Converted Wave Receiver Statics from First Break Mode Conversions

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Summary

The estimation of good quality receiver statics solutions for converted wave data is often problematic. This work applies a technique which uses P-to-S conversions by a refracted P-wave to derive the S-wave receiver statics. When a refracted P-wave converts to an S-wave at the base of the weathered layer both phases are recorded at surface. The arrival time difference between the two can be used to solve for statics. We estimate the converted wave static correction from receiver functions that are calculated by correlation or deconvolution of early arrivals like refracted energy on the vertical and radial component. This is demonstrated using synthetic and real data.

Introduction

One important hurdle in processing converted wave data is the estimation of S-wave receiver statics. S-waves interact differently with the water table so that their statics cannot be approximated by simple scaling of the P-wave statics. The most commonly used statics estimation technique works by correlating an event on a converted wave receiver stack with the same event on the equivalent P-wave stack. This can be cumbersome in structurally challenging areas. It also relies heavily on the processors ability to recognize and track equivalent arrivals on both stacks. Moreover, large S-wave receiver statics will often degrade the initial velocity estimates that are needed to produce the converted wave stack.

Method

Our method is largely based on findings by Li (2002) and van Manen et.al. (2004). These authors describe situations where (1) an upcoming P-wave generates a converted upcoming S-wave at the base of the weathered zone, (2) a downgoing P-wave reflects and converts to an S-wave at the base of the weathered zone. Manen et.al. (2004) also discuss the possibility of a refracted P-wave that converts to an S-wave just below the receiver. Such conversion of the refracted arrival has moreover been previously observed on real data by Lash (1986). In either case the main P-wave arrival will be recorded mainly on the vertical component whereas the associated converted arrival will be recorded on the radial component of a 3C receiver.

This type of converted wave arrivals have some particularly useful properties. First, the conversion occurs at the base of, or at some internal interface within, the weathered zone. Second, we can assume near-vertical rays so that the conversion point is located approximately below the receiver. The arrival time difference between the P-wave and its associated converted arrival at any given receiver location is therefore only a function of the thickness, P-wave velocity and S-wave velocity of the weathered zone at that receiver location. Both van Manen et.al. (2004) and Li (2002) propose the use of receiver functions to estimate the time difference between the P-wave arrival and the converted wave arrival from the base of the weathering layer. Receiver functions are commonly used in global seismology experiments to infer crustal and upper mantle properties. Receiver functions are obtained by deconvolving, or correlating, the radial component with the P-wave arrival that is extracted from the vertical component. Receiver functions from the same receiver can be stacked to increase the signal-to-noise ratio.

The combination of receiver functions with near surface P-wave velocity information obtained from conventional P-wave refraction statics allows us to derive a S-wave receiver static. Receiver function analysis provides us with an estimate of the time difference between a S-wave arrival and an P-wave arrival from the base of the weathering layer. P-wave refraction statics provide us with an estimate of the time it takes a P-wave to travel from the base of the weathering layer to the receiver. A simple sum of these properties results in the S-wave static shift or S-wave travel time from the base of the weathering layer to the receiver.

Synthetic Data Example

We generated synthetic vertical and radial component gathers using the elastic 3-layer model in Figure 1 (Left). This model contains a low velocity S-wave anomaly at the center of the most shallow layer, which is 200 m thick and represents the weathering layer.

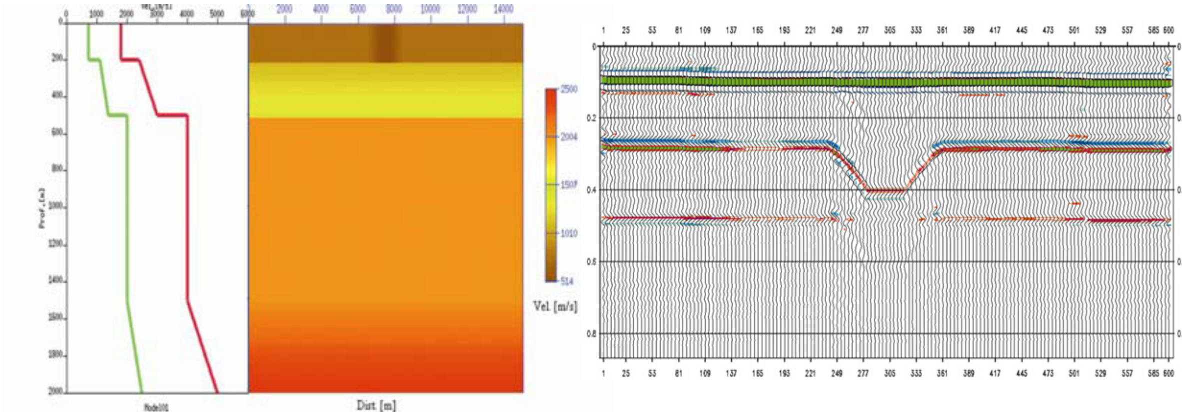

Figure 1: (Left) Vp (red) Vs (green) logs corresponding to the background model. The Vs velocity model includes a velocity anomaly in the shallow layer between 7000 m and 8000 m offset. (Right) Profile of stacked receiver functions.

The calculation of PS receiver statics using receiver functions requires that a conventional P-wave drift statics solution is obtained first. This was done using a tomographic inversion of first break picks. At each receiver location the receiver functions were then calculated and stacked to produce the profile in Figure 1 (Right). The receiver function profile shows three clear events. The first event occurs at zero lag and relates to ‘leaked’ P-wave energy on the radial component. The second and third event occur at time lags of approximately 0.25 s and 0.5 s. These times define the time delay between a P-wave arrival and its associated converted wave arrival from the first and second interface in our model. On the second event we can clearly observe the imprint of the low velocity S-wave anomaly between stations 250 and 350. This event is picked and used to calculate the converted wave receiver statics solution.

Figure 2 shows the effect of applying converted wave receiver statics derived from receiver functions. The stack on the left was generated using P-wave source statics only. There is a clear loss of reflection continuity in the area with the near surface S-wave velocity anomaly. The stack on the right was generated using both P-wave source statics and our S-wave receiver statics calculated using the described receiver function method. Reflection continuity through the anomalous zone has been restored. Note that there is significant steeply dipping noise associated to this part of the stack which is caused by diffractions at the edges of the low velocity anomaly.

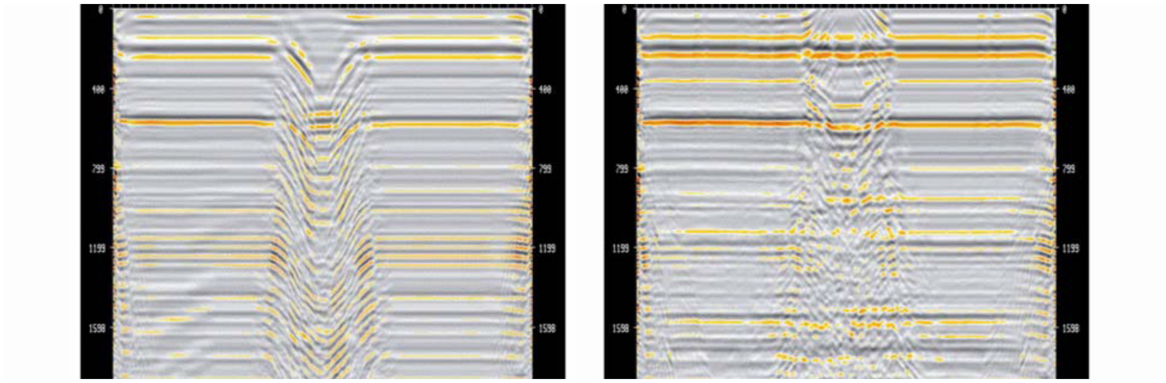

Figure 2: (Left) Converted wave stack of model data without receiver statics (Right) Converted wave stack of model data with receiver statics calculated from receiver function analysis.

Real Data Example

We use data that was acquired in 2008 by the CREWES project near Spring Coulee, Alberta. A 2-D seismic line was acquired using 2 kg dynamite shots, two 48,000 lb vibrators and an 18,000 lb vibrator. The seismic line consists of 652 stations at 10 m spacing with co-located three-component (3C) geophones and 3C Digital Seismic Units (DSU's). In this study we consider only the data that was acquired on the 3C geophones using the 48,000 lb vibrators. Figure 3 shows a radial component and vertical component receiver gather for station 427. The data has been LMO corrected using the P-wave first break pick times. Some mild noise attenuation was also applied as well as a 100 ms bulk shift and a divergence correction. Corrections are consistent between the two components. The P-wave first break arrival is clearly visible on the vertical component receiver gather at 100 ms. On the radial component there is a faint arrival at 100 ms which is leaked P-wave energy. The main arrival comes in at approximately 200ms. We believe this to be a converted wave arrival that was generated by the refracted P-wave, just below the receiver and at the base of the weathered zone. Receiver functions for each station are generated by correlating the windowed portions (red boxes on figure) of the vertical and radial component data and then stack.

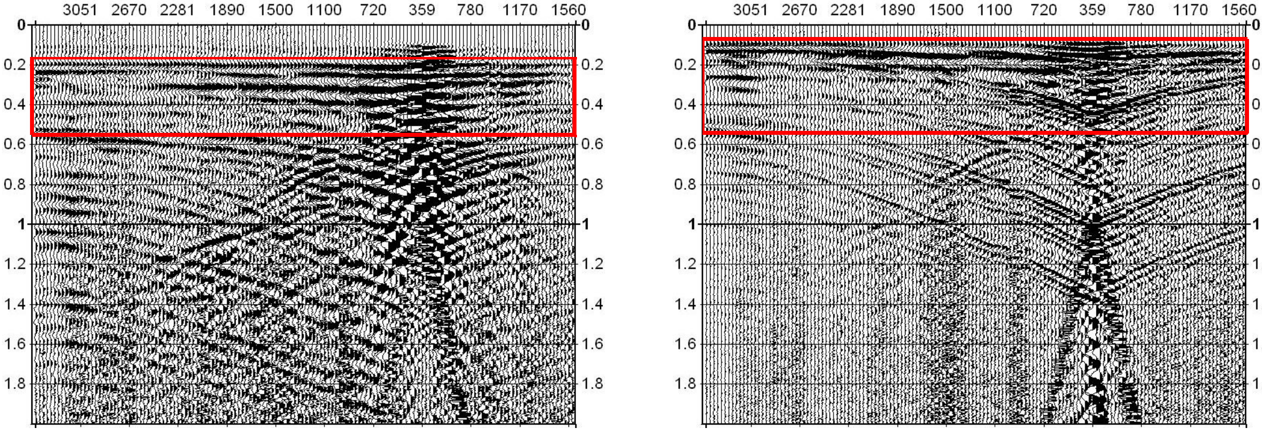

Figure 3: Linear moveout (LMO) corrected receiver gather with divergence correction, mild noise attenuation and a 100ms bulk shift. The LMO correction is based on the P-wave First break picks. Left: radial component. Right: vertical component. The red boxes indicate the correlation windows used in the calculation for the receiver function analysis.

The influence of receiver function converted wave statics on ACP stack quality is illustrated in Figure 4. Example A shows a ACP brute stack that was obtained after applying mild noise attenuation and P-wave source statics. No deconvolution was applied. Example B was obtained using the same data, but we added our receiver statics correction on the NMO corrected ACP gathers and prior to stacking. There is a clear improvement on stack quality. This is especially noticeable between ACP 160 and 400 and between ACP 800 and 880. The shallow event around 0.75 ms has become more coherent after application of receiver function statics and appears 'flatter', or less structured. We attribute this to the ability of receiver function statics to compensate for short wavelength as well as long wavelength effects.

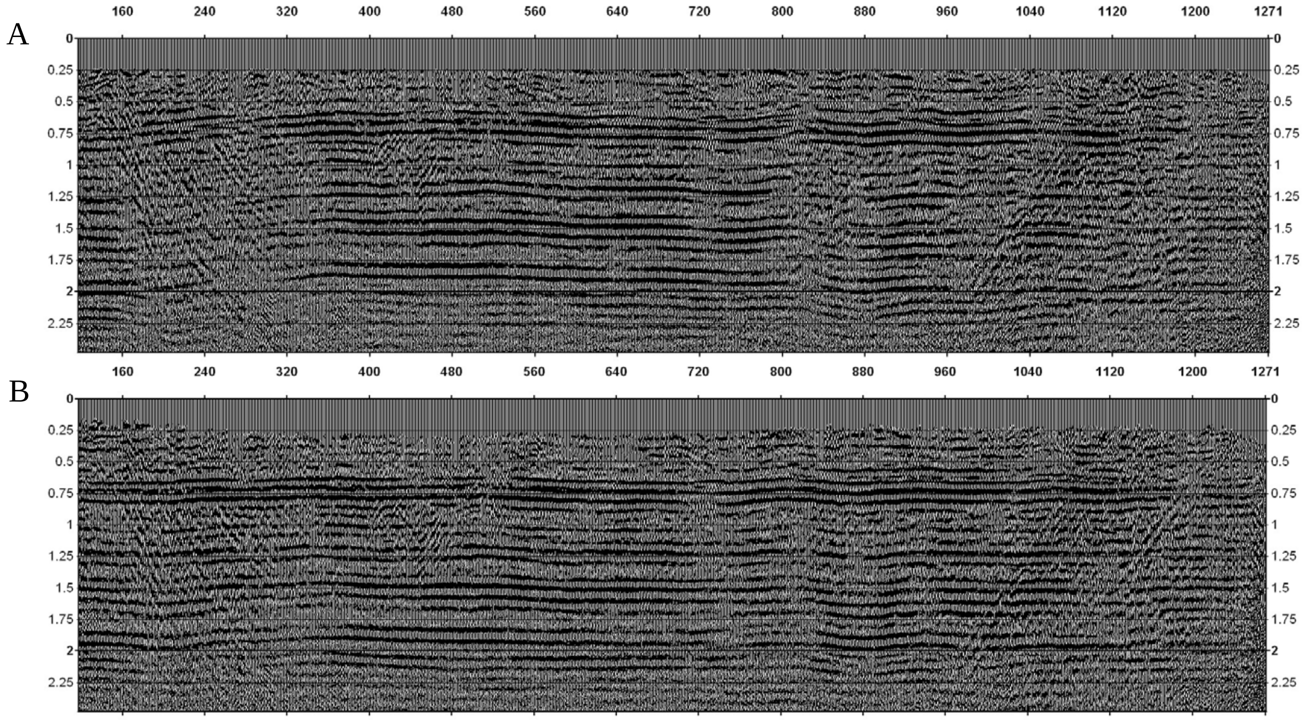

Figure 4: Converted wave brute ACP stacks. (A) stack without converted wave receiver statics. (B) stack with converted wave receiver statics as obtained from receiver function analysis.

Conclusions

This work shows a successful application of converted wave receiver statics calculation using receiver functions on synthetic and real data. Our receiver functions are generated by cross correlating or deconvolving the first break energy recorded on the vertical component with that on the radial component and stacking in the station domain. One advantage of this method is that receiver statics can be obtained prior to the first pass velocity analysis thus greatly improving the initial velocity estimates. This is a major advantage over conventional methods. More research is needed however to address the general use of this method. It remains to be seen whether the technique applies equally well to foothills, oil sands and permafrost data as it does to this plains dataset.

Acknowledgements

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References

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