Hybrid interferometry: surface corrections for converted waves

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ABSTRACT

Recently, a number of seismic processing techniques, collectively termed ‘interferometry’ have been devised to help image various types of seismic data, or to remove unwanted effects from raw data attributable to source/receiver coupling, surface layer irregularities, and scattering. Although varying in their objectives and formulation, these techniques are generally based on cross-correlations of raw seismic traces. Previously, we demonstrated success in applying near-surface corrections to two sets of arctic data using two different implementations of interferometry, ‘virtual trace gathers’ and ‘static deconvolution’. Additionally, for one of these data sets, surface-consistency was generalized to ‘raypath-consistency’, and stationarity was abandoned. Interferometry was then applied successfully in the radial trace domain.

Since interferometry can handle very large ‘statics’, as demonstrated with the arctic data, we made some initial attempts to apply similar techniques to converted wave data, but with limited success. We demonstrate here a more recent attempt to remove surface effects from converted wave data, using a ‘hybrid’ approach, in which we correlate traces from two different vector components at the same receiver positions in order to detect and remove the receiver ‘static differences’. The results show greatly improved coherence; but have yet to properly account for the ‘structural’ term and can exhibit spurious coherent events due to fortuitous correlation of unrelated PP and PS events.

INTRODUCTION

Cross-correlation has long been an important tool for seismic processing, playing a crucial role in spectral analysis, filter design, statics correction, etc. Only in the last few years, however, has the full power of cross-correlation begun to be utilized for such diverse uses as forming images from large volumes of passive seismic data, estimating the Green’s Function of a seismically illuminated target, and removing scattering and other near-surface effects from seismic reflection data (Wapenaar et al. 2006). Cross-correlation has been used for decades to find and correct the relative shift between two similar seismic traces, but usually just by using the time position of a cross-correlation maximum as a shift to apply to one of the traces. Only recently, however, has use been made of the entire correlation function to correct one seismic trace relative to another, either by applying the correlation as a match filter or by deriving an inverse filter for the cross-correlation and applying the inverse (Henley 2004, 2005, 2006). The use of the entire cross-correlation function, rather than a ‘time pick’ of the maximum, is what distinguishes an interferometric approach in the context of surface corrections.

Bakulin and Calvert (2006) used source-receiver reciprocity and time reversal to formulate their innovative ‘virtual shot’ method for removing near-surface effects from VSP data recorded at downhole geophones. In this technique, traces from two receiver gathers are matched in pairs by common shot and cross-correlated over gated early arrival portions of the traces. The cross-correlations are applied as match filters to the corresponding traces in one gather and summed over all the shots in the gather (or a selected 'aperture'). This forms one 'virtual trace' corresponding to a virtual shot at the receiver position of one gather, with a receiver at the position of the other gather. Repeating this procedure for all the receiver gathers with respect to each of the traces in one gather creates a 'virtual shot'. In 2007 we extended the virtual source technique in an attempt to apply approximate corrections for both source and receiver surface effects by correlating traces over gated reflections and assuming that reflections are more slowly varying laterally than the near-surface layers (Henley and Daley, 2007). In addition, we provided a mathematical comparison of the extended 'virtual gather' method with our own 'statics deconvolution' technique, in which summed raw traces (pilot traces) are correlated with corresponding raw traces, and the cross-correlations, or their inverses, are applied as surface corrections to the raw traces. A variation of this approach uses correlations of pairs of raw traces to derive inverse filters for the trace-to-trace, or 'differential' statics. This approach is attractive because it does not rely on the subjective creation of 'pilot' traces. However, it encounters difficulty with noisy data.

We compared the extended virtual source method with statics deconvolution on our Hansen Harbour data set, in which, fortuitously, there were no significant receiver statics to derive; and the results were quite comparable for applying shot surface corrections (Henley and Daley, 2007). Bandwidth and unresolved embedded wavelet problems remain in the extended virtual source method, however, and we have made no attempt to further develop that approach at this point. We continue to use the statics deconvolution method for further interferometric investigation.

When it became evident on one of our Arctic data sets that surface-consistency was seriously violated, we proposed a more general 'raypath-consistency' criterion, which required transforming the raw data to a common-raypath domain, for which the radial trace transform is a good approximation. By transforming source or receiver gathers into the radial trace (RT) domain and sorting the traces into common-angle gathers (analogous to common-offset gathers in the X-T domain), we can obtain surface correction filters for all the data at each common near-surface raypath angle. Since these filters are derived and applied independently for each different angle, the 'statics' can vary with near-surface angle and consequently with depth (Henley 2006, 2008). If near-surface corrections are surface-consistent for a particular data set, then the inverse filters derived for a particular surface location at each common angle will be quite similar; but the surface-consistent constraint is not actually used for the filter derivation.

Because of our success with a difficult Arctic data set (Henley 2007, 2008), we decided to apply some of the same interferometric techniques to converted wave data. Recently, we reported the results of initial tests of these techniques on data from Spring Coulee (Henley and Daley 2008). We attempted several variations of our interferometric technique, using pilot traces to correlate with both shot gathers and receiver stacks. We were never able to obtain satisfactory pilot traces for the receiver stacks, but had more success with shot gathers. However, we attained the most success by transforming the data to the raypath domain, creating pilot traces for common-angle gathers, and correlating these pilot traces against their corresponding raw traces. The inverse filters from these correlations corrected the angle gathers sufficiently that converted wave event coherence on the re-constituted data was greatly improved. Although the common-angle gathers themselves were noisy, and the corrected angle gathers showed relatively modest improvement, the common-conversion point (CCP) stack of the reconstituted X-T data was dramatically improved. One reason for the dramatic improvement is almost certainly due to the inherent redundancy involved in correcting each of the many angle gathers independently, then reconstructing the original X-T gathers from the radial trace transforms.

Early in 2009, DeMeersman and Roizman (2009) introduced an innovative approach to converted wave receiver statics. In their method, demonstrated on our Spring Coulee data, they removed the linear moveout from the first arrivals in both the vertical and radial component source gathers, then cross-correlated the first arrival events of corresponding vertical (PP-waves) and radial components (PS-waves converted at the base of weathering). The cross-correlation maxima were then picked to yield the difference between PP-wave and PS-wave receiver statics for each receiver station.

Intrigued by this idea, we decided to re-visit interferometry by correlating corresponding reflected and converted events between gathers of vertical and radial component data, and using the correlations to derive inverse filters to remove the difference between the PP and PS statics at each receiver. Following is our description of tests of this idea. In the remainder of this work, we use the terms ‘radial component’ and ‘inline component’ interchangeably to mean particle motion which is horizontal and directed toward the shot position. Since this is a 2D survey, with source and receiver positions collinear, the approximation is quite good.

HYBRID INTERFEROMETRY

When we first explored the possibility of using interferometry to apply receiver corrections to converted wave data, we tested our raypath interferometry method using data from the Spring Coulee multi-component survey (Henley and Daley 2008). Our first approach was to emulate the technique that proved successful on our two sets of arctic seismic data (Henley 2007). This method relies on the construction of ‘pilot traces’ from the raw data, which are then cross-correlated with individual raw traces in order to estimate ‘statics functions’. The statics functions are used, in turn, to derive inverse filters for removing the effects of the statics functions from the raw traces, and thus to correct the data for near-surface effects. We found it much more difficult to construct acceptable pilot traces from the radial component trace gathers than we had anticipated, although some measure of success was eventually achieved by going to the raypath domain, with its inherent redundancy. Nevertheless, we began to look for other ways of estimating statics functions that did not require the construction of pilot traces.

The unique method presented by DeMeersman and Roizman at the 2009 CSPG-CSEG joint convention (DeMeersma and Roizman 2009), for deriving converted wave receiver statics stimulated us to modify and extend their method into what we call ‘hybrid interferometry’. In this new method, like DeMeersman and Roizman, we use the static-corrected vertical component data as de facto pilot traces, only we cross-correlate reflected and converted events, rather than direct arrivals. We first match a prominent reflection on the vertical component data with its corresponding converted wave event on the radial component data, and for all subsequent processing we shift the radial component event up in time to match the vertical component event. We then cross-correlate the event on various ensembles of the radial component with the corresponding event on comparable ensembles of the vertical component and use the cross-correlations to derive inverse filters, which are then applied to the traces of the input radial component trace ensembles to remove the 'statics' or other surface effects. To date, we have tested two different types of ensemble for hybrid cross-correlation: conventional shot gathers, and common-angle gathers created from the radial trace (RT) transforms of conventional receiver gathers. In all cases, we assume that the vertical component data have been corrected for shot and receiver statics, and that the same PP-wave shot statics have been applied to the inline component data. Furthermore, we assume that all data, both vertical component and inline component, have been corrected for NMO.

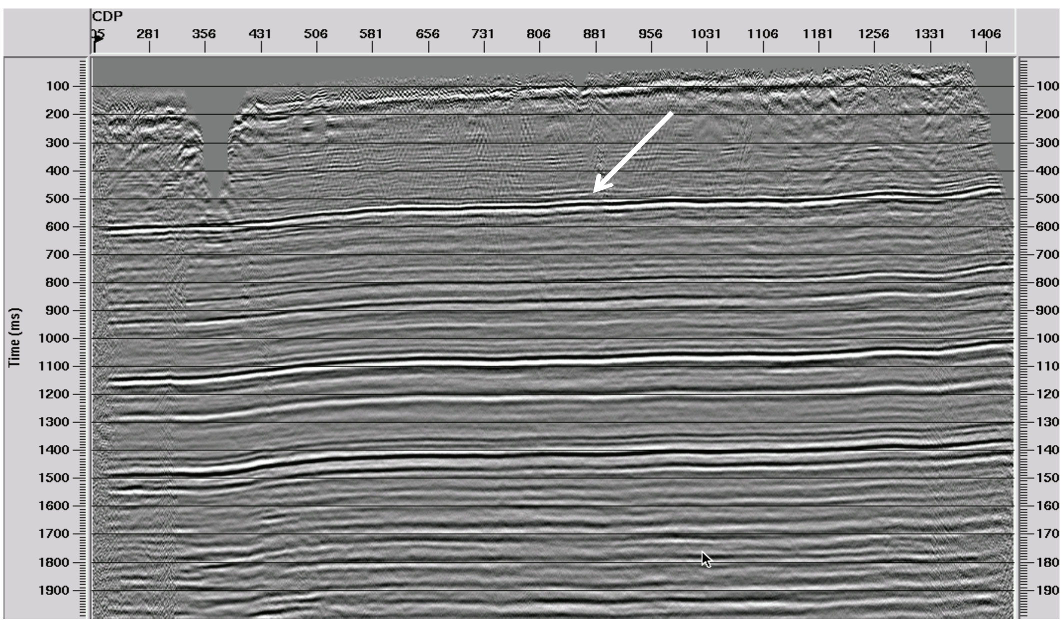
Since we are considering cross-correlations between two different modes of seismic data (PP-waves and PS-waves) rather than different representations of the same mode, we have termed the approach 'hybrid' interferometry. By targeting reflected/converted events rather than direct arrivals, we immediately introduce complications into our approach. Direct arrivals are typically strong, relatively clean single events, which can be isolated by appropriately chosen gates. Correlations between them should embody mainly the phase/time differences between them. Reflected events (on vertical component data), and their corresponding converted events (on radial component data), on the other hand, are usually embedded with other, similar events; and any significant window around a desired event contains some of these smaller amplitude events, as well as inter-bed multiples and other coherent energy. In addition, the intrinsic 'reflectivity' function for a particular lithological sequence will not be the same as the 'convertivity' function for the same lithological sequence. This means that an attempt to correlate a single windowed reflected event with its corresponding windowed converted event will be complicated by spurious correlation side-lobes due to the secondary events included in the window. Furthermore, if more than one strong reflection is included in the window, and more than one strong converted event is included in its window, other larger amplitude correlation maxima will arise, usually at larger shifts, due to unwanted correlation between the principal reflected event and the secondary events in the converted event window. Finally, because of the velocity difference between PP and PS events, corresponding events on PP and PS gathers will have different arrival times and different event intervals, as well.

Our hope, then, is that the hybrid cross-correlation functions will be dominated mainly by the relative shift between a chosen reflected event and its corresponding converted event, rather than by the phase and character differences between PP and PS events, and that an inverse filter derived from the correlation will appropriately correct the converted events for the gross surface effects (like large statics) without introducing significant spurious events. A companion report chapter (Henley 2009) explores some of these issues with a model study. The results of this model study indicate that, while spurious events can arise with the hybrid technique, there are measures that can be used to limit the amplitude of such events. Furthermore, using the full angle gather interferometry approach, rather than surface gather interferometry, improves the redundancy and further suppresses spurious events.

One unresolved issue which occurs in this form of interferometry is that both the vertical and radial components reflect the time structure of the subsurface events, albeit to a somewhat different degree, determined by the Vp/Vs ratio of the rocks. In any event, the statics or near-surface functions, derived by hybrid interferometry will embody only the *differences* between receiver statics for compressional and shear modes plus the differences in time structure between the reflected event on the vertical component and its corresponding converted event on the inline component. A way to compensate for the structural component, which we have only partially explored, is to pick the reflected event on the vertical component stack as a horizon, and to add the horizon picked times (perhaps scaled by the Vp/Vs ratio), to the receiver statics differences estimated by the interferometry.

RESULTS

To illustrate the quality of the data at Spring Coulee, Figure 1 shows the CDP stack of the vertical component data from the 3C line. Marked on this figure is the prominent reflected event to be matched with its corresponding converted wave event on the radial component data.

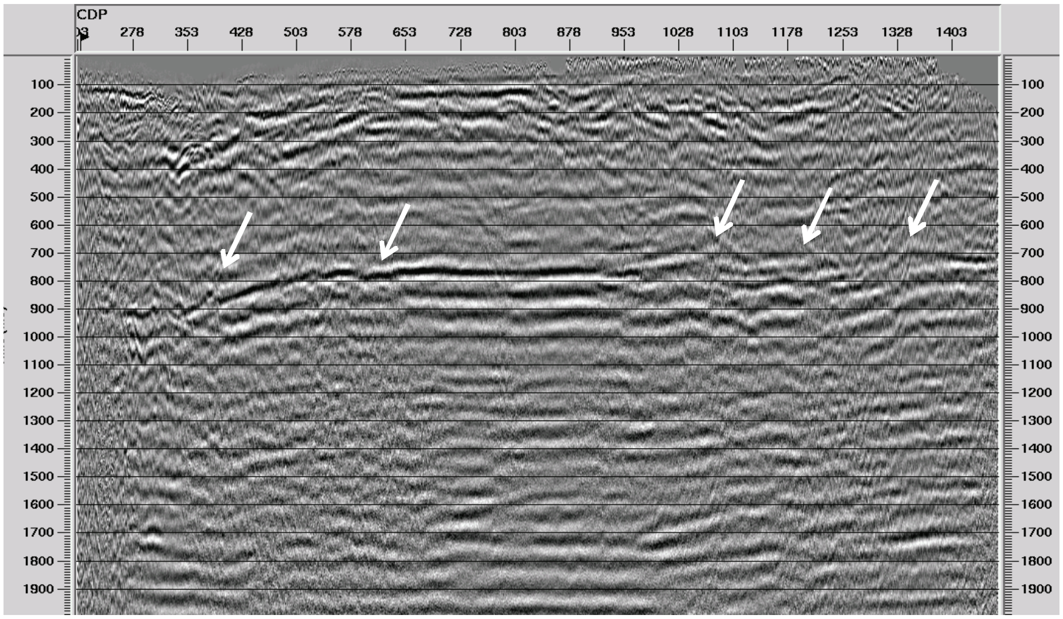


CDP stack of vertical component (PP reflection section). Arrow marks reflected event at 500 ms which matches a converted wave event at 800 ms.

FIG. 1. CDP stack of vertical component of Spring Coulee 3C 2D survey. The first strong reflected event at about 500 ms is the event chosen for correlation with radial component data.

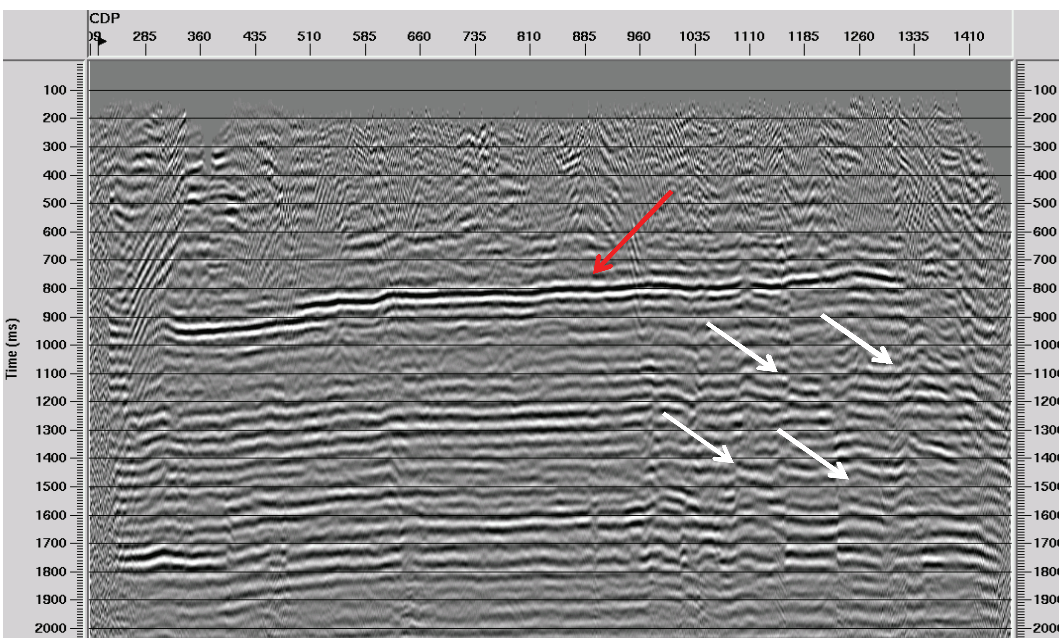
In contrast, Figure 2 shows the CCP stack of the radial component from the same Spring Coulee 3C line. The converted wave event at about 800 ms corresponds to the 500 ms reflected event in Figure 1. The data in Figure 2 have had no statics applied, and it is obvious that serious statics problems exist at many points in the section (arrows).

Figure 3 shows a ‘conventional’ statics solution applied to the inline component. While the overall event coherence has been greatly enhanced, it is evident that corrections which are appropriate for the 800 ms converted wave event do not properly correct deeper events. We thus seek solutions which correct all converted wave events, regardless of travel time. Our experience with arctic data (Henley 2007, 2008) showed that interferometric methods can provide such solutions. Since we were able to obtain a solution for one of the arctic data sets by correlating conventional trace gathers (source and receiver gathers), we decided to initially attempt this type of interferometry on the Spring Coulee data set; but to also apply the full raypath-consistent approach, using common-angle gathers. We then compared results between the two approaches. In a companion report chapter (Henley 2009) we demonstrate both these approaches on synthetic data and discuss the relative benefits of each.



Uncorrected radial component shots stacked over CCP bins. Arrows mark zones of significant uncorrected receiver statics

FIG. 2. CCP stack of radial component of 3C Spring Coulee survey. Disruptions of the converted wave events due to unresolved statics are evident.

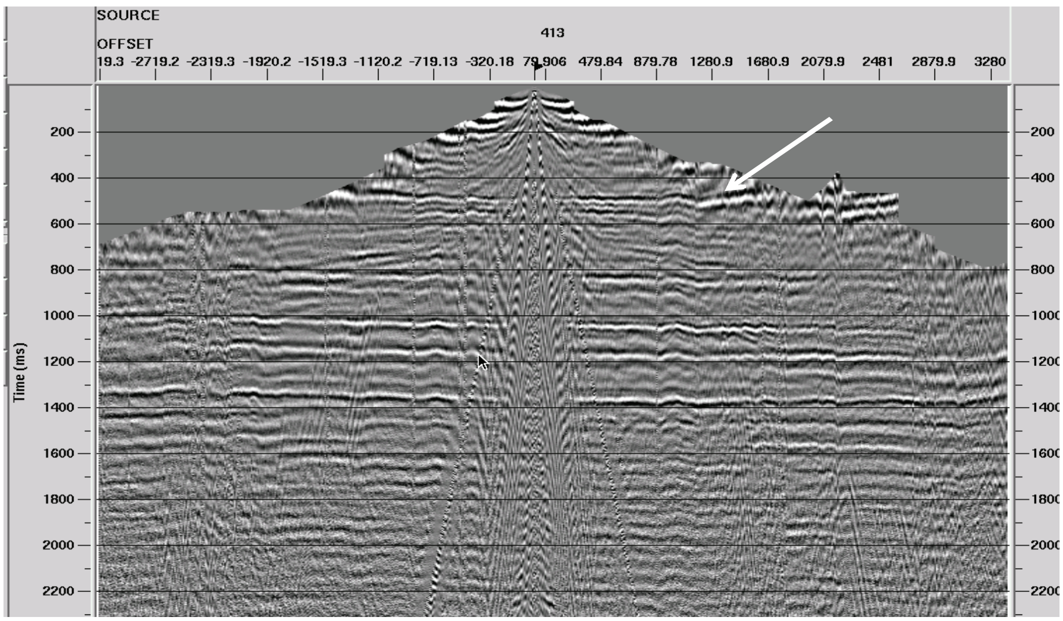


CCP stack of radial component after hand, residual, trim statics. Red arrow marks converted wave event matching the reflected event at 500 ms in Figure 1. Deeper events (white arrows) not properly corrected by these statics.

FIG. 3. Spring Coulee radial component with ‘conventional’ statics applied. While the 800 ms event (red arrow) is reasonably well imaged, deeper events are still disrupted by unresolved statics (white arrows).

Shot gather interferometry

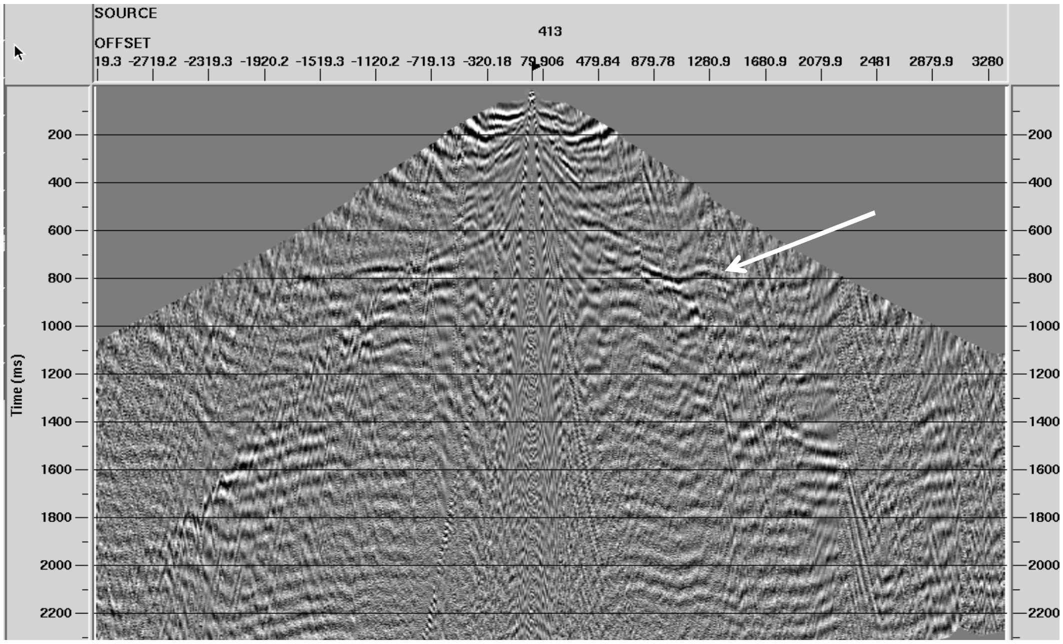
To perform shot-gather-oriented interferometry, we first apply all source and receiver statics to the vertical component data, and apply the vertical component source statics to the inline component data, as well. Then we apply the best-known NMO corrections to both sets of data. A typical vertical component shot gather is shown in Figure 4 with the reflected event at 500 ms flagged by an arrow.



Typical vertical component shot gather. Arrowed event at about 500 ms is the one used to match this component to inline component.

FIG. 4. Typical vertical component shot gather for Spring Coulee 3C survey. PP-wave receiver statics have NOT yet been applied to this gather. This event appears on only about half the traces in the gather, due to its shallow time and early muting.

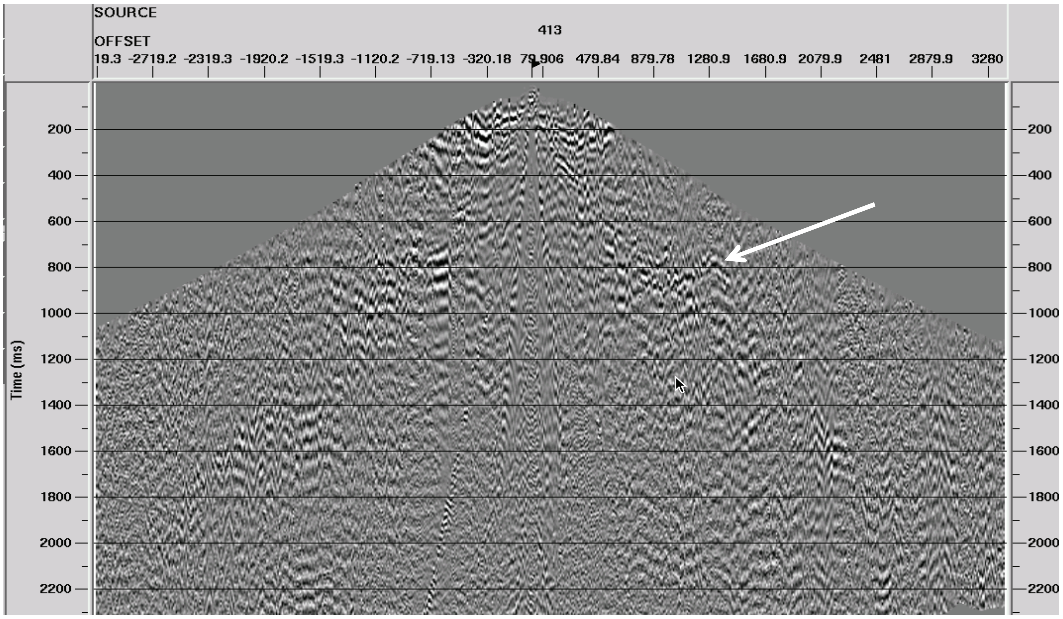
Corresponding to this gather is the radial component shot gather displayed in Figure 5. It is evident from this figure that the S/N is much lower on the radial component data, and that the receiver statics are much larger for the converted wave event at 800 ms that matches the 500 ms reflection in Figure 4.



Typical radial component shot gather. Arrowed event at about 800 ms corresponds to arrowed reflected event on vertical component gather in Figure 4.

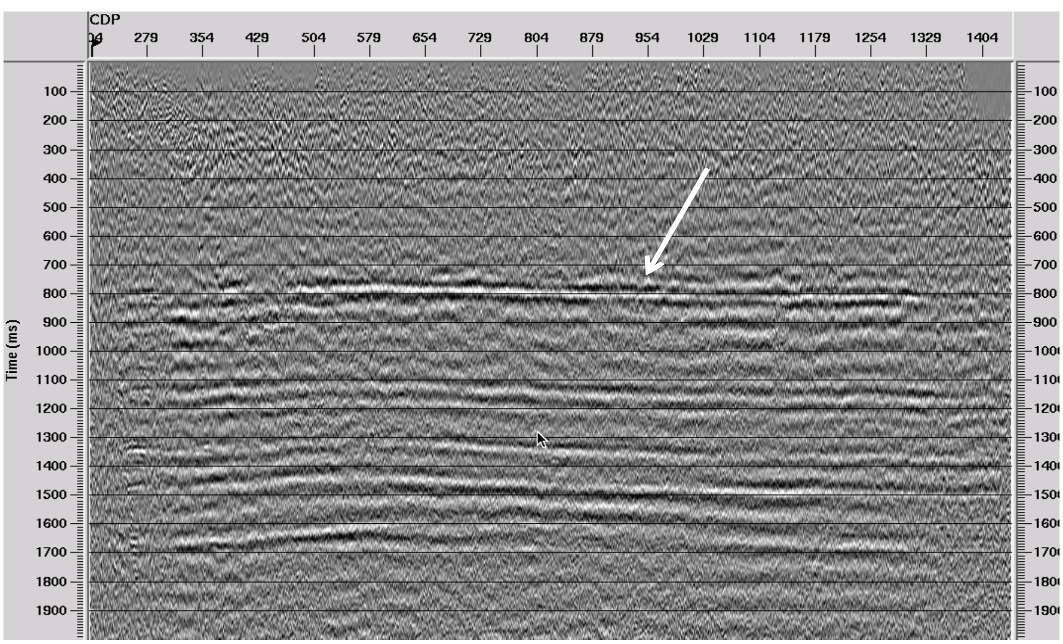
FIG. 5. Radial component shot gather corresponding to the vertical component gather in Figure 4. S/N is much lower for this gather, and receiver statics are larger as well, as evidenced by the converted wave event at 800 ms. The indicated event appears on just over half of the traces in the gather.

Our shot gather interferometry method cross-correlates corresponding traces between the gathers in Figure 4 and 5 (traces with the same receiver), 'conditions' the correlation functions (Henley 2009), derives an inverse filter for each correlation function, then applies each filter to its corresponding trace from the radial component shot gather. One problem with the shot gather interferometry approach, particularly for shallow events like our chosen one, is that the event may not appear on all traces due to muting, so that as many as half of the traces in a given shot gather cannot be used to derive inverse filters. Another problem emerges as shown in Figure 6, which shows the same gather as Figure 5 after application of a set of inverse filters. It is not evident from this figure that the deconvolution process has provided any net benefit—event coherence certainly has not improved on this particular gather! The fault here, however, is an inadequate cross-correlation window length—400 ms—which is too short to properly accommodate the converted wave event and its full range of static shifts. When we lengthen the correlation window to 1000 ms and apply the shot gather interferometry to the entire set of inline gathers, the resulting CCP stack is shown in Figure 7. The high stack fold, in addition to the increased correlation window length, makes this result appear better than would be expected from the result in Figure 6. Note that most of the geological structure has been removed by this procedure (compare with Figures 2 and 3), since the structure is quite similar for both vertical and inline components, except possibly for a scale factor relating Vp and Vs.



‘Corrected’ radial component shot gather. Arrowed event at 800 ms corresponds to marked reflected event at 500 ms on vertical component gather. The random appearance of this gather is deceptive.

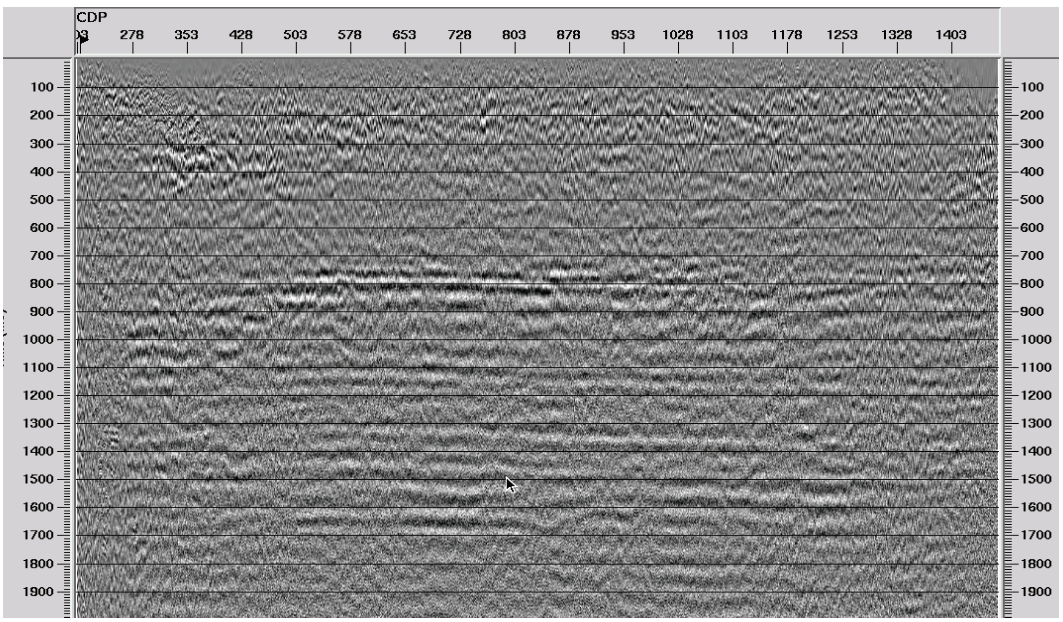
FIG. 6. Radial component shot gather of Figure 5 after application of inverse filters designed to remove the receiver statics differences. Correlation window is 400 ms—too small for proper correction of even the event at 800 ms. A correlation window of 1000 ms improves the results.



CCP stack of radial shot gathers corrected by inverse filters from PP and PS correlations on corresponding shot gathers. Event match was done for event at 800 ms. Note loss of geological structure, since statics are ‘difference’ statics between PP and PS

FIG. 7. CCP stack of radial component shot gathers corrected for receiver statics ‘differences’ between radial and vertical components. Correlation window is 1000 ms. High stack fold apparently helps to compensate for irregular results on individual shot gathers.

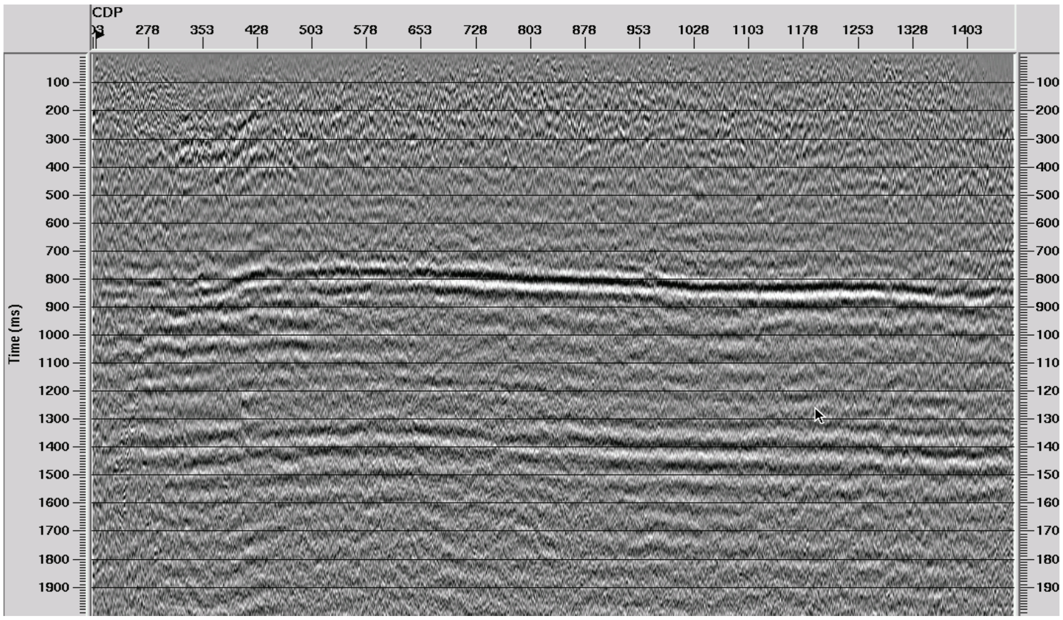
Results like those in Figure 6, where individual inverse filters seemed ineffective, prompted us to attempt to use surface-consistency to increase the robustness of the filter derivation. Hence, we cross-correlated corresponding traces on vertical and radial component gathers for the same shot, as in Figure 6, but instead of deriving inverse filters on the individual cross-correlations, we sorted them by receiver, then shot. We then summed all cross-correlations over their common receivers and derived a single inverse filter for each receiver. The inverse filter for each receiver was applied to the appropriate trace on each individual radial component shot gather. The resulting shot gathers were stacked over CCP, and the results shown in Figure 8. Since the results in Figure 8 are not as good as those in Figure 7, we conclude that this application of surface-consistency is inappropriate.



CCP stack of radial receiver gathers corrected by inverse filters from PP and PS correlations on corresponding shot gathers, summed over receivers. 1000 ms correlation window.

FIG. 8. CCP stack of radial shot gathers corrected by inverse filters derived from PP vs. PS cross-correlations summed over common receiver location to utilize surface-consistency.

Since we were concerned that the hybrid interferometry approach might introduce spurious events into the deconvolved results due to the correlation of vertical and inline coherent events that are not physically related to each other, and not properly matched in travel time, we tested an idea designed to reduce this effect. By comparing travel times for our known correlated event (500 ms PP vs 800 ms PS), we determined a stretch factor to apply to the vertical component data so that the 500 ms reflected event would match the 800 ms converted event, then applied the stretch factor via two resampling operations. Subsequently, reflected events on the vertical data which corresponded to converted wave events on the radial component data were all approximately matched to their corresponding events, with no additional time shifting required (assuming relatively small changes in Vp/Vs with depth). With all reflected events matched to their corresponding converted wave events, cross-correlation functions should then contain only the relative event displacement due to receiver statics. Using ‘stretched’ vertical component gathers, we performed the same shot gather interferometry as demonstrated in Figure 7, where individual inverse filters generated from cross-correlations of matched vertical and radial component traces were applied to the radial component traces to ‘correct’ them. The CCP stack of the radial gathers corrected in this fashion is shown in Figure 9.



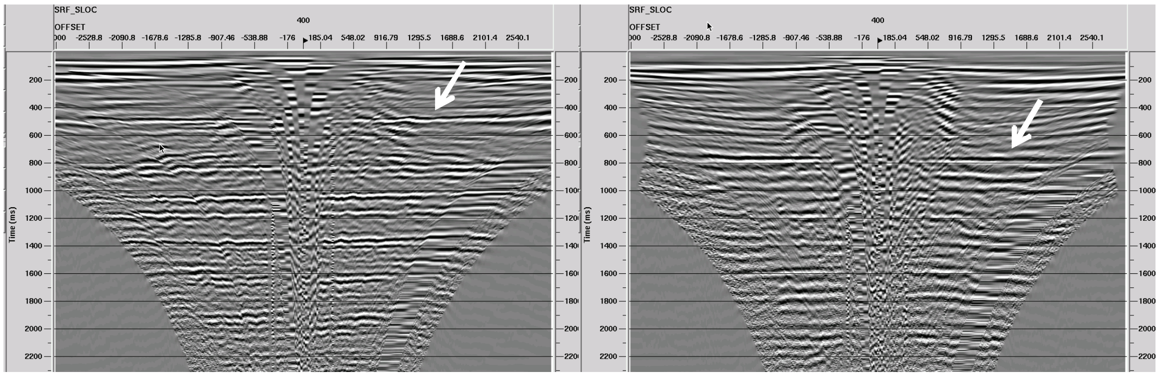
CCP stack of radial shot gathers corrected by inverse filters from stretched vertical component gathers correlated with matching inline gathers. 1000 ms window. Note that stretching of vertical component leads to stretching of deconvolved inline component.

FIG. 9. CCP stack of radial component shot gathers corrected using inverse filters generated from cross-correlations between inline traces and ‘stretched’ vertical component traces.

The strength of the event at 800 ms may indicate that the relative shift between corresponding events on vertical and radial component traces has been more robustly corrected when the vertical traces are stretched; but we also see an unexpected problem. It appears that the stretching of the vertical component gathers has led to inverse filters which cause stretching of the radial component traces such that the second prominent converted wave event now appears at about 1400 ms rather than 1200 ms, and all events are visibly lower in frequency than on earlier results (Figures 7 and 8). This is likely due to the fact that a cross-correlation involving a stretched event will naturally be lower in frequency than one involving its unstretched counterpart. We have subsequently learned from our model study, as well, that spurious events, while of concern, can be greatly attenuated by the use of long correlation windows and ‘conditioning’ of the cross-correlations prior to deriving inverse filters (Henley 2009). Thus, stretching vertical component data may be unnecessary.

Raypath interferometry

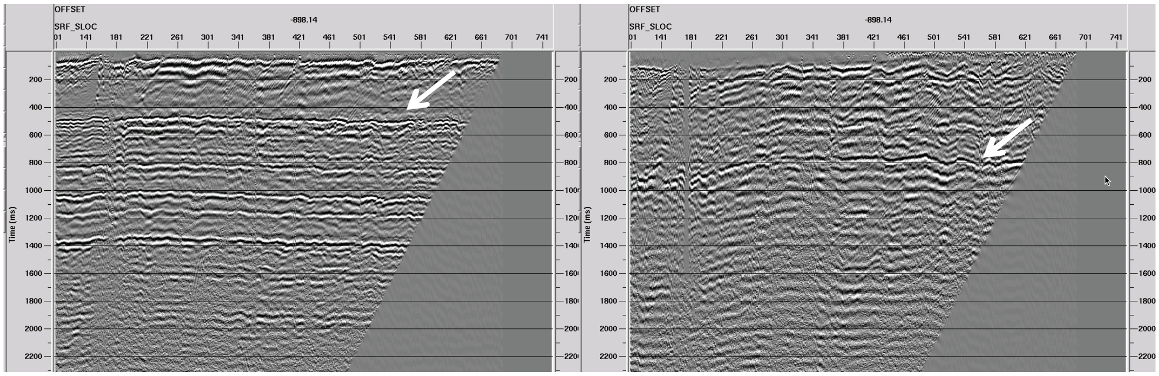
To begin the raypath interferometry procedure, we sort both vertical and radial component data sets into receiver gathers. For surface-consistent statics, each receiver gather will have a common receiver static or static function for all traces; but surface-consistency is *not* a requirement for the procedure. Next, we transform all receiver gathers in both data sets into radial trace gathers, as in Figure 10. Proper choice of RT transform parameters will ensure that almost all vertical component traces have corresponding radial component traces on which converted wave events match vertical component reflection events.



Radial trace transforms of typical vertical component receiver gather (left) and matching radial component receiver gather (right). Arrows marks events to be matched.

FIG. 10. Radial trace transforms of corresponding receiver gathers for vertical component (left) and radial component (right).The arrows mark the reflected event (500 ms) and converted wave event (800 ms), respectively, that are used to match the data. Note that in the radial trace domain, proportionally more reflected event traces have corresponding converted event traces than in the original X-T domain.

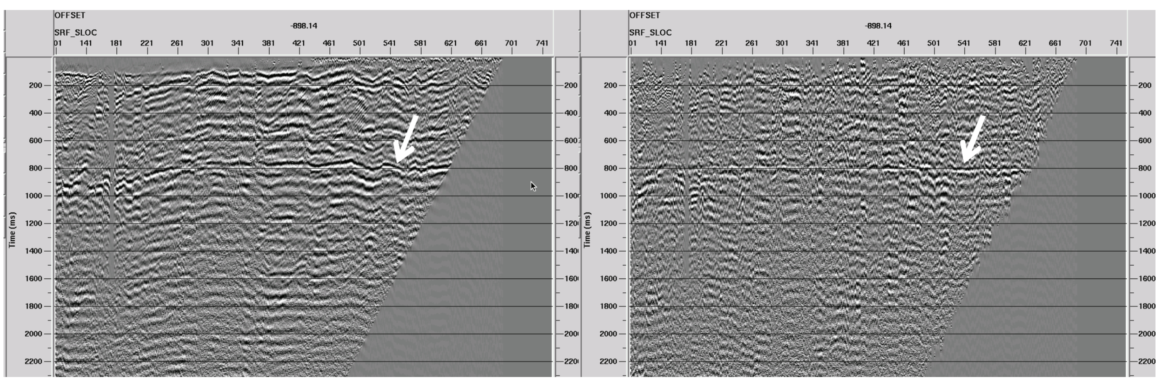
To match vertical and radial component traces by raypath, we need only to sort the RT transforms of each component into common-angle gathers (sort data by apparent velocity and surface location). Figure 11 shows the common-angle gathers for the angle corresponding to the apparent velocity of -898 m/s. Of note is the fact that the S/N of events appears higher on these gathers than on conventional shot gathers as in Figures 4, 5, and 6. Also, the unresolved receiver statics for the inline component are clearly seen.



Common angle gathers for vertical component receiver data (left) and radial component receiver data (right) for angle (apparent velocity) of -898 m/s. Arrows mark event used for match between PP and PS.

FIG. 11. Common-angle gathers for vertical component (left) and radial component (right) for the angle represented by the apparent velocity of -898 m/s. The reflected event (left) and corresponding converted wave event (right) are designated by arrows.

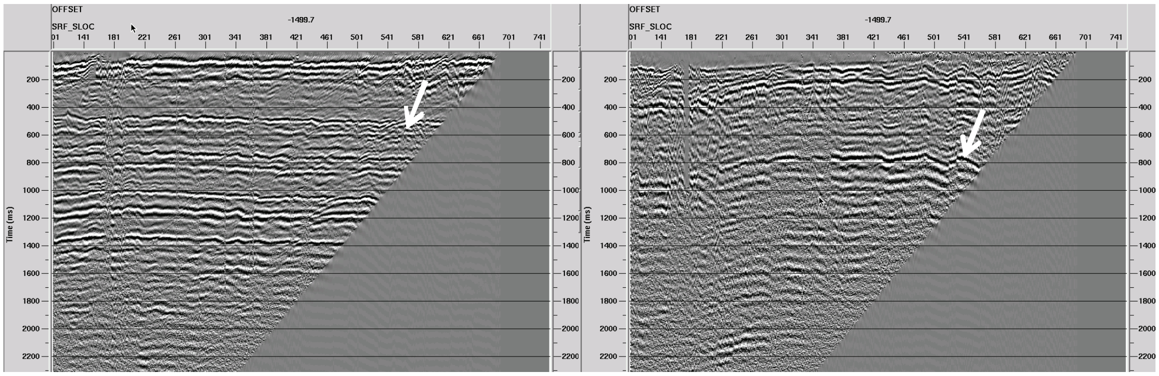
When we cross-correlate common-receiver pairs of the traces in Figure 11, condition the correlations, derive inverse filters, and apply the filters to the inline traces, the result is as shown in Figure 12.



Common angle gather of radial component receiver data for angle of -898 m/s. Raw gather on left, gather corrected with raypath interferometry on right. Arrow marks event matched with vertical component.

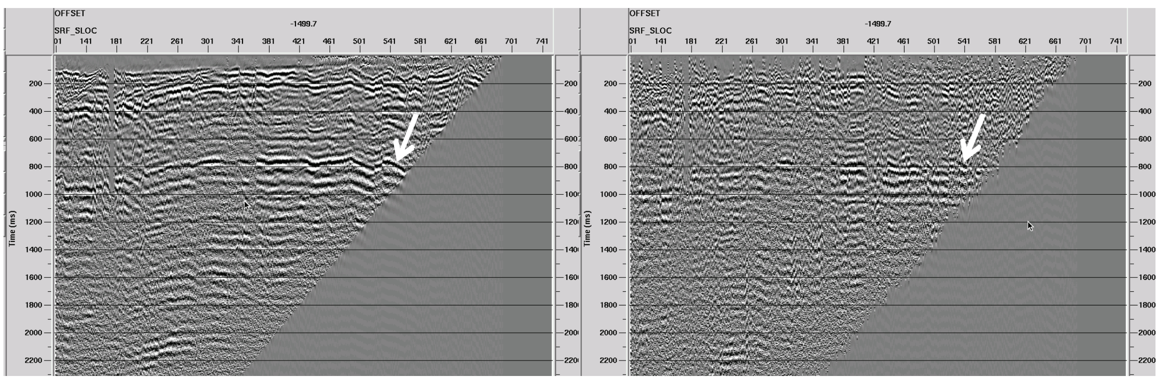
FIG. 12. Common-angle gather of radial component data for angle represented by apparent velocity of -898 m/s before correction by inverse filters (left) and after correction (right).

Figure 13 shows the vertical and radial component common-angle gathers for the angle represented by the apparent velocity -1499 m/s, and Figure 14 shows the radial component common-angle gather before and after inverse filtering.



Common angle gathers for vertical component receiver data (left) and radial component receiver data (right) for angle (apparent velocity) of -1499 m/s. Arrows mark event used for match between PP and PS.

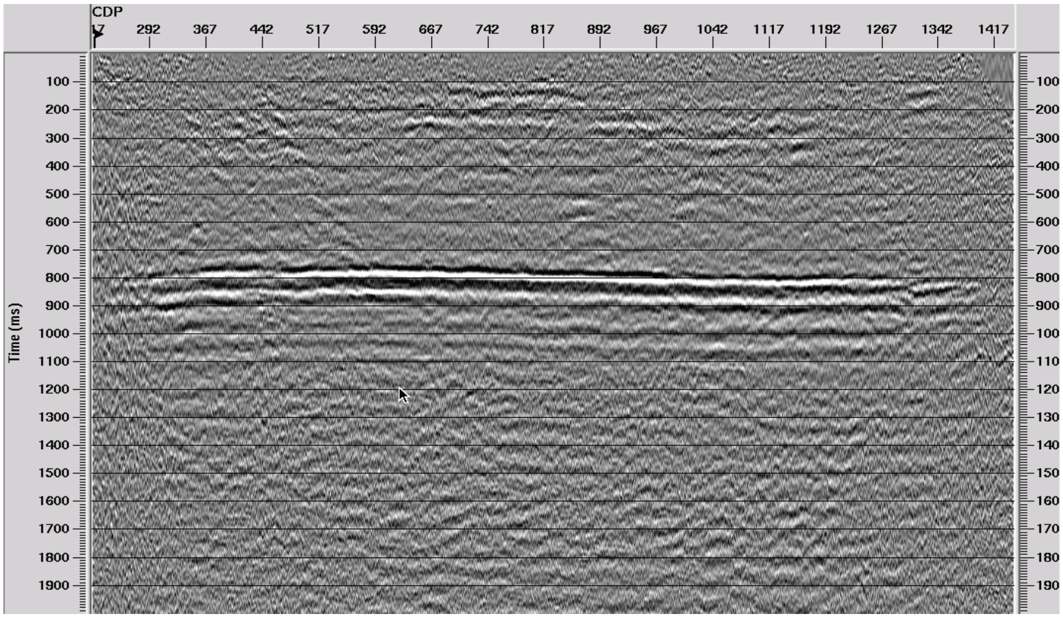
FIG. 13. Common-angle gathers for vertical and radial components for the angle represented by apparent velocity -1499 m/s.



Common angle gather of radial component receiver data for angle of -1499 m/s. Raw gather on left, gather corrected with raypath interferometry on right. Arrows mark event matched with vertical component.

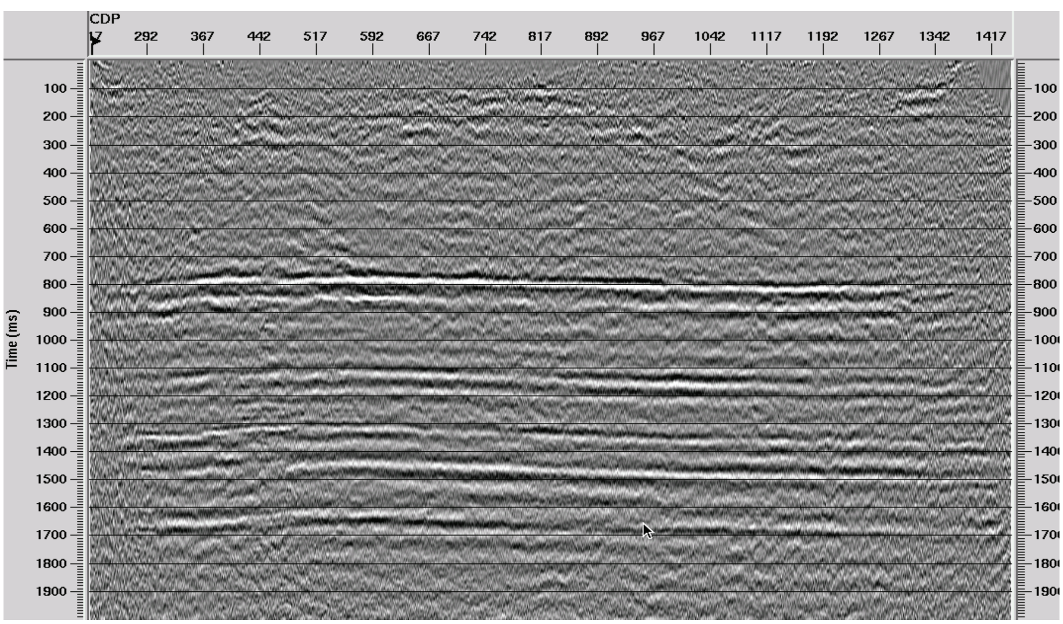
FIG. 14. Common-angle gather of radial component at angle represented by apparent velocity of -1499 m/s before (left) and after (right) correction by inverse filters.

For both these common-angle gathers, the inverse filtering appears to improve the statics visibly. To assess the overall success, however, we must re-sort the common-angle gathers into RT receiver gathers, invert the RT transforms to receiver gathers, then stack the receiver gathers over CCP. This has been done in Figures 15, 16, and 17, each corresponding to a different correlation window length (the length of input traces included in the cross-correlation).



CCP stack of receiver gathers corrected using 'raypath interferometry', 400 ms correlation window. The corrections work best on the event (800 ms) which is centred in the window.

FIG. 15. CCP stack of inline component receiver gathers corrected using 'raypath interferometry'. For this result, a 400 ms correlation window was used—resulting in corrections optimized for the event centred in the window—the 800 ms event.



CCP stack of receiver gathers corrected using 'raypath interferometry', 1000 ms correlation window. The corrections work better for all converted wave events included in the window.

FIG. 16. CCP stack of inline receiver gathers corrected using 'raypath interferometry' with a 1000 ms correlation window. The resulting corrections are better optimized for a larger range of converted wave events.

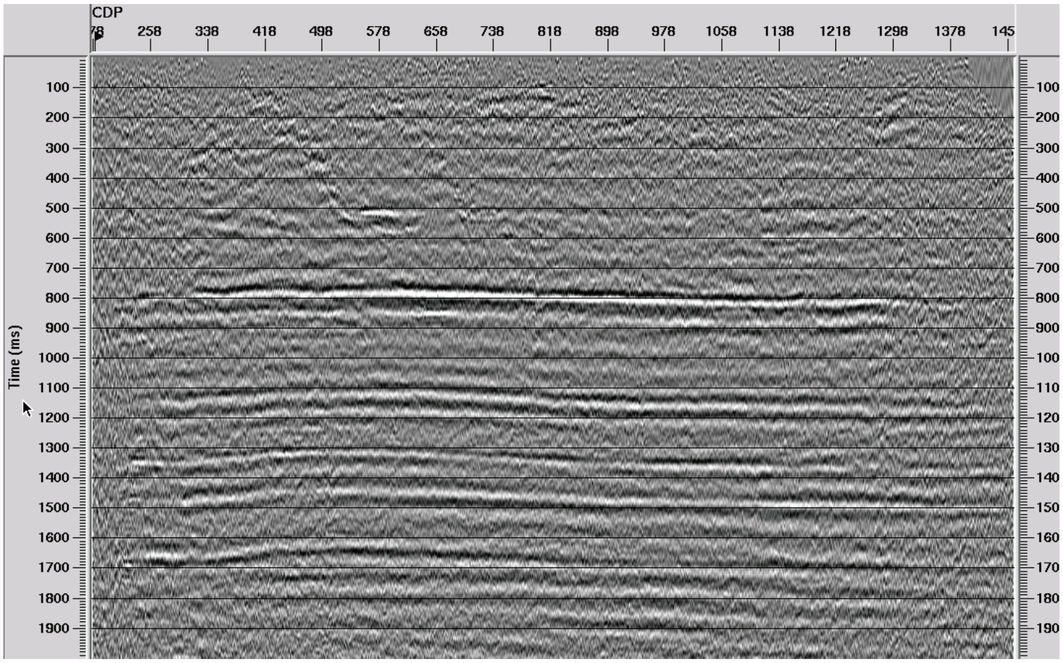


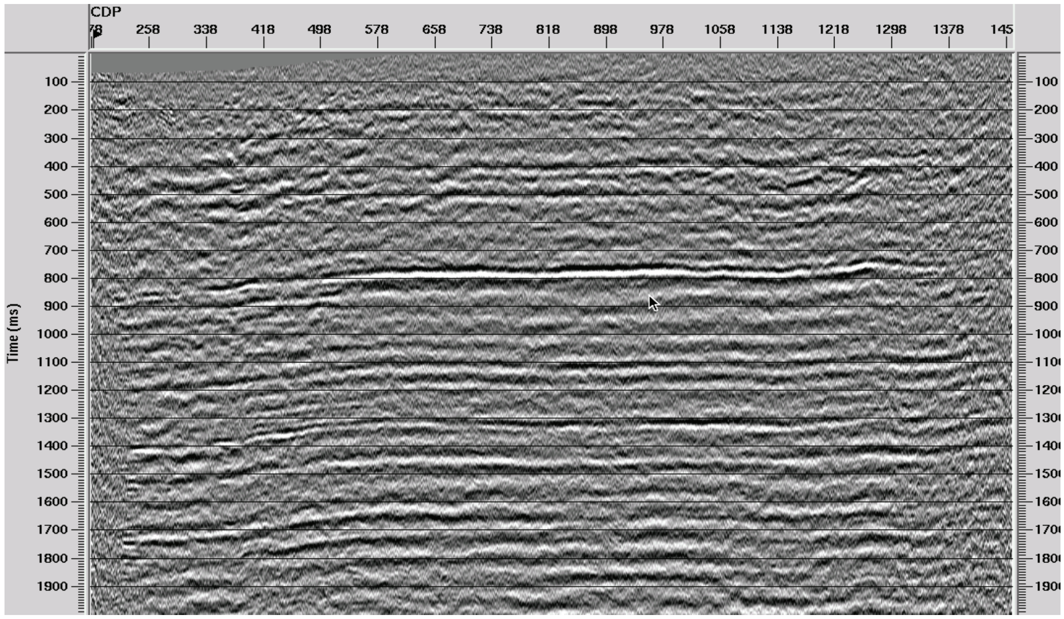
FIG. 17. CCP stack of inline receiver gathers corrected using 'raypath interferometry' with a 2000 ms correlation window. The corrections work well for all converted wave events regardless of depth.

DISCUSSION AND CONCLUSIONS

From the results presented above, we conclude that 'hybrid interferometry' appears to be a viable technique for removing the receiver statics affecting converted wave data. In order to apply the method, the vertical component (PP-wave) data must first be properly corrected for their own statics, and NMO velocities for both vertical and inline component data should be reasonably good. Although shot gathers from vertical and radial components can be used to generate the cross-correlations required for the statics deconvolution, it is difficult to get good correlations for many pairs of traces. A more robust technique is the 'raypath interferometry' method, which, because of the inherent redundancy and geometry of the radial trace transform, leads to many more cross-correlations for deriving inverse filters. In addition, the S/N is sometimes higher on an individual common-angle gather than on the original shot gathers which contributed to the common-angle gather, leading to more robust cross-correlations and inverse filters.

FUTURE PROMISE

Late in our investigation, an attempt was made to produce the best currently possible converted wave stack using hybrid raypath interferometry, a picked reference horizon on the P-wave section (Figure 1) to partially restore structure, and post-stack deconvolution and FX deconvolution to increase the bandwidth and enhance resolution. This result is very preliminary, but is shown in Figure 18 as a hint of what may be possible when we further refine the method.



CCP stack of receiver gathers after raypath interferometry—2000 ms correlation window. PP reflection horizon structure added. Post-stack Gabor deconvolution, FX decon.

FIG. 18. CCP stack of receiver gathers after raypath interferometry using 2000 ms correlation window (400 ms correlation length). The structure was partially restored via a picked horizon on the PP-section in Figure 1, and the section was whitened post-stack via Gabor deconvolution.

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