Deconvolution in the radial trace domain

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ABSTRACT

The radial trace (R-T) domain has been shown to be useful for coherent noise attenuation and other seismic wavefield separation operations because of the particular geometric distortion produced by the R-T transform. The same distortion also means that the R-T domain is better suited for deconvolution than the X-T domain, because R-T raypaths more nearly satisfy the assumptions of the standard convolutional model. A comparison between deconvolution results computed in the X-T domain and those computed in the R-T domain for the same Blackfoot shot gather highlights some of the expected advantages of R-T domain deconvolution.

INTRODUCTION

Radial trace domain techniques for attenuating coherent noise in seismic data were introduced by Henley (1999; 2000; 2003), based partly on earlier work by Claerbout (1975; 1983), who introduced the radial trace (R-T) transform primarily for use in migration and related imaging algorithms. R-T coherent noise attenuation techniques rely on the fact that separation of linear noise from reflections can be achieved in the radial trace domain by aligning the transform coordinate trajectories with the coherent noise wavefronts in the X-T domain. Part of the geometric effect of the transform is to remap the wavefield so that samples associated with a single trace are more closely associated with a single outgoing raypath and parallel reflecting raypaths. The trace then more nearly fits the assumptions of the convolutional model.

The standard convolutional model, upon which most efforts to increase the temporal resolution of seismic data are based, is essentially a 1-dimensional model which assumes that a seismic signal is transmitted and reflected along a single raypath. For all seismic data except those recorded at normal incidence, however, the single raypath model is not appropriate. When X-T domain seismic data are mapped to the R-T domain, the raypaths associated with the new domain simulate a geometry which more nearly corresponds to the convolutional model. Hence, the R-T domain should be better in some respects than the X-T domain for applying deconvolution operations. Taner (1980) showed that predictive deconvolution is more effective in the R-T domain than in the X-T domain for removing long-period surface multiples, because of the common raypath segments and reflection points shared by primary and multiple. Here, it is shown that Gabor deconvolution (Margrave, 2001), seems marginally more effective in the R-T domain, particularly in the presence of various noises associated with an X-T domain shot gather.

DECONVOLUTION IN THE R-T DOMAIN

The schematic raypath diagram shown in Figure 1 corresponds to the seismic record obtained from one geophone. This represents the situation for any trace of an X-T source gather. Each individual reflection is associated with a distinct raypath, only one reflection per raypath. Figure 2, however, depicts the raypaths associated with one trace of an R-T transform. In this case, all the reflections on the trace are associated with a single descending raypath and parallel reflecting raypaths whose corresponding segments are of the same length.

The simple one-dimensional convolutional model of a seismic trace assumes that energy propagates along a single raypath, with portions of the energy being reflected back along the incident raypath from each interface in the earth. Since this can only be true for a normally incident ray, most of the traces in a standard X-T gather do not fit this model, but represent a sum over incident angle of numerous raypaths like those shown in Figure 1. The coincident downward raypath segments of an R-T gather (Figure 2) correspond more nearly to the single outgoing raypath of the convolutional model; and the upward-travelling segments mirror the downward ones in length and angle (even though they don't physically coincide) so that reflection travel times and amplitudes are appropriately preserved. If an accurate velocity function is used in the R-T mapping (an option available in the ProMAX *radial trace transform* module), deconvolution in this domain can potentially recover accurate reflectivity as a function of angle. The geometric relationship portrayed in Figure 2 also suggests that raypath segments within particular layers have a common angle, which implies that all orders of interbed multiples should have exact time delays and geometric amplitude ratios on radial traces and thus be susceptible to predictive deconvolution for their removal, following Taner (1980).

To explore the differences in deconvolution results due to trace geometry, a familiar shot gather from the Blackfoot seismic survey was deconvolved using the Gabor deconvolution algorithm with Lamoureux windows. The gather and its R-T transform are shown in Figures 3 and 4, respectively. The gather was deconvolved both in its normal X-T presentation and in the R-T domain. In both instances, exactly the same parameters were used in the deconvolution. Figures 5, 7, and 9 show the gather and two zoomed enlargements after Gabor deconvolution in the X-T domain, while Figures 6, 8, and 10 show the same gather and zoomed versions after Gabor deconvolution in the R-T domain. The raw shot gather was used as input, so direct arrivals, refractions, ground roll, and other coherent noises were all present before deconvolution. In addition, in the X-T domain, linear moveout was applied to the gather to align the arrivals horizontally before deconvolution, then removed. It can be seen in Figures 5 and 6 that Gabor deconvolution is very effective in removing the ground roll, whether applied in the X-T domain or the R-T domain. Only in the R-T domain, however, is the direct arrival and refraction energy significantly attenuated (the noise reduction in both domains is due primarily to the action of the bandlimited deconvolution operator as a low-cut filter).

The R-T domain deconvolution appears somewhat noisier overall, but there are several interesting features of this deconvolution result that should be noted. Because the direct arrivals and refractions have been significantly attenuated, the shallow reflections can be observed at greater offsets on the R-T domain deconvolution (Figures 7 vs. 8, Figures 9 vs. 10), and the relative amplitudes of these reflections with respect to deeper reflections is significantly greater on the R-T domain deconvolution (Figures 7 vs. 8, Figures 9 vs. 10).

Figure 11 shows a close-up of a small portion of the gather deconvolved in the X-T domain, while Figure 12 shows the comparable portion of the R-T domain result. Two features of particular interest are highlighted by the ellipses and arrows. Inside the ellipse, it can be seen that the X-T domain deconvolution appears to manifest high frequency 'ringing' over a relatively small range of offsets for this reflection sequence, while the R-T domain deconvolution shows no such effect, but simply an apparent strengthening of the reflection amplitudes in this zone. Perhaps this particular range of offsets 'tunes' an interbed multiple for this reflection sequence, which is amplified by the whitening of the deconvolution, and the R-T domain geometry is more effective for attenuating it. The arrow in both figures indicates a trace that is dominated by 60 Hz noise on the raw shot gather. While it yields partially to deconvolution in the X-T domain, it is more effectively handled in the R-T domain, where the input trace is distributed across a number of R-T traces. The reconstituted trace in Figure 12, although diminished in amplitude, appears to conform better in character to neighbouring traces than its counterpart in Figure 11. In contrast to these notable differences, other comparable events in Figures 11 and 12 appear very similar in character and bandwidth. This gives further credibility to the idea that the highlighted differences are, in fact, geometry-related, and that the R-T domain deconvolution is the more correct approach.

A PROCESSING CAVEAT

Although it may sometimes be desirable to apply deconvolution in the R-T domain, care should be taken to assess the computation time required for the specific deconvolution algorithm used, since a well-sampled R-T transform usually produces an order of magnitude more output traces than input. For a relatively time-consuming algorithm like Gabor deconvolution, expanding the input gather to the R-T domain, may prove prohibitively time-consuming, unless the R-T domain deconvolution is undertaken for diagnostic purposes only, on a limited number of input trace gathers.

PROMAX MODULE MODIFICATIONS

Since the *radial filter* module maintains a complete internal representation of the input X-T trace panel, the original panel, with selected regions modified by filtering in the R-T domain can be easily reconstructed. The *radial trace transform* module itself, however, has no such provision, since the forward output consists of radial traces only, with mostly dummy trace headers. It may be desirable to transform radial traces back to the X-T domain, however (when applying deconvolution in the R-T domain, for example). The new version of the *radial trace transform* module stores the minimum and maximum offset values in the unused SOU_X and REC_X trace headers, respectively, of the radial traces. When the module is used to compute the inverse transform, default (zero) values for minimum and maximum offset parameters cause the algorithm to construct a set of linearly distributed offsets between the minimum and maximum values stored in SOU_X and REC_X. No matter what the actual distribution of offsets in the original X-T panel, however, the output X-T panel will always have linearly distributed offsets.

CONCLUSIONS

Because of the differences in the raypath geometries represented by X-T gathers and R-T gathers, R-T traces may more closely conform to the assumptions of the convolutional model than X-T traces. Interesting differences observed between R-T domain and X-T domain deconvolutions of a shot gather lend support to this idea. Although computation times can be large for R-T domain deconvolution, with appropriate deconvolution parameters, coherent noise attenuation can be accomplished simultaneously while in the R-T domain.

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REFERENCES

Claerbout, J.F., 1975, Slant-stacks and radial traces, Stanford Exploration Project Report, SEP-5, 1-12.

Claerbout, J.F., 1983, Ground roll and radial traces, Stanford Exploration Project Report, SEP-35, 43-53.

Henley, D.C., 1999a, Coherent noise attenuation in the radial trace domain: introduction and demonstration, CREWES Research Report Vol. 11.

Henley, D.C., 1999b, Demonstration of radial trace domain filtering on the Shaganappi 1998 2-D geotechnical survey, CREWES Research Report Vol. 11.

Henley, D.C., 1999c, Radial trace computational algorithms at CREWES, CREWES Research Report Vol. 11.

Henley, D.C., 2000a, Wavefield separation in the radial trace domain, Geo-Canada 2000, Expanded Abstract No. 131

Henley, D.C., 2000b, More radial trace domain applications, CREWES Research Report, Vol. 12.

Henley, D.C., 2003, Coherent noise attenuation in the radial trace domain, Geophysics, Vol. 68, No. 4, pp 1408-1416.

Margrave, G.F., 2002, Gabor deconvolution, CREWES Research Report, Volume14.

Taner, M.T., 1980, Long-period sea-floor multiples and their suppression, Geoph. Prosp Vol. 28, 30-48.

FIGURES

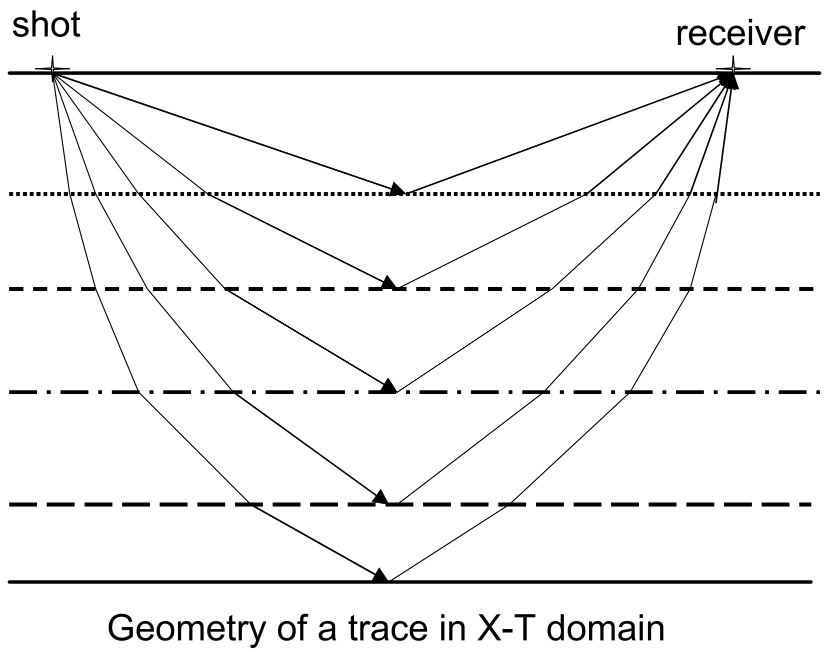

FIG. 1. Raypaths involved in observing reflections on a seismic trace recorded by a single receiver.

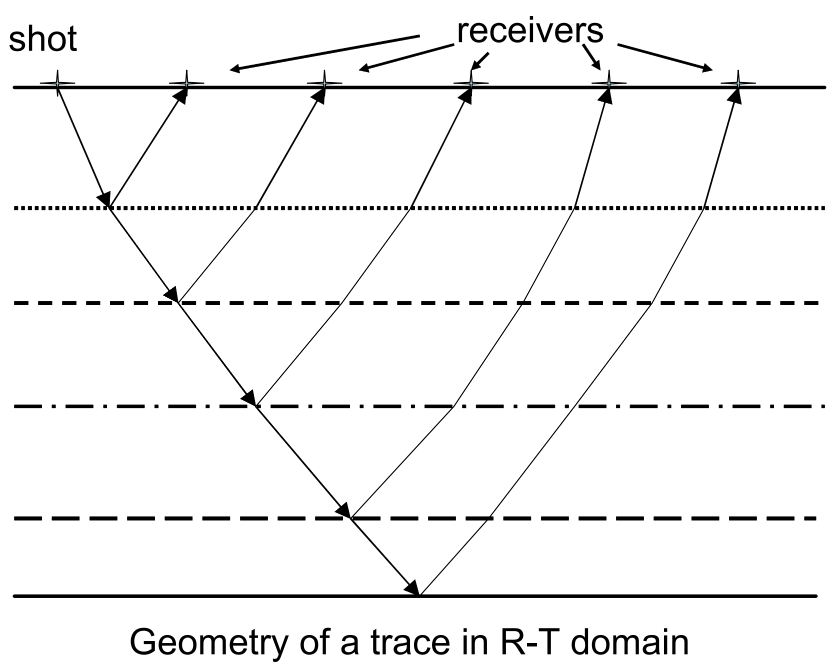

FIG. 2. Raypaths involved in observing reflections on a single radial trace. Note that the downgoing raypath is common to all reflections, and upgoing raypaths are all parallel, a closer approximation to the assumptions in the convolutional model.

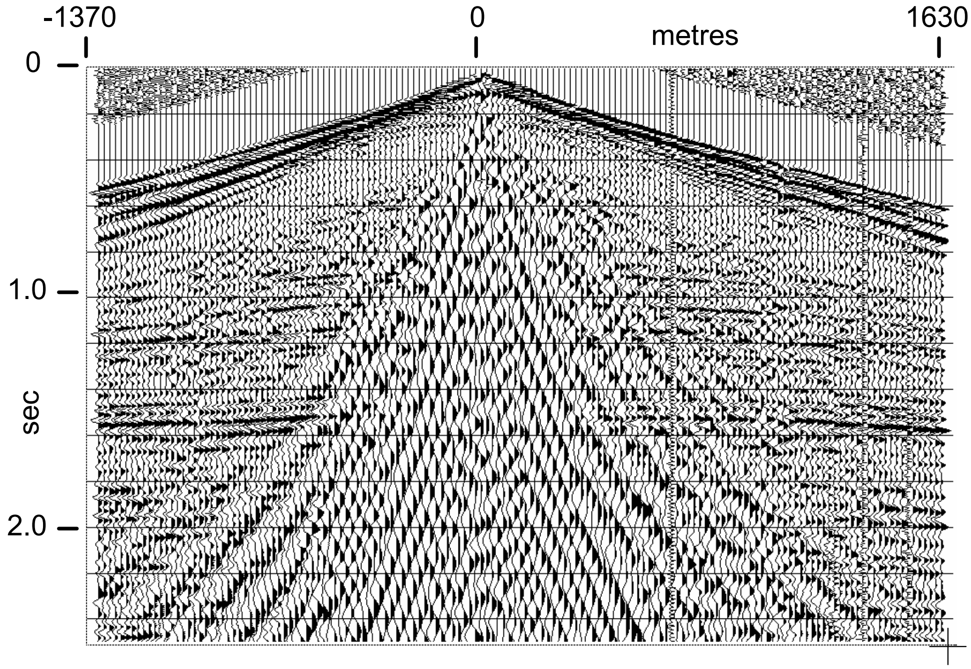

FIG. 3 Raw shot gather from the Blackfoot 2D survey

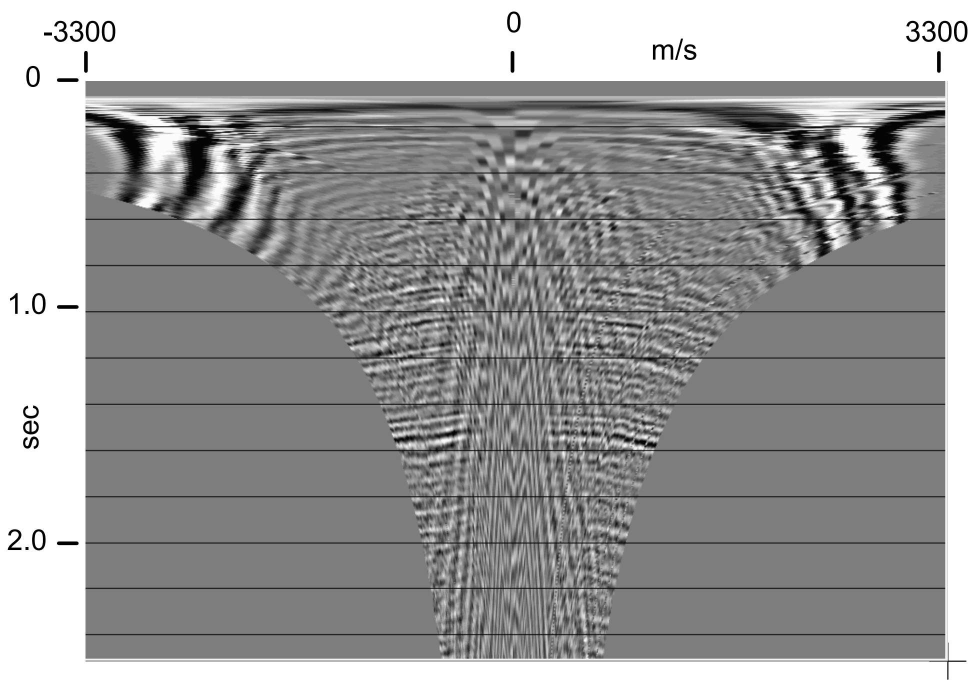

FIG. 4. R-T fan transform of raw Blackfoot shot gather

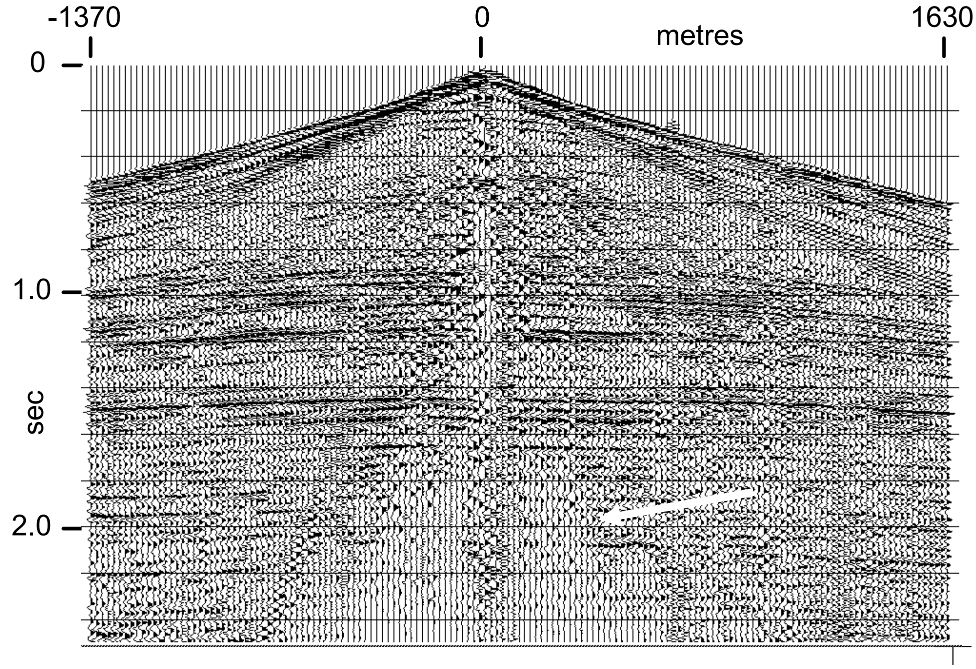

FIG. 5. Blackfoot shot gather after Gabor deconvolution in the X-T domain. Low frequency shot-generated noise is attenuated (white arrow), but direct arrivals still present.

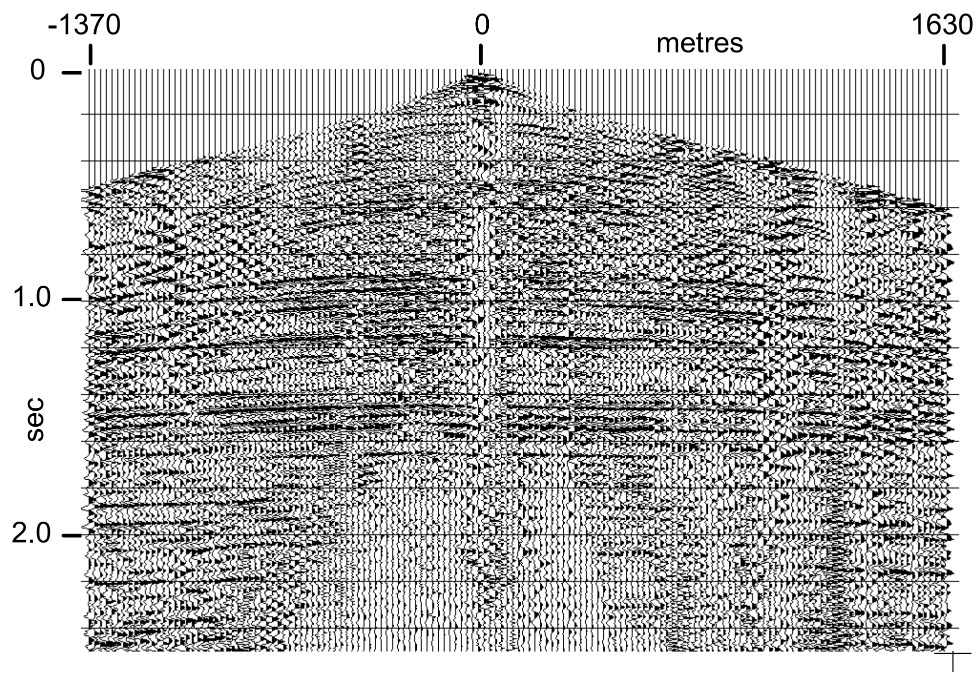

FIG. 6. Blackfoot shot gather after Gabor deconvolution in the R-T domain. Direct arrivals are greatly diminished.

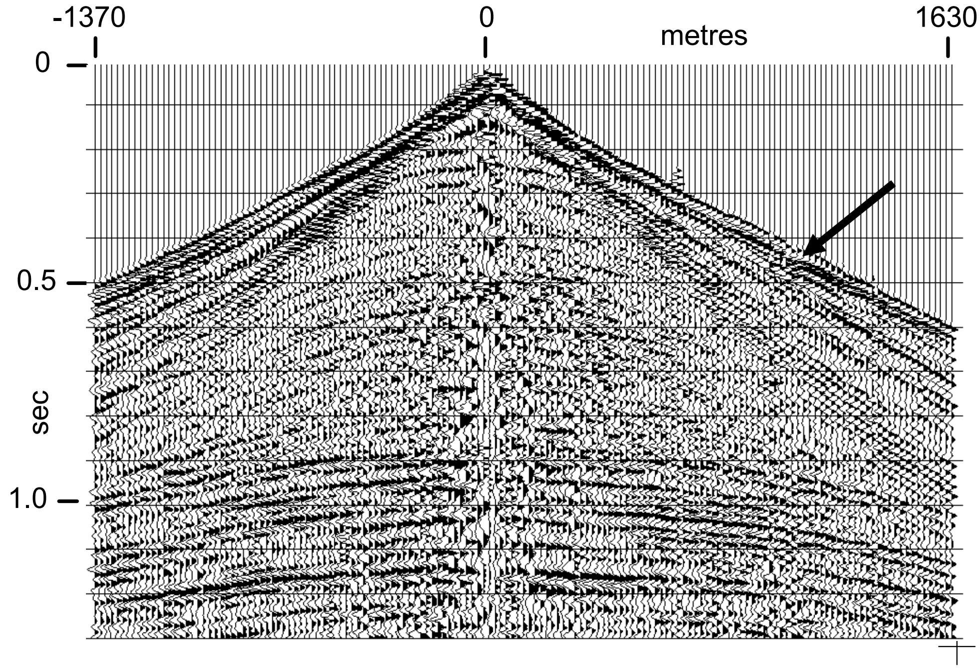

FIG. 7. Zoom of deconvolved gather in Figure 5. Direct arrivals still present (arrow).

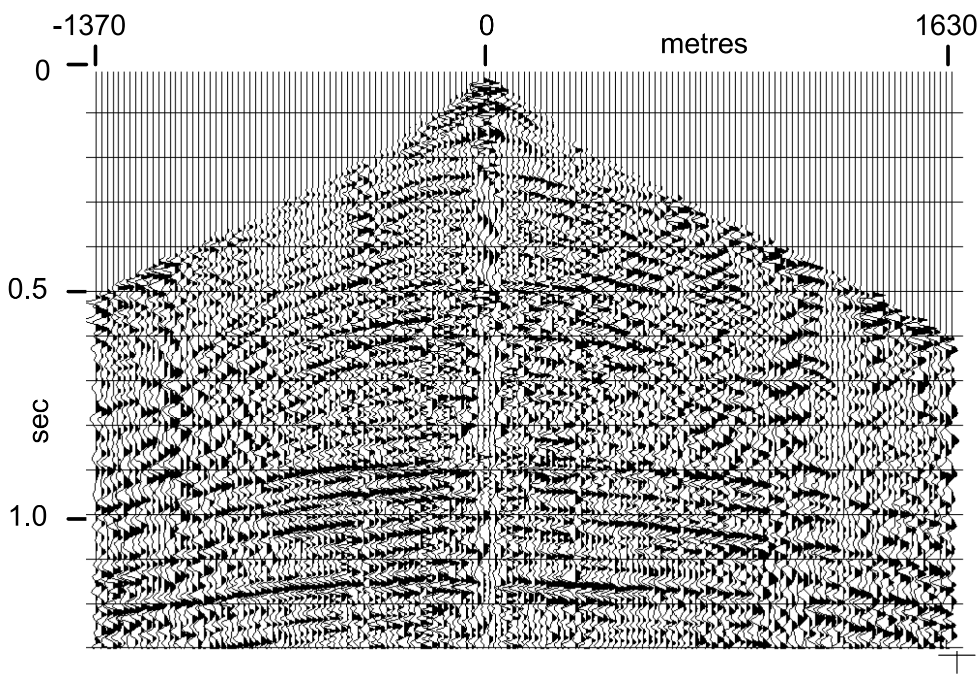

FIG. 8. Zoom of the gather in Figure 6. Compare with Figure 7. Direct arrivals greatly attenuated, amplitudes of shallow reflections no longer dominated by these arrivals.

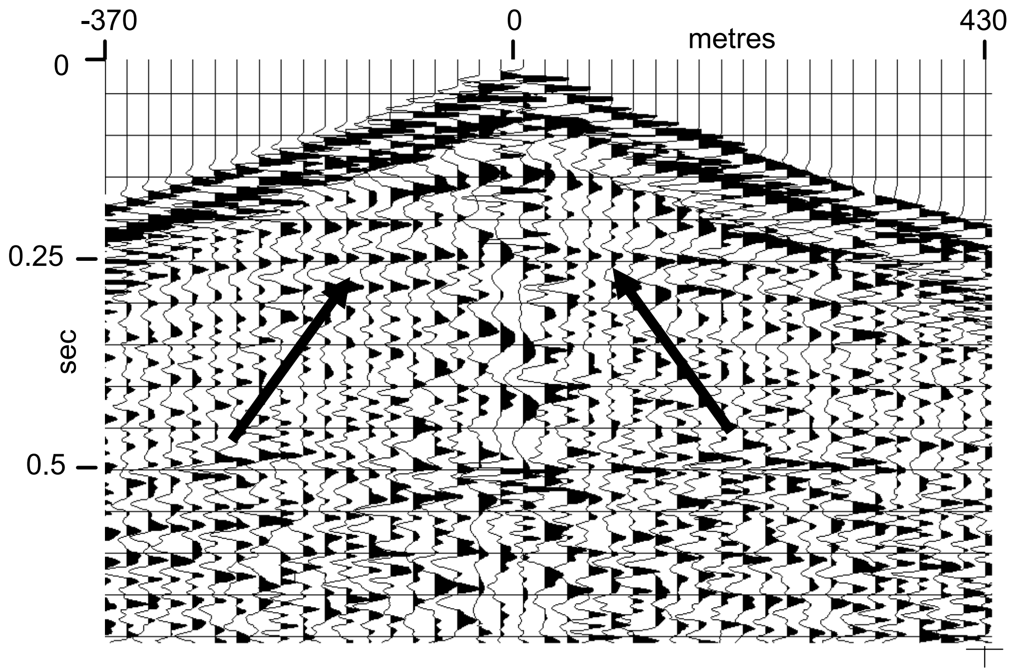

FIG. 9. A closer zoom of deconvolved gather in Figure 5. Shallow reflection (arrows) loses amplitude with offset and is obscured by much stronger first arrivals.

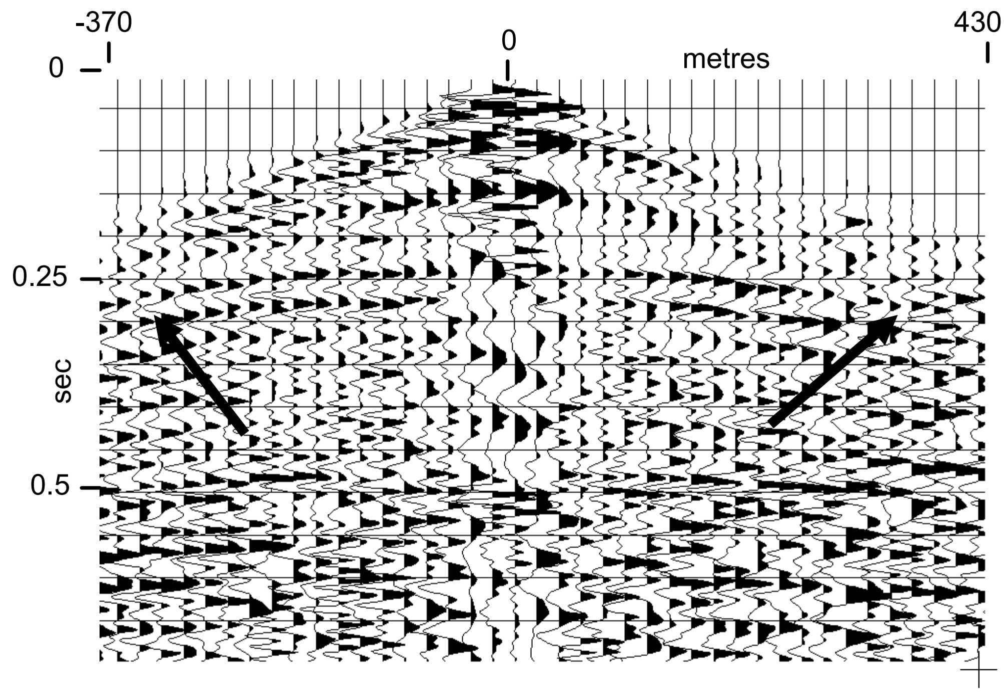

FIG. 10. A closer zoom of Figure 6. Shallow reflection (arrows) now extends further and is stronger in amplitude.

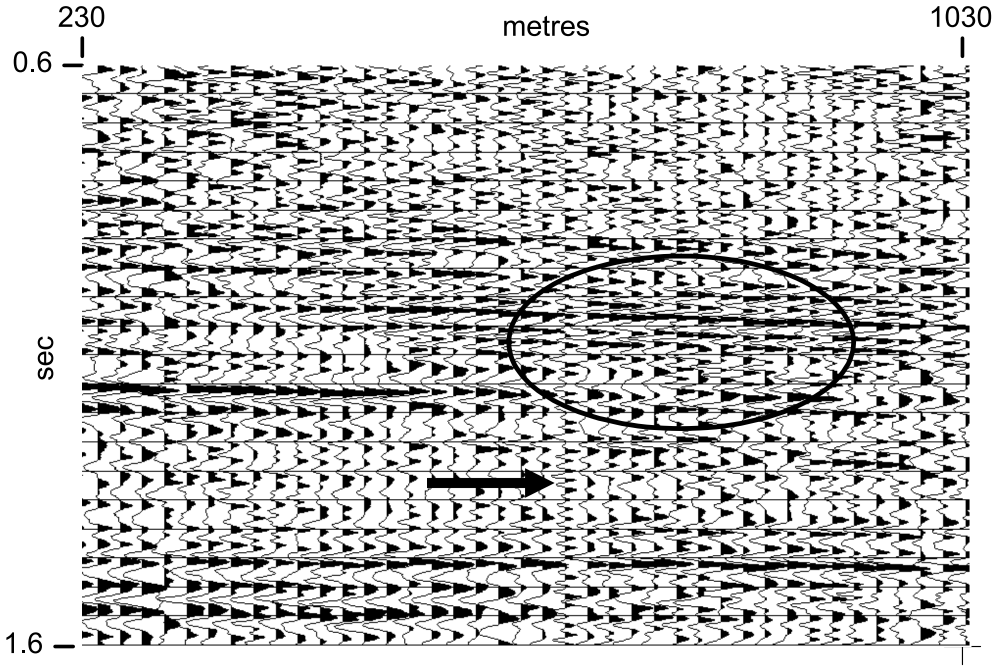

FIG. 11. Close-up of X-T domain deconvolution. Outlined events appear to have ringing, possibly due to interbed multiple tuned at these offsets. Noisy trace (arrow) remains mostly noise.

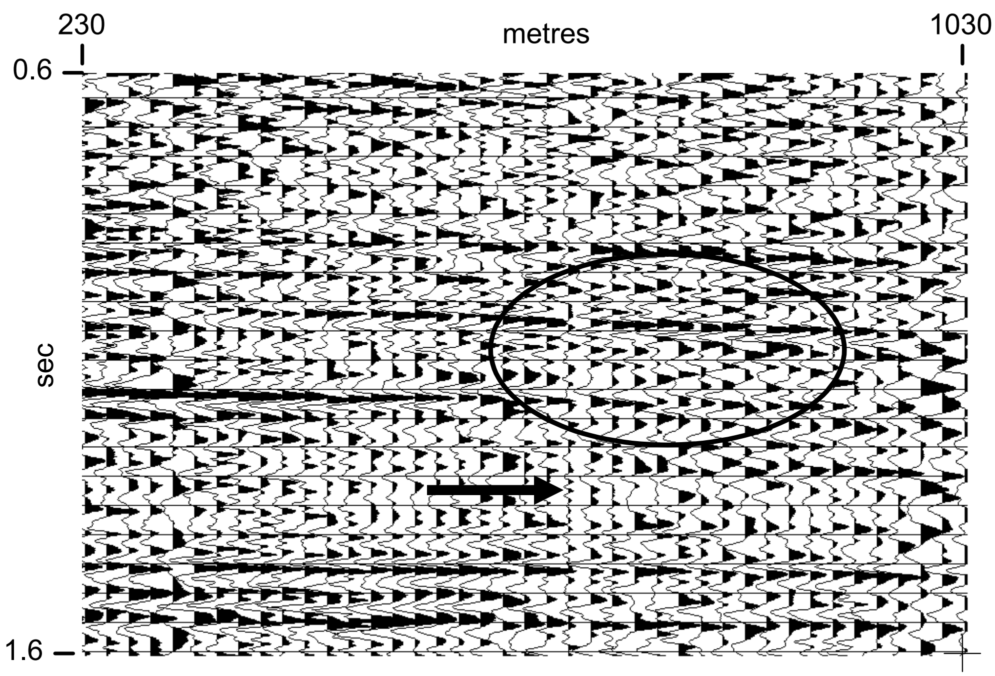

FIG. 12. Close-up of R-T domain deconvolution. Outlined events do not ring, noisy trace has at least some signal restored.