Multimode deconvolution

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ABSTRACT

This paper suggests that multimodes or transmitted conversions between P and S seismic energy can cause degradation of seismic sections. Clear evidence of these conversions is found on VSP data. Proposed here are procedures to suppress multimoding events on both converted-wave VSP and surface seismic sections. The procedure relies on either measuring or estimating the downgoing P-to-S conversions, then deconvolving this energy.

INTRODUCTION

A great multitude of wave types are generated as a seismic wave propagates in the subsurface. While we generally use P-wave transmissions and reflections, and more recently the P-S converted wave, many other wave types or modes exist. At this point in seismic analysis, most of these other events just complicate seismic images and are filtered. Someday we will undoubtedly use this energy, but for now we are most interested in its identification and removal. For example, interface and surfaces waves are usually undesirable and are attenuated. Multipathing events (e.g., peg-leg or interbed multiples), where energy repeats a depth interval, also compromise the clarity of a primary-reflection section. These events are filtered. An event type that has received less attention but is likely the source of further degradation of our sections is the multimode. By multimode, I mean any energy that has changed between P to S waves *on transmission* through an interface. Figure 1 below shows several possible multimodes.

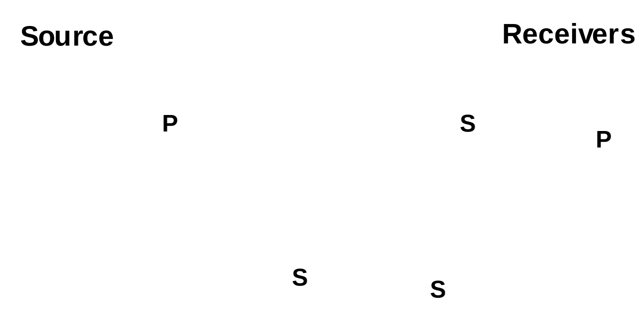

Figure 1. Schematic diagram of wavetype changes (multimoding) between P and S waves.

Some of these multimodes appear to have a beneficial role in seismic imaging through high-velocity layers. In the salt case, we can have a significant conversion from P to S energy at the top of the salt and conversion back to a P wave at deeper interfaces. This multimoded downgoing wave can reflect back upwards as a P wave. We might use the nomenclature PSP-P for a P-to-S-to-P conversion on the downgoing leg with reflection back as a P wave. Imaging algorithms need to account for the velocity change in using these events. Similarly, there has been some success in using the PS-SP multimode in sub-basalt imaging. In this case, there is a P-to-S conversion at the top of the basalt layer, transmission through the basalt as an S wave, reflection from strata below the basalt as an S wave, and conversion back to a P wave at the top of the basalt. These kinds of events remind us that the Earth is elastic. Again, it is also true that each conversion will significantly decrease the amount of energy in the wave mode. So in general, the more complicated events will exist, but they will likely be extremely small.

TRANSMITTED CONVERTED WAVES

In this paper, I will concentrate on a multimode that appears to be problematic in imaging with P-S data: the transmitted converted wave (P-to-S downward) that reflects as a shear wave. We could label this as a PS-S event. Figure 1 showed this event in the surface geometry, while Figure 2 outlines it in the VSP geometry.

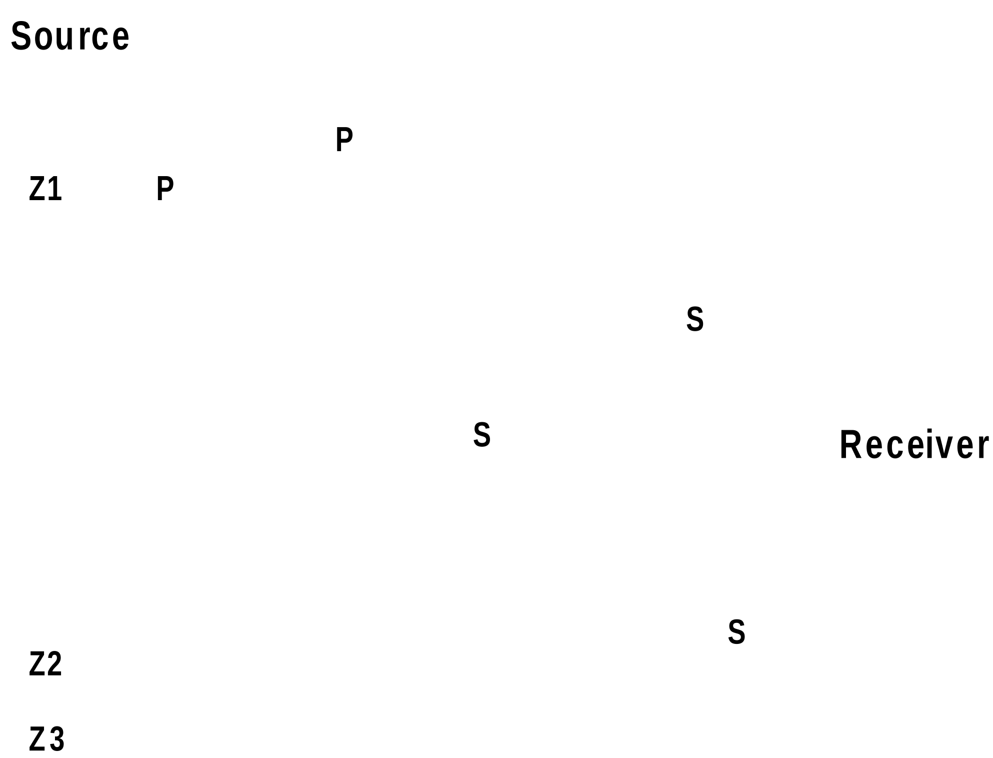

Figure 2. Schematic diagram of raypaths in the VSP geometry.

We often see the downgoing conversion of P to S energy quite clearly on VSP data. The horizontal (radial) channel of a VSP recorded in southern Alberta is shown in Figure 3a (from Geis et al., 1990). The source used was a vibrator offset 325m from the well and recorded over the depths 520m to 1840m. We note the very strong cascade of downgoing PS energy even from this modest offset (or incidence angle).

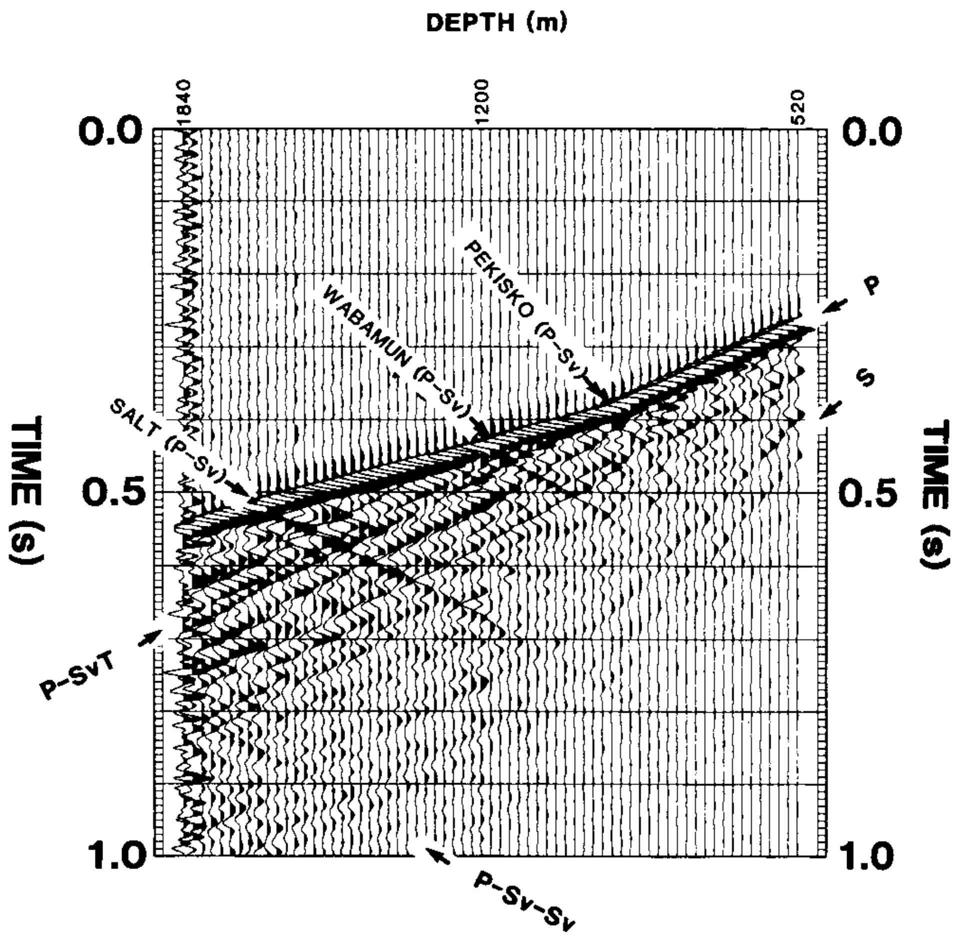

Figure 3a. Horizontal (radial) channel data from a VSP conducted in southern Alberta. The vibrator source was offset 325m from the well and recorded from 520m to 1840m depths (from Geis et al., 1990). Note the strong downgoing P-to-S conversions following the first-breaking P waves.

This converted energy is even more apparent when we remove the downgoing P-wave energy and gain the resultant residual (Figure 3b). This downgoing shear energy can now reflect as a shear wave and be recorded on the radial channel. Algorithms do not generally distinguish this PS-S energy from primary P-S events. Thus when mapping or migrating P-S energy, we will have this PS-S energy interfering. Geis et al. (1990) noted, in their southern Alberta case, that a multiimode appeared to be interfering with primary P-S reflections. This caused distortion of the final section (Figure 4).

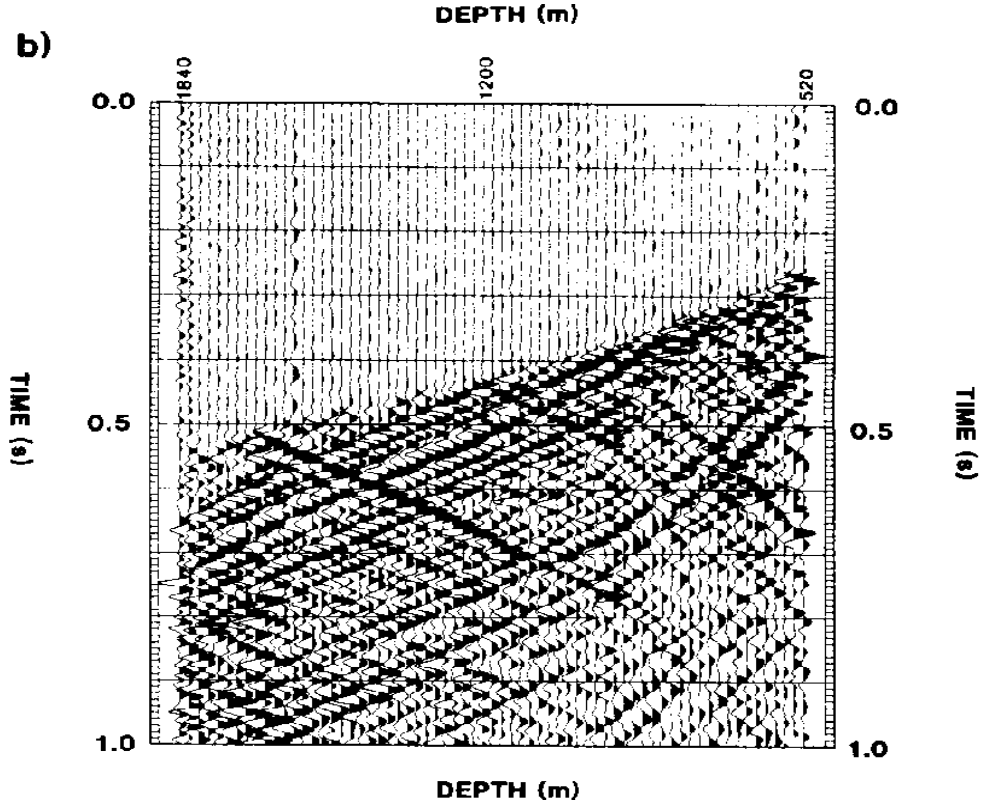

Figure 3b. Radial channel data, as in Figure 3a, after removal of the downgoing P waves and gain (from Geis et al., 1990).

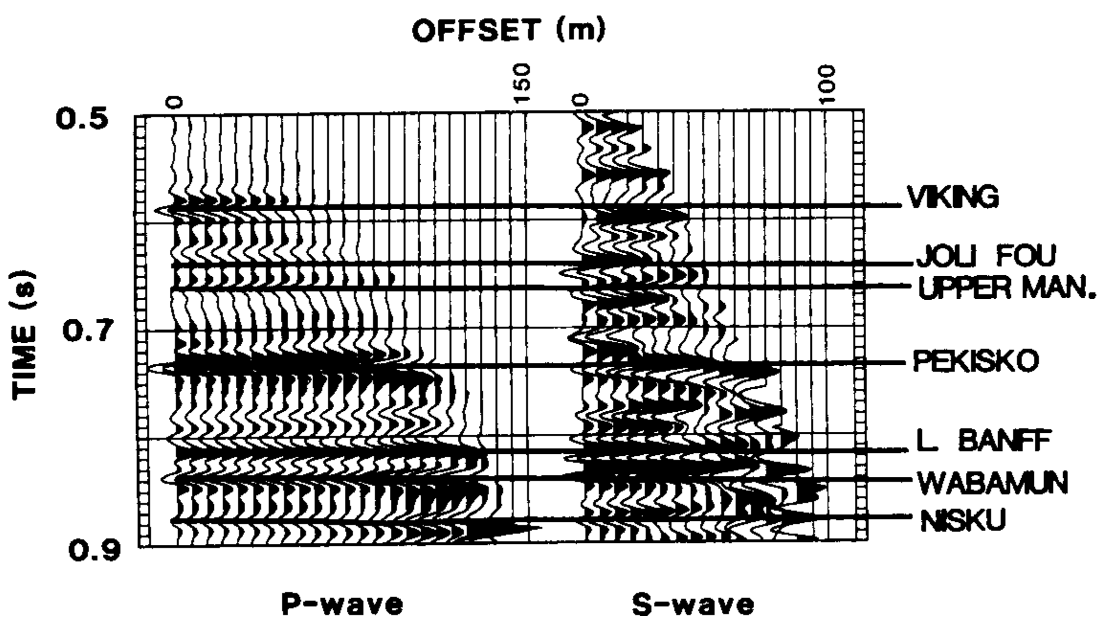

Figure 4. P-wave and P-S wave sections after mapping. Note the interference evident on the P-S section at farther offsets, especially at the Pekisko level (from Geis et al., 1990).

If we are seeing this interference in VSP images, then the problem is also likely embedded in our P-S surface seismic sections. It may be a complication that significantly degrades P-S sections. The following sections will investigate some methods to ameliorate the problem.

VSP DECONVOLUTION METHOD

As shown above, when we separate the upgoing and downgoing P and S waves in VSP data, we often see a veritable cascade of downgoing S energy. In fact, any time that we have P waves propagating at an angle to an interface with an S-wave velocity change, we will have a transmitted P-to-S conversion. This downgoing S wave will also reflect as an S wave. Again, on the receiving end, there will be not only primary P-S reflections but PS-S reflections. Modal filters separate P from S events, but they will not distinguish the various types of S arrivals. These events will be somewhat delayed from the P-S reflections and have different amplitudes. When we map or migrate the data these delayed events they will compromise the resultant images. Coulombe et al. (1996) show another example of these downgoing P-to-S conversions (Figure 5). The upgoing S waves also indicate delayed S-wave energy, at about 1.3s, that is not likely primary P-S energy.

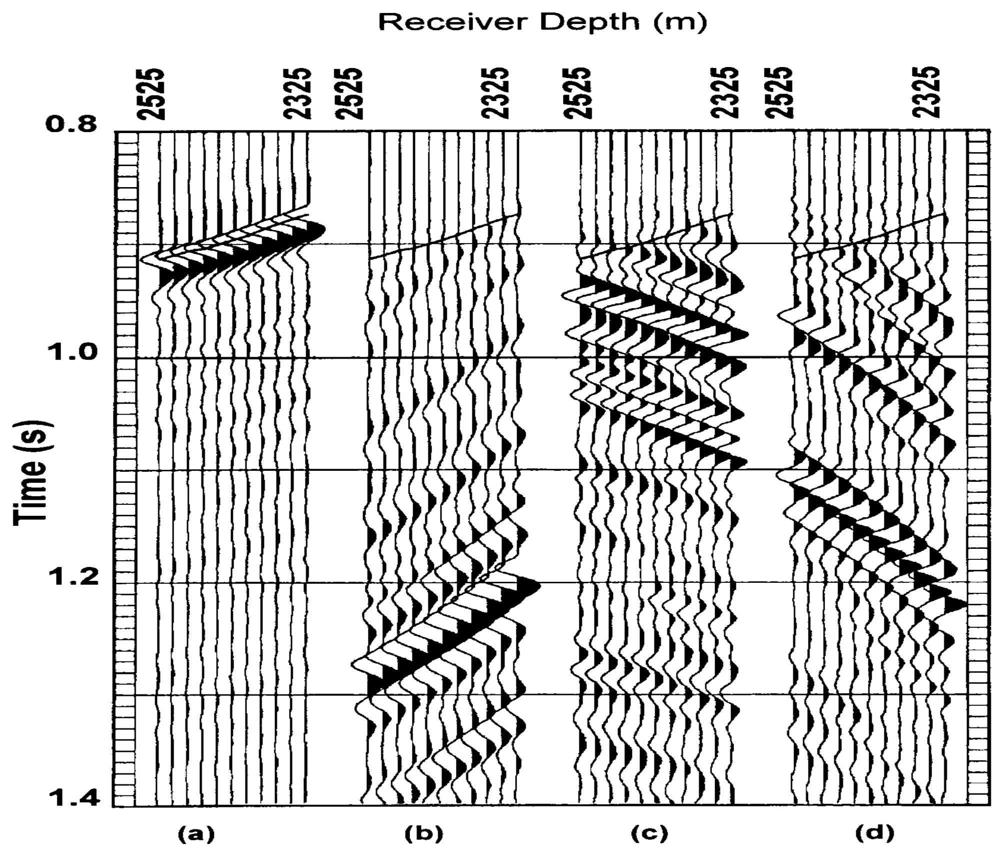

Figure 5. Ten-level VSP data from northern Alberta. A vertical vibrator source offset 2000m from the well was recorded into downhole receivers over the depths 2325m to 2525m. The vertical and horizontal geophone records were separated in to a) downgoing P-wave energy, b) downgoing S-wave energy, c) upcoming P events, d) upcoming S events (from Coulombe et al., 1996).

In designing a procedure to suppress the multimode (PS-S) events, we consider the total upgoing S wavefield U. At any given level:

$$U = Rps*P + Rss*S, \tag{1}$$

where Rps is the converted-wave reflectivity, P is the downgoing P wave, Rss is the S-wave reflectivity, and S is the downgoing S wave.

Now, we have three measurements U, P, and S in one equation with two unknowns remaining. So to solve the equation for Rps or Rss, we are going to have to make some kind of approximation to Rps and/or Rss, develop a relationship between them, or apply some constraint. For example, if the P-wave and S-wave velocities are proportional, then at zero-offset, P-wave reflectivity Rpp = -Rss (Aki and Richards, 1980). But we have measured Rpp and so we might approximate equation (1) with:

$$Rps*P \cong U + Rpp*S \tag{2}$$

$$\text{and } Rps \cong P^{-1} * (U + Rpp*S). \tag{3}$$

This estimate of Rps should now have the PS-S multimode attenuated and provide a more clear image.

Alternatively, we could write:

$$Rps \cong cpRss, \tag{4}$$

where c is a constant and p is the ray parameter, and then

$$U \cong cpRss*P + Rss*S$$

$$\cong Rss*(cpP + S). \tag{5}$$

$$\text{And } Rss \cong U * (cpP + S)^{-1}, \tag{6}$$

where p is not zero.

In this case, we would produce a pure-shear reflectivity section. However, as the converted-wave energy is likely to be larger than the multimode, it is probably better to estimate Rps. This could be calculated as:

$$Rps \cong U * (P + S/cp)^{-1}, \tag{7}$$

where p is not equal to zero.

SURFACE SEISMIC DECONVOLUTION

If we are seeing this phenomenon in VSP data then it should be occurring in surface seismic data also. Unfortunately, in the surface seismic case, we do not have access to the downgoing waves. Thus, the problem becomes estimating the downgoing S wave. There are several possible approaches. In the first, we could obtain an estimate of the transmitted conversions Tps from Rps. In fact, at larger offsets the converted wave reflectivity is approximately the negative of the converted-wave transmission. So,

$$Tps \cong -Rps*P \tag{8}$$

$$U \cong Rps*P - Rss*Rps*P \tag{9}$$

$$U \cong Rps*P(1 - Rss) \tag{10}$$

Again assuming that Rpp ≅ - Rss then

$$U \cong Rps*P(1 + Rpp), \tag{11}$$

$$\text{And } Rps \cong U*[P(1 + Rpp)^{-1}] \tag{12}$$

CONCLUSIONS

Transmitted converted waves are evident on VSP data. These conversions will reflect as shear waves and may be confused with primary P-S reflections. One suspects that these events will also compromise surface seismic P-S data. Several deconvolution procedures are proposed here that may attenuate these multimode events.

FUTURE WORK

These concepts need to be tested on a suite of synthetic and field data. There may be additional possible procedures available by exploiting the relationship between Tps and Rps. Indeed, with VSP data we have Rpp, Rps, Tpp, Tps, so we should be able to solve for density and the P and S velocities.

ACKOWLEDGEMENTS

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