance with zero amplitude for converted wave data at zero offset. Larger displacements are desired to improve the signal to noise ratio, but displacements that are too large violate the hyperbolic assumption required when using a single velocity V_c. From this data, a maximum range of 100 m was chosen for an initial velocity analysis.

A comparison of the P-S data with conventional processing with the described method is shown in Figure 2.

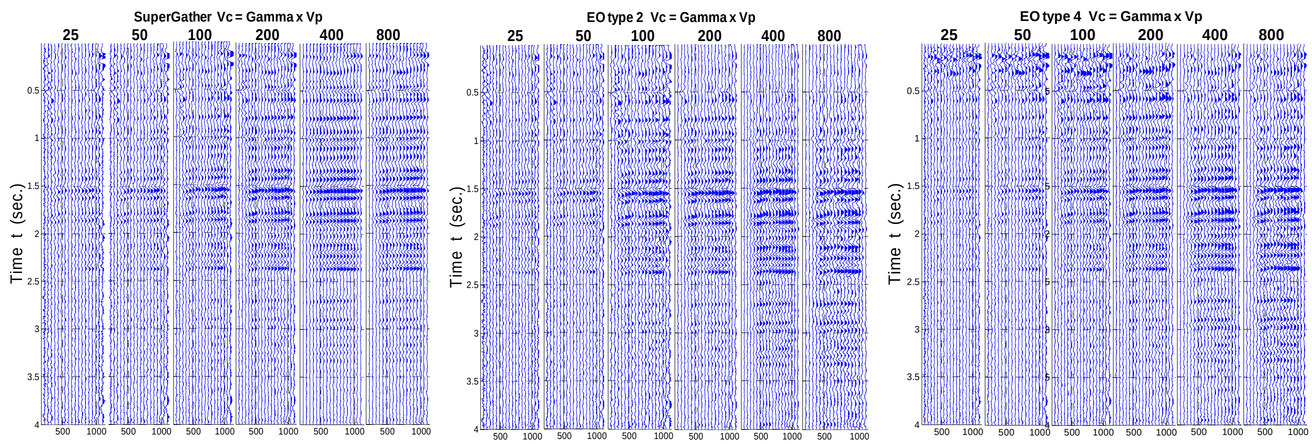
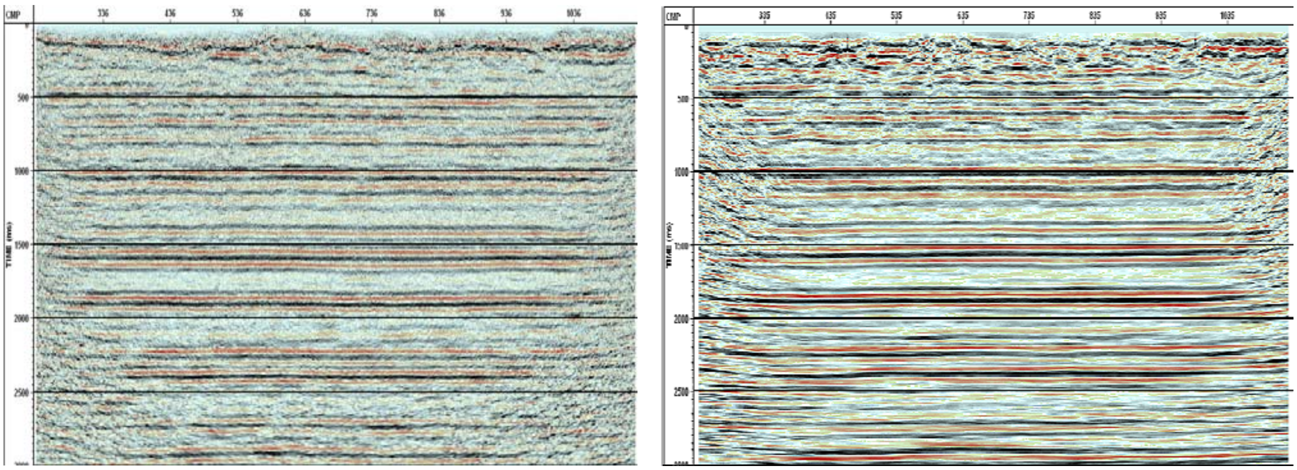


Fig. 1 Three groups of six micro stacks formed for various ranges of displacement. Each group was formed with a different process. The range of displacement in meters is displayed at the top of each panel.

A prestack migrated P-P section is compared with a prestack migrated P-S section in Figure 3. Both sections underwent the equivalent offset method of processing. The P-S section was time shifted and scaled to align the geological events shown on the right. Note the superior resolution and imaging of the shallow P-S data. No attempts were made to align the data with pseudo depths, however, synthetic data from a nearby well has been included in this figure.

The RMS velocities V_s are converted to Interval velocities and compared with shear velocities in Figure 4. Note the extended range in the lower and upper depths of the seismic velocities.



a) b)

Fig. 2 Comparison of a) conventional P-S processing and a poststack migration and b) a prestack migration using the described method.

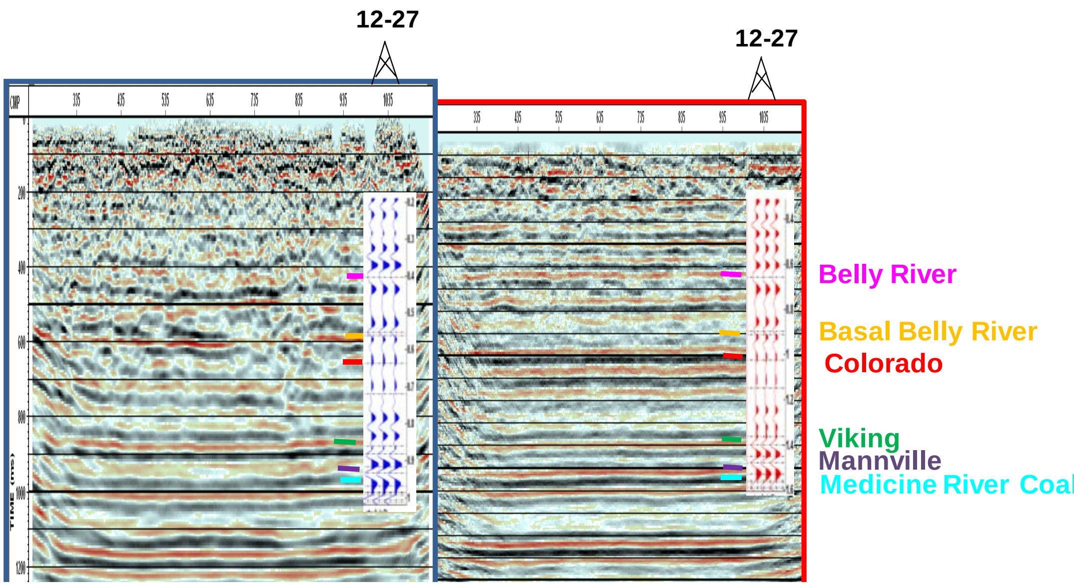


Fig. 3 Final stacked P-P section after EOM (left) and Final stacked P-S section after EOM scale to P-P time with the synthetic seismograms.

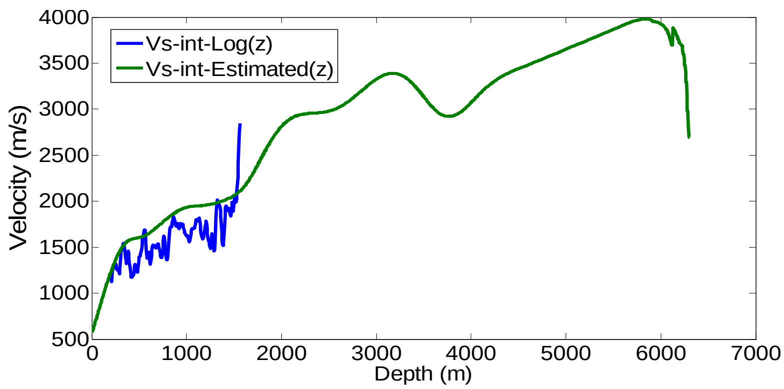


Fig. 4 Interval shear velocities, estimated from $V_{RMS\text{-}S}$ (green), are compared with interval shear velocities from a well log (blue).

Conclusions

Converted wave or P-S data can be processed economically with processing flows similar to those for conventional P-P data. Specialised processing skills are not required

The results can add to the interpretation of the geology, or can be used to evaluate whether complete registered processing with P-P data will add to the estimation of rock properties.

Acknowledgements

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