# Constraints on shallow subsurface from P/S mode conversions within the first-arrival coda

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## Abstract

P/S mode conversions identified in the first arrivals could provide valuable information about the S-wave velocity contrasts within the shallow subsurface. Near-receiver P/S conversions are routinely employed to constrain the crustal thickness in teleseismic seismology, in a technique known as receiver functions (e.g., Vinnik, 1997). Recently, Morozov et al. (2002) applied it to recordings from an ultra-long-range refraction profile in Northern Eurasia and showed that travel-time lags between the direct P- and converted P/S waves could be utilized to map the thickness of the sediments along the profile. However, in exploration, as well as in conventional wide-angle crustal seismology, mode conversion in the first-arrival coda has still been underutilized. In this study, we use such phases to constrain the shallow subsurface using records from a multicomponent crustal profile and discuss the utility of these phases for subsurface mapping and measuring S-wave statics in reflection seismology.


## Method

Whenever a P wave strikes a near-receiver velocity interface (particularly with significant S-wave velocity contrast) at an oblique incidence, it generates a converted P/S wave that also propagates forward and contributes to the coda of the P-wave arrival recorded at the receiver (Figure 1). With three-component recording, the resulting P/S wave can be identified by its transverse character of particle motion. From its travel-time lag relative to the primary first arrival $\delta t_{PS}$, the depth to the converting interface can be estimated (Figure 1).

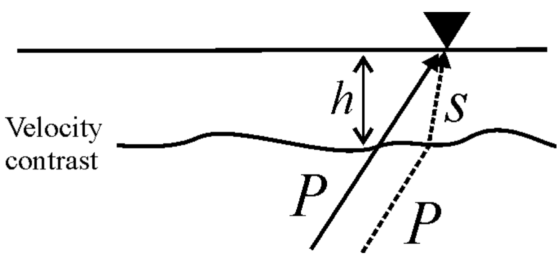


**Figure 1. Ray diagram of a direct *P* and its converted *P/S* wave from a distant source.**

$$h \approx \frac{\delta t_{PS}}{1/V_S - 1/V_P}. \qquad (1)$$

Note that this determination of the interface depth requires only deployment of two or three-component receivers, with only sparse shots performed at a large distance, or with using natural seismicity. Also note that as the waves in the shallow part of the section propagate subvertically, P/S converted wave mapping should provide high horizontal resolution. Good vertical resolution, however, would require knowledge of $V_P$ and $V_S$ velocities of the subsurface.

## Application

The depth mapping approach (1) is widely used in teleseismic seismology (e.g., Vinnik, 1997), and it has also been successfully applied to a ultra-long refraction/reflection profile using nuclear explosions in Russia (Morozov et al., 2002) In order to test it in more conventional crustal seismics, and also to evaluate its potential in exploration imaging, we applied it to the seismic dataset from a joint U.S.- Canadian ACCRETE experiment conducted in 1994 across the Coast Plutonic Complex in SE Alaska and Coastal British Columbia (Morozov et al., 2001). The dataset included 1700 km of marine multichannel profiling in BC fjords that were also recorded by ~60 three-component Reftek seismographs deployed on land at 3-5 km spacing. To date, this dataset provides one of the best-quality S-wave recordings, including reflections and conversions from the Moho.

Figure 2 shows three component particle motion from a typical ACCRETE first arrival at 8.4 km from the shot. When analyzed by using the particle motion diagram technique (3-Component Hodogram Analysis in ProMAX), a P/S mode conversion was identified in almost all the shots, by the change from linear to transverse motion within ~200 milliseconds of the first arrivals. The delay between the P and P/S-wave arrivals was independent of shot locations (Figure 3). Therefore, as expected, the travel-time lags between the P and P/S modes should be due to the subsurface structure near the receiver (Figure 1).

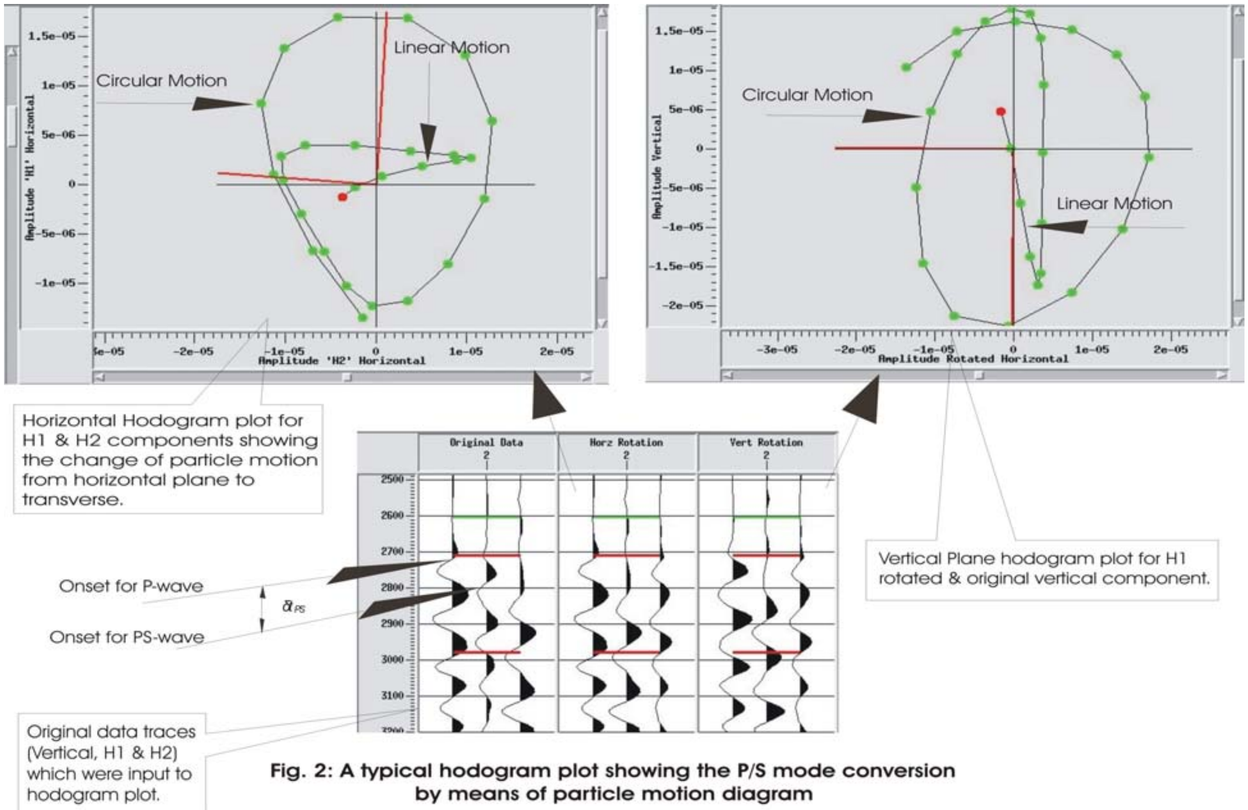


**Fig. 2: A typical hodogram plot showing the P/S mode conversion by means of particle motion diagram**

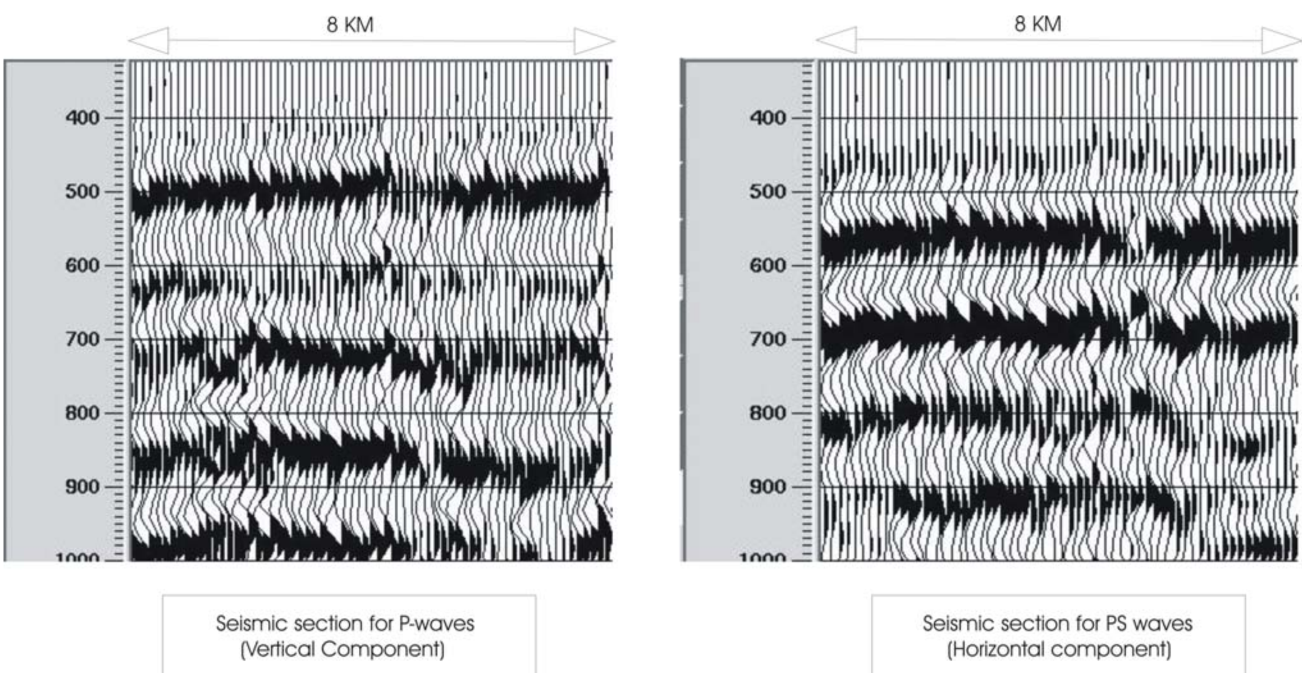


**Fig 3: Two seismic sections for vertical & horizontal component showing the travel time lag between P & P/S mode conversion in the first arrivals which were interpreted as associated with receiver.**

For station 67 shown in Figures 2 and 3, the measured P/S travel-time lag was ~ 90 ms, and therefore, the distance to the converting boundary was approximately 248 m (using $V_P$ = 2000 m/s and $V_S$ = 1160 m/s), This value suggests that the P/S mode conversion was most likely taking place at the base of the sediments, similar to the observations of Morozov et al. (2002). However, large interstation distance (3-5 km) and complex geometry of ACCRETE (with stations located on the side of the fjord with strong cross-line topography of its bottom) still leaves a significant uncertainty on this interpretation. A denser three-component recording would provide robust mapping of the subsurface using shallow P/S conversions.

## Potential applications

Two important applications of P/S mode conversions found in the first-arrival coda are suggested by this pilot study. First, when a strong S-wave velocity contrast (e.g., the base of a weathered layer, or water table) is expected in the area, it could be mapped in detail by deploying a grid of three-component instruments and conducting only a few shots (moreover, no shots may be necessary if sufficient natural seismicity is available). Note that the P/S conversions can be mapped into depth in 3-D, similarly to the way reflections are migrated (Morozov and Dueker, 2003).

Another useful application of this technique could be determination of the S-wave statics in reflection imaging. S-wave statics could be 2-10 times greater than the P-wave statics at the same location (Tatham and McCormack, 1991) and they are often most problematic from the processor's perspective. Even with the uncertainties in the S-wave velocities remaining, the measured P/S lag times $\delta t_{PS}$ (eq. 1) could be measured added to the P-wave statics to produce accurate S-wave statics.

## Conclusions

Consistent *P*/*S* mode conversions can be recognized in the coda of first arrivals by the change of polarization from linear to predominantly circular. From the time lag of these conversions relative to the *P*-wave, depth to the S-wave velocity contract could be mapped with high horizontal resolution. Moreover, the measured *P*/*S* lag times could be used to directly measure the vertical *S*-wave travel times in the shallow subsurface. In this way, the proposed method could contribute to estimation of the S-wave statics that are difficult to estimate by other methods.

### References


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