SV-P imaging compared to P-SV imaging: analysis of statics and velocities required to create an SV-P image

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Summary

Standard 3D seismic data recorded into traditional vertical geophones can produce an SV-P converted-wave data volume. However, there is a challenge in resolving both the statics and velocities while separating out the SV-P image from the P-wave portion of the data. The primary difficulty is in resolving the velocity and statics associated with the signal of interest, SV-P, which is buried in the slower velocity and deeper time portion of the seismic P-wave record. In other words when looking at a gather in offset order and moved out with a P-wave velocity, you will often see many under moved out events and more of those events with increasing time. This is the portion of the gather that has always been referred to as containing noise, coherent noise, multiples, and mode-converted responses. This presentation looks at a real-data example which took advantage of using the traditional P-SV processed converted-wave-stack velocities and statics as the basis for looking for the SV-P equivalent stack. In particular, if we know the velocity field and the final P-SV stack from traditional converted wave data, can we successful resolve statics and velocities to create the SV-P image? This data example shows it can be done.

Introduction

The observance of converted and even shear direct arrivals on downhole VSP data from a P-wave source has been documented (Hardage and Wagner, 2014a, 2014b; Hardage et al., 2014; Li and Hardage, 2015). This presentation example involves high quality traditional 3D surface seismic P-to-P and P-SV converted-wave data volumes. Therefore it proved to be a good survey to search for the SV-P image in the P-wave record and compare that image with a reliable P-SV image. The relatively high quality reflections show there is very good signal in the P-wave data at the gathers and stacked stages. P-SV data recorded by the horizontal geophones also shows good reflectivity and provided a fairly easy registration between the P-P and P-SV images. The first challenge proved to be the receiver statics on the converted-wave P-SV data. The receiver statics turned out to be a magnitude of 10 greater than the P-wave receiver statics. The second challenge was looking for the SV-P velocity field in the traditional P-wave records. Approaches for estimating S-static corrections required for converted-mode data, and particularly for SV-P data, will be discussed in this presentation. Velocity analyses are also a key data-processing step when making seismic images with any wave mode, and are particularly important when data-processing objectives are to make images with converted-mode data. Concepts that have proven to be useful in determining optimal stacking velocities for SV-P data will be discussed in this presentation.

Comparison of the P-wave image to the converted wave P-SV image

The presentation starts with a look at the high quality P-wave stacked image and compares it with the traditional P-SV converted wave image. Next, I review the P-wave gather and highlight the under-moved-out reflectors that are believed to be some of the mode converted events that we are actually looking for to create the SV-P images (Figure 1). In conjunction with the gather, I look at a standard P-wave constant velocity panel to estimate where mode- converted wave images would reside in the P-wave recorded data volume (Figure 2).

S statics for SV-P imaging

The map in Figure 3 shows near-surface receiver S static values from the P-SV data. The color bar in the figure indicates the magnitudes of the S-static corrections that exist across the image space. The data acquired in this seismic survey involved 3C geophones and two types of P sources: buried explosives and vertical vibrators. The static corrections shown on this map were determined from analysis of P-SV data acquired at receiver stations with horizontal sensors. Note the large variations in the S-static estimations, which range from +30 ms to -80 ms across the image space, and the short lateral distances over which large variations in S statics can occur. In order to process SV-P data, this S-static behavior, which is based on horizontal-sensor responses, has to be translated into S-static corrections that are appropriate for applying at P source stations, not at receiver stations.

An example profile through the processed 3D P-SV data volume is displayed in Figure 4. The image quality is excellent, which confirms that S-statics were accurately estimated at horizontal-receiver stations. The corresponding SV-P profile, which required that different S-statics be applied at the P-source stations (not at the receiver stations), and additional trim statics is shown as Figure 5. Comparison of Figures 4 and 5 confirms that accurate source plus trim statics were required to create very similar stack images. At this data-processing stage, it is obvious that the frequency bandwidth of the SV-P reflection signal (Figure 5) is less than the frequency bandwidth of the P-SV reflection signal (Figure 4); however, the image detail is remarkably similar even at the lower frequency response.
The will be logic and methodology that allowed accurate S statics to be determined at the P-source stations involved in this seismic program illustrated and discussed in the presentation.

**Velocity analysis for SV-P data**

The final section of the presentation will look at examples of SV-P velocity analysis with comparisons to the P-SV velocity results. Part of the discussion will illustrate how stacking velocities needed for converted-mode imaging (SV-P and P-SV data) can be determined by examination of constant-velocity stacks of single-mode data (P-P and S-S modes) across the same image (Figure 2 again). This discussion about the interplay of stacking velocities for converted-mode data and single-mode data will be an important piece of this presentation and they, too, are not easily resolved.

**Conclusions**

SV-P data are contained in traditional P-P mode traces. Static estimations and velocity analyses needed for imaging SV-P data can be challenging, but are not an impossible task. The experience that has been learned in several projects will be shared to aid others to make progress toward creating SV-P images from data generated by P sources and recorded by vertical geophones. One strong take away for continuing the development of SV-P processing is to continue to leverage data sets that have P-SV data to compare against. Another strong take away would be to find areas where shear wave statics are much smaller in magnitude than the statics dealt with in this analysis. One basin that comes to mind as having modest static corrections is the Midland basin.

![Figure 1. Traditional processed P-wave gather. Processing includes pre-processing wavelet correction, refraction statics, 1st pass surface consistent residual statics, 1st pass of velocities, and a FX decon filter. Green line is the approximate mute to be applied based on NMO. Under-moved-out events represent possible mode-converted events.](image)
Figure 2. This figure is a P-wave constant-velocity panel based on midpoint binning. Red represents 1\textsuperscript{st} pass P-wave velocity picks. Green projects where the 1\textsuperscript{st} pass P-SV or SV-P velocity would be if a constant Vp/Vs=1.8 were the case. Orange boxes represent possible SV-P packages of geology and where they would approximately reside on the P-wave constant velocity panel. If Vp/Vs is 1.7, it would shift the green marks more into the orange boxes. 1.7 to 1.8 are very reasonable Vp/Vs values for this region. The binning, however, is still mid-point and not ACP binned like traditional converted wave data would be.

Figure 3. Area spanning near-surface conditions where S-static corrections change rapidly with distance and exhibit large variations in magnitude. However, the statics do follow patterns that are probably related to the near surface weathering geology.
Figure 4 top, Figure 5 bottom.
Comparison of traditional post-stacked migrated data of P-SV (Figure 4) and SV-P mode-converted data from the P-wave source into the vertical geophone (Figure 5).