A discussion on the shear- to compressional-mode (SP): theoretical, practical and economic

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2004 CSEG National Convention

Abstract

While it is very common to acquire, process and interpret compressional-mode (P) data that have been converted to the shear-mode (S), the reciprocal scenario, S to P (SP), is very uncommon. We discuss some of the practical, economic and theoretical issues associated with the SP mode. Since P-wave seismic is the standard within our industry, SP will likely only be available when nine component data are being acquired. The two main advantages of SP over PS would be that we have a controlled source polarization and that vertical sensors, used to measure the upcoming P energy, couple better than horizontal sensors. The main difference in SP processing, as compared to PS processing, is that the binning is a function of γ^{-1} as opposed to γ, while the converted-wave moveout is the same for both SP and PS. The rotation to radial and transverse domains is done in the receiver domain for Sp as opposed to the shot domain for PS. We show comparisons of SP and PS sections on real data.

Introduction

It is obvious that SP seismic will not be available unless nine-component 9C data are being acquired. At present we are not aware of any unique advantages of the SP data by itself, yet we are interested in how to handle the full vector wavefield with controlled sources. Therefore, knowing how to process the scalar SP mode is a necessary first step.

In a nine component survey, there are two S-wave sources, S1 and S2, oscillating perpendicularly, which generate converted-wave (SP) energy on the vertical component. Since the coupling effect is usually good for vertical geophones, the converted wave SP can be of fairly good quality. Processing of the SP-wave, in principle, should be similar to that of the PS-wave, if the shot and receiver locations are exchanged. However for prestack processing, there are two critical issues worth mentioning, one addresses the rotation of the sources in a similar sense as we rotate the receivers for PS processing, the other is binning and moveout correction. Otherwise the SP processing is very analagous to PS processing and, with the exception of binning, is possible with only minor updates to such critical steps as velocities and statics.

Polarization Issues

In an isotropic, homogeneous and flat earth, shear waves will retain a polarization direction equal to that of the source. Furthermore, only SV waves will mode convert to P upon reflection and transmission. Anisotropy, inhomogeneities and structure will all provide for exceptions to this condition. It is this shear-wave polarization that allows for the vertical components recorded from S1 and S2 sources to contain both SV and SH energy if the orientations of S1 and S2 are not to be coincident with the natural orientation of the rocks. To better focus the SV to P converted-wave energy, source-receiver rotation is required as the first step. It is obvious that once we exchange the positions of shots and receivers, the rotation algorithms employed in PS-wave processing can be exactly applied to SP-wave processing without any modification. Thus, once we know the polarization direction, we can rotate the receiver gathers as we do for shot gathers on the PS data. We can also azimuthally restrict the common image points and independently solve for velocities and statics for the S1P and S2P sub-volumes to further improve to continuity and coherence of these SP sections.

Binning and moveout correction

When the media is homogenous and not considering the diodic effect, the moveout formula for the SP-wave is the same as for the PS-wave moveout as shown in the following equation:

$$t_{sp} = t_{ps} = \sqrt{\frac{\gamma_0^2 t_{sp0}^2}{(1+\gamma_0)^2} + \frac{x_s^{\;2}}{v_{s2}^2}} + \sqrt{\frac{t_{sp0}^2}{(1+\gamma_0)^2} + \frac{x_p^2}{v_{p2}^2}}$$

Therefore, the velocity analysis tools and travel time correction used for PS-waves can be applied to the SP-wave. However, the conversion points are shifted towards the source for the SP-wave as opposed to the receiver, as for the PS-wave. As for the asymptotic binning locations, in the PS-wave case it is approximated to $x_c \approx \frac{\gamma}{\gamma+1}x$, where *x* is the offset, x_c is the distance between the conversion point and the source location and γ is the *Vp/Vs*. In the SP-wave case, it is been changed to $x_c \approx \frac{1}{\gamma+1}x$. It is equivalent to replacing γ by $1/\gamma$ for the PS-wave case.

Economics and practical considerations

While we realize that the only time we are likely to see SP data is when 9C data are being acquired. We also realize that it is inappropriate to continue to ignore these two components of the 9C data volume. The cost of acquiring 3C data (P source, 3C receiver) is continuing to drop while the data quality is continuing to improve. The main driving factor has been the advent of single sensor digital multicomponent (MEMS) technology. Acquisition errors are being reduced and processing capabilities are continually improving. A common processing flow for 4C pure-shear data usually requires solving for PP statics and velocities followed by PS statics and velocities and finally SS statics and velocities. This means that we merely have to take into account the differences in binning and we have everything necessary to stack the SP data. The data can be rotated to radial and transverse in the receiver domain, while for PS we do this in the shot domain.

A common motivation for acquiring SS data is that it can be processed with conventional CMP style approaches. Furthermore, having both the sources and receivers orientations controlled allows for a less ambiguous and more robust birefringence analysis. It would be irresponsible to not process and analyse the entire data volume that of course include the SP data.

Data Examples

Figure 1 (left) is an example of the Weyburn baseline PS data, while Figure 1 (right) is an example from the same line for the SP data. It should be noted that the statics and velocities for the SP were taken directly from the previous PP, PS and SS solutions. We anticipate that a better section could be produced given some minor refinements in the static and velocity solutions. Figure 2 illustrates how the binning and hence fold differs for the SP (top) and the PS (bottom). Note the difference in fold distribution caused by the differences in bin locations for equivalent source-receiver pairs.

Conclusions

We have a discussed some of the issues regarding SP processing in addition to economic and practical considerations. While we are not endorsing the recording of SP data by itself, we do realize that these two components may indeed add value, given a 9C recording effort. The major differences in the processing are in the rotation analysis and in the binning. The moveout equations are identical. We have also shown that it requires very little effort to process these components since a typical SS processing flow naturally leads to the statics and velocities necessary for stacking the SP.

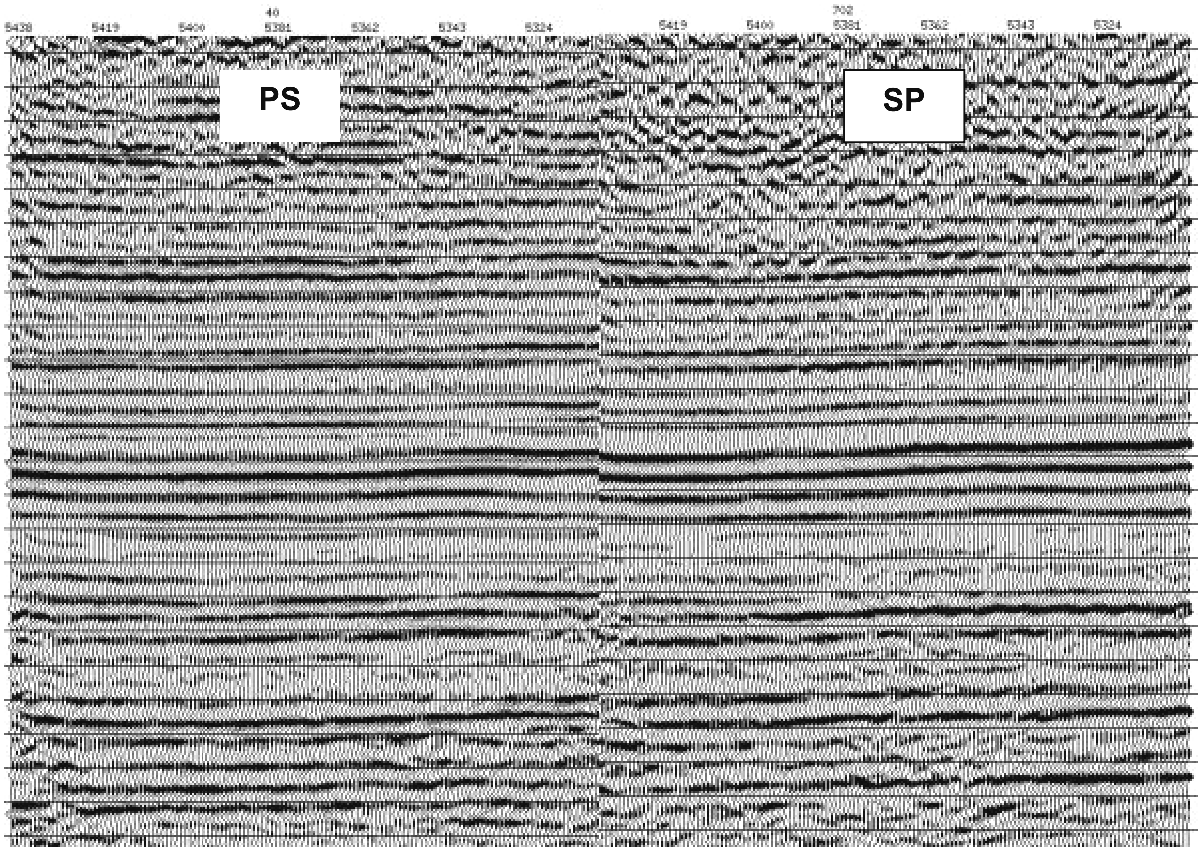

Figure 1: *Comparison of PS migrated volume (left) and the SP migrated volume (right).*

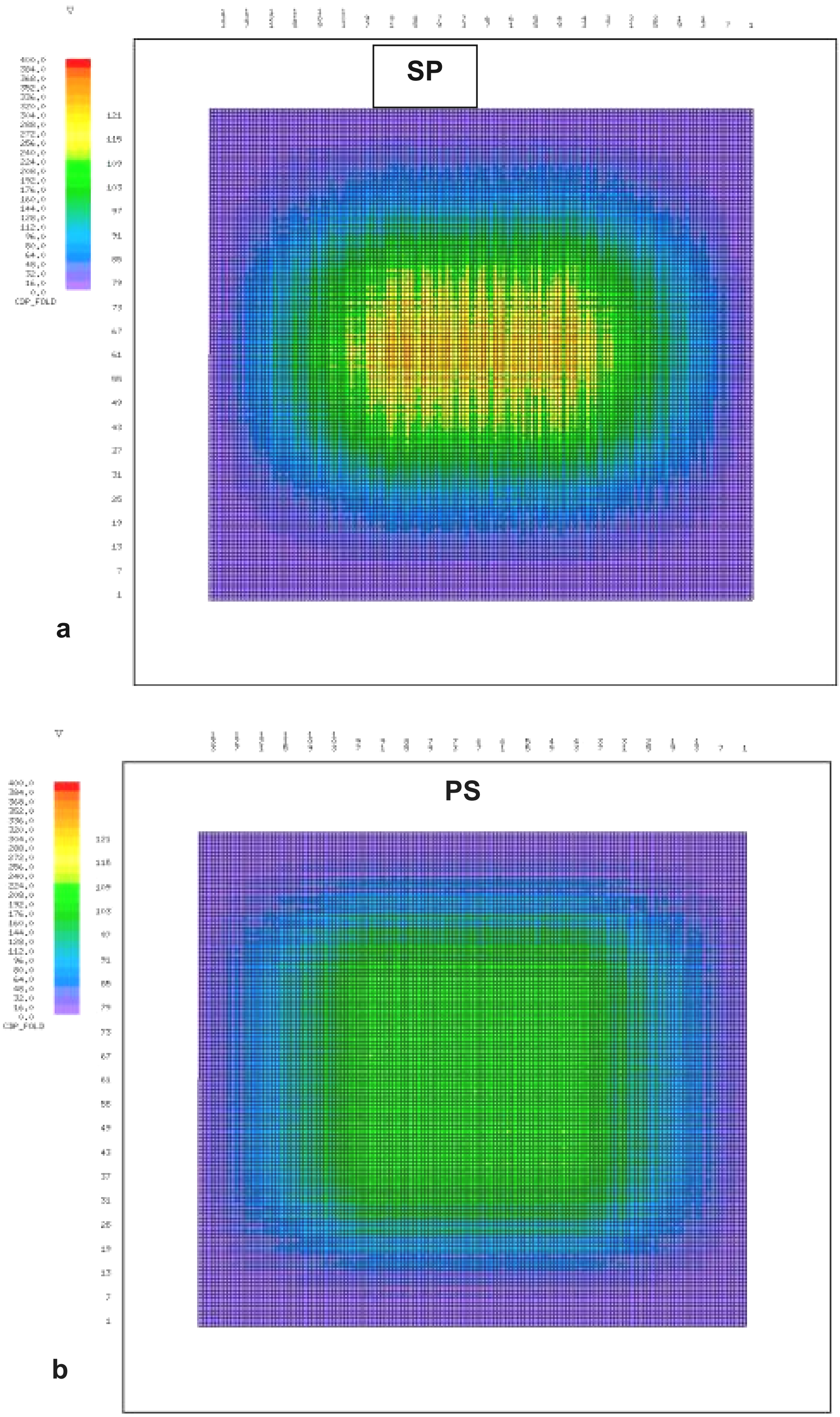

Figure 2: *Fold diagram for SP (top) and for PS (bottom).*
Note the concentration in fold at the center of the survey for the SP.