Advances in radial trace domain coherent noise attenuation

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ABSTRACT

The radial trace transform, introduced by Jon Claerbout and the Stanford Exploration Project, produces significant separation, in its coordinate space, of reflection signal and coherent noise. This allows effective attenuation of the noise using a variety of ordinary single trace operations in the radial trace domain.

Recent experience has shown that one of the more effective techniques for coherent noise attenuation is to model the noise by applying a low-pass filter to the radial trace transform of an input gather, then to subtract the inverse transformed ‘modeled noise’ from the original input gather.

Interpolation is an integral part of the discrete radial trace transform. Several alternative interpolation algorithms are possible, however, and some can lead to better modelling of coherent noises in the radial trace domain for subsequent subtraction from the input.

The Shaganappi high resolution seismic survey, appearing in earlier work to demonstrate radial trace noise attenuation, is utilised once again to illustrate the improved performance of current radial trace techniques and to compare results with those from more conventional K-F filtering.

Introduction

Techniques for attenuating coherent noise in seismic data were introduced by Henley (1999, 2000), based on earlier work by Claerbout (1975, 1983), who introduced the radial trace transform primarily for use in migration and related imaging algorithms. Radial trace (R-T) noise attenuation techniques utilise the separation of linear noise from reflections achieved in the R-T domain when the transform coordinate trajectories are properly aligned with the coherent noise wavefronts in the X-T domain. A linear noise distributed across many traces of an X-T gather maps into relatively few radial traces; and the apparent frequencies of these noise traces shift from the seismic band to sub-seismic frequencies (Henley, 1999). Both these effects of the R-T transform can be used to attenuate the noise relative to reflection signal in the R-T domain. As well, the R-T transform algorithm itself can be tailored to enhance chosen components of the X-T domain wavefield.

Effective Coherent Noise Attenuation

The most straightforward way to attenuate coherent noise in the R-T domain is to apply a high-pass (low-cut) filter to the radial traces, which directly suppresses coherent noises mapped by the R-T transform to sub-seismic frequencies. Applying a low-pass filter to the same radial traces, however, estimates or 'models' this coherent noise, whose inverse R-T transform can then be subtracted from the input data. Equivalent in theory, actual practice usually shows visible differences between the two approaches due to numerical computation differences. Experience has shown that the low-pass model-and-subtract method is preferable on most data; reflection bandwidth appears to be less affected by this approach, and lateral geological features and other spatial wavefield discontinuities like statics are left intact.

V-Interpolation

Interpolation is the means by which radial trace sample values at R-T grid points not coincident with the X-T grid are evaluated from nearby X-T sample values. The choice of neighbouring X-T sample values to use in the estimation of a particular R-T sample can greatly influence which X-T wavefield events are best captured or enhanced in the R-T transform, as shown by Claerbout (1983) and Brown and Claerbout (2000). In general, horizontal or reflection-like events are preferred, so interpolation is usually done horizontally (X-direction) in both the forward and inverse R-T transforms. However, to capture non-horizontal linear events, which are often horizontally aliased, interpolation parallel to these events along the radial trace trajectory direction (V-interpolation), can be useful. In some cases, such interpolation can provide a better estimate of aliased, low velocity linear events than the usual X-interpolation.

Fig. 1 shows the difference between X-interpolation and V-interpolation. In *Fig. 1a*, radial trace samples are evaluated at two R-T grid points which fall between traces in the X-T domain. Since, by definition, R-T sample times are the same as those of the original X-T trace samples, each new sample value is determined by interpolation between the two nearest X-T trace samples at the same travel time. This constitutes X-interpolation. Figure 1b, on the other hand, illustrates the two step process used to evaluate the same R-T samples by interpolation along the R-T trace direction (V-interpolation). First, the point at which the R-T trajectory intersects each of the two nearest X-T traces is determined. At each of these two points, the wavefield value is determined by linear interpolation of the X-T trace samples above and below the point. The intersection points define the endpoints of a segment of the R-T trace, and the desired R-T sample values lying on this segment are evaluated by linear interpolation from the segment endpoint values to the sample positions at the intersections of the R-T trajectory with the time grid.

Shaganappi Then And Now

When R-T filtering was first introduced as a coherent noise attenuation technique in 1999, the Shaganappi high-resolution seismic data survey was used to illustrate the effectiveness of multiple passes of R-T filtering on very noisy data (Henley, 1999). *Fig. 2* shows representative raw shot gathers on which linear noise totally obscures any reflections. The result of applying several R-T filter passes to the same shot gathers is shown in Figure 3. All the filters were simple low-cut filters in the R-T domain, where each R-T transform was designed to best capture and attenuate a particular linear noise mode. As can be seen, the results show some remaining linear energy as well as some undesirable lateral smear.

To illustrate first the effectiveness of V-interpolation for estimating aliased linear noise, *Fig. 4* shows the four gathers from *Fig. 2* after application of a R-T dip filter designed to subtract the 300 m/s air blast from the raw shot gathers, where standard X-interpolation was used. In contrast, *Fig. 5* shows the improved results obtained by using V-interpolation in the 300 m/s dip filter.

This filter pass was only the first of six R-T noise subtraction filters applied to the gathers. Figure 6 shows a raw shot gather on the extreme left followed by the results of six successive passes of R-T subtraction filters. Note the emergence with successive filter passes of shallow hyperbolic events at 80 and 150 ms, as well as deeper flat events (650 and 950 ms) that are all likely reflections. Note, as well, that there is no smeared look to the gather as it emerges from all these filter passes, in contrast to earlier results (*Fig. 3*).

An attempt to achieve a similar result with K-F filtering is documented in *Fig. 7*. Here, the raw shot gather on the left is followed by the R-T filtered version, then the K-F filtered version. The K-F filtered gather was obtained from the successive application of two different K-F filters, one to pass only velocities associated with reflection events, the other to reject velocities characteristic of the direct arrival and refractions that mask the shallow reflections. As can be seen, in spite of considerable effort to obtain the best possible K-F results, the R-T filtered results appear superior.

The true test of coherent noise filtering, however, is whether the stack is improved by the filtering. *Fig. 8* shows the stack of unfiltered shot gathers for comparison, while *Figs. 10 and 11* are the stacks of R-T filtered and K-F filtered results, respectively. Most of the coherent event energy on the unfiltered stack (*Fig. 8*) is due to refraction events with nearly the same moveout as the underlying hyperbolic events. The K-F filtered result in *Fig. 10* clearly retains more of this refracted energy than does the R-T filtered section in *Fig. 9*. In addition, the R-T filtered section shows more detail, particularly in the shallow portion, and has a more “geologic” look to it, particularly near the centre of the section where some faint apparent diffractions can be seen. The point should be made, as well, that the NMO velocities used for all three sections were obtained from analysis of the R-T filtered data, since no reflections could be clearly identified on the unstacked raw or K-F filtered data.

Conclusions

The practice of R-T filtering has been advanced by experience as well as by an algorithm enhancement. Subtraction of noise modelled in the R-T domain appears to be the most generally effective and least damaging technique for coherent noise removal. An alternative interpolation method for the R-T transform sometimes yields a better estimate of low-velocity partially aliased linear noise for subsequent removal. In some cases, R-T filtering outperforms K-F filtering.

Acknowledgements

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References

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Figures

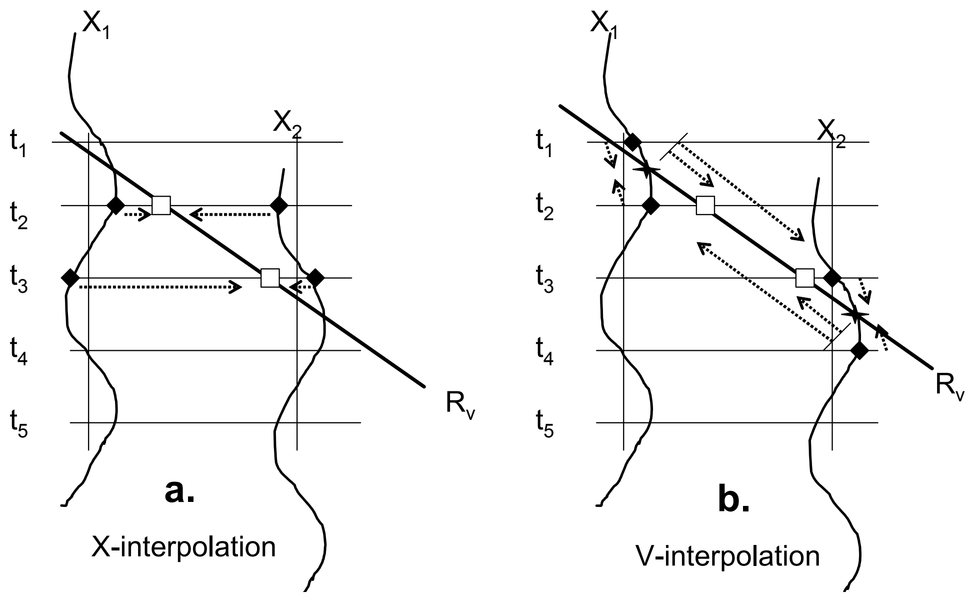

*Fig. 1. The difference between X-interpolation and V-interpolation **a**.) R-T values (white squares) are found by interpolating the samples (black diamonds) from traces at X_1 and X_2 to the points at which the R-T trajectory intersects the common time grid. **b**.) R-T samples are obtained by interpolating between values (black stars) on the R-T trajectory at the intersections with traces X_1 and X_2. These (black star) values are first interpolated from the trace samples at the nearest sample times (t_1 and t_2 for the trace X_1 and t_3 and t_4 for the trace X_2).*

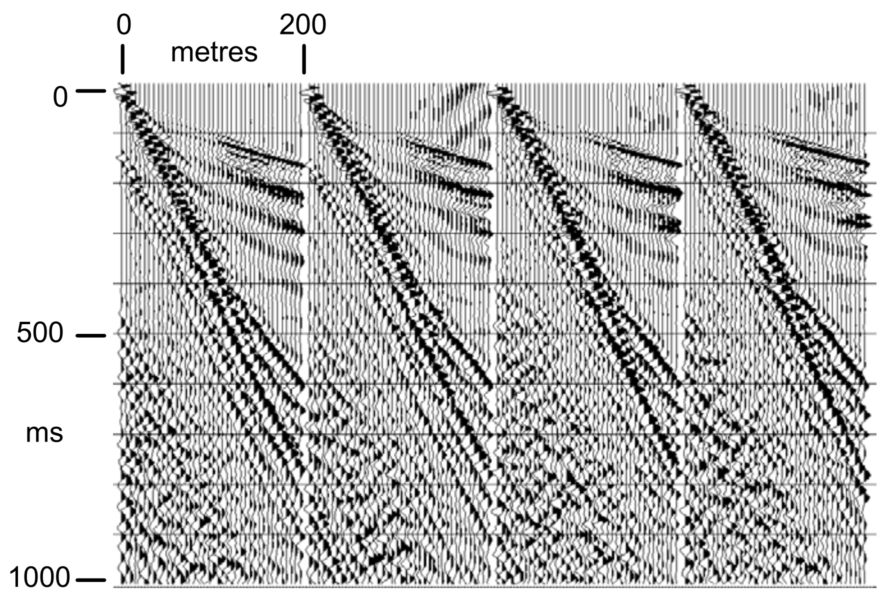

Fig. 2. Raw shot records from the Shaganappi high-resolution survey. Reflections are invisible on these records.

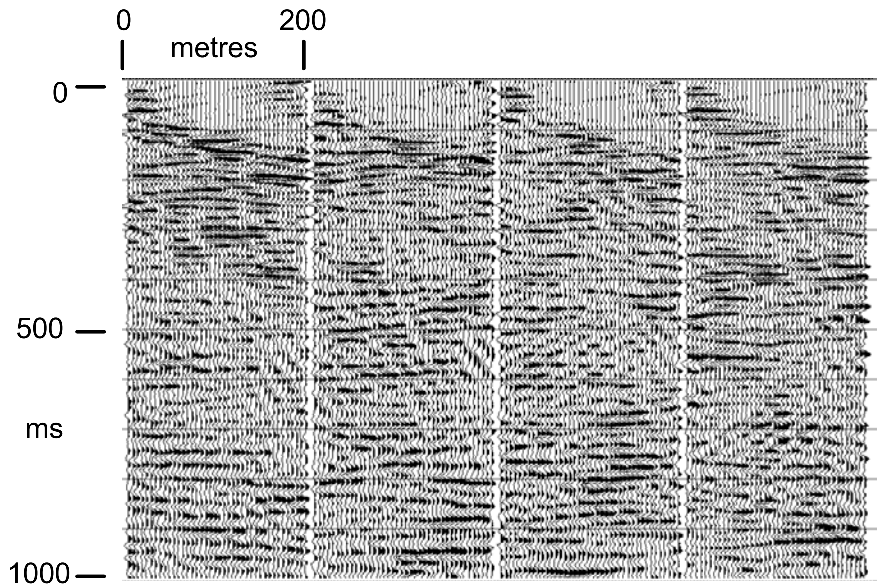

Fig. 3. Shaganappi shot gathers filtered using a cascade of "old" R-T filter passes (low-cut filter in the R-T domain).

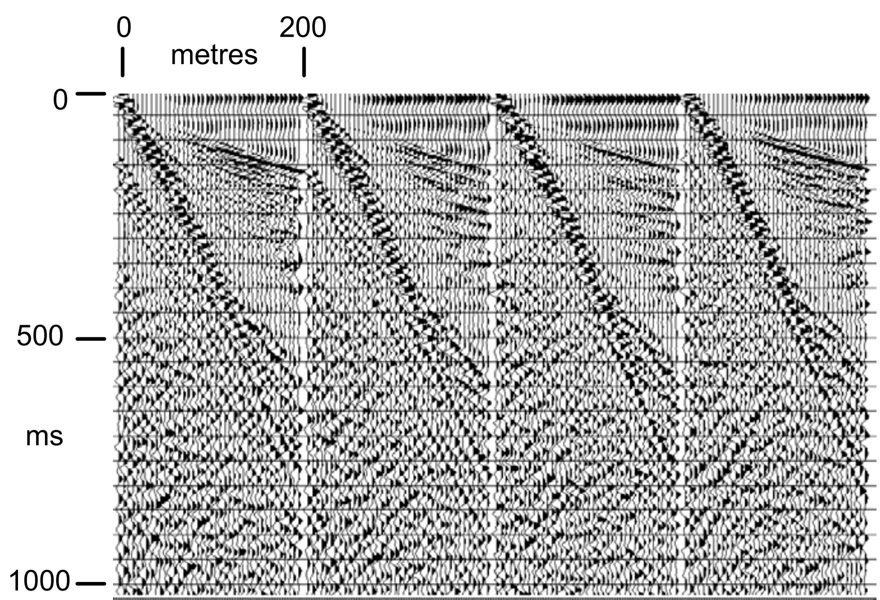

Fig. 4. Shaganappi shot records filtered with X-interpolated R-T filter. Significant coherent air-blast energy survives. Aliasing is quite apparent.

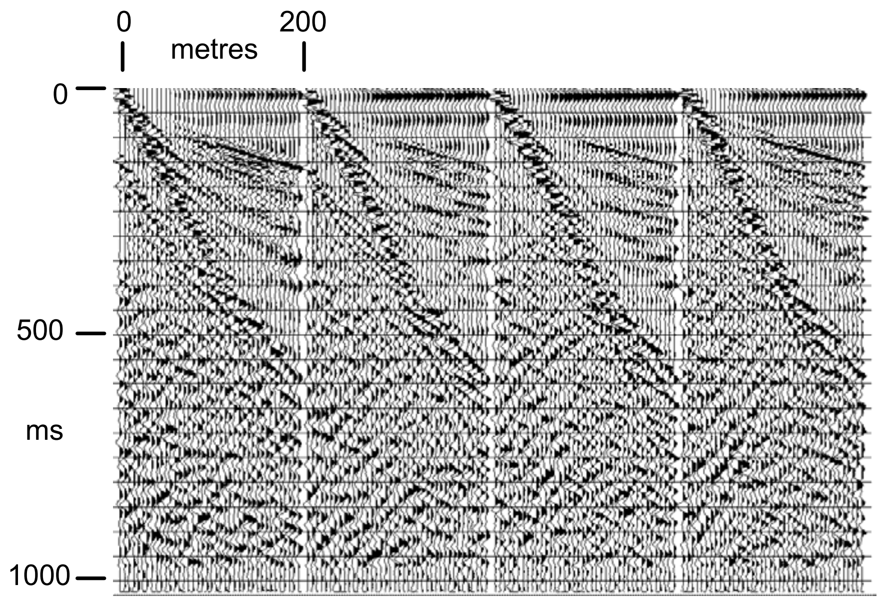

Fig. 5. Shaganappi shot records filtered with V-interpolated R-T filter. While some air-blast energy survives, most of it is not coherent, and it doesn't have a velocity of 300 m/s. Other coherent modes (like scattered air-blast) are now stronger in comparison. Aliasing is much less apparent.

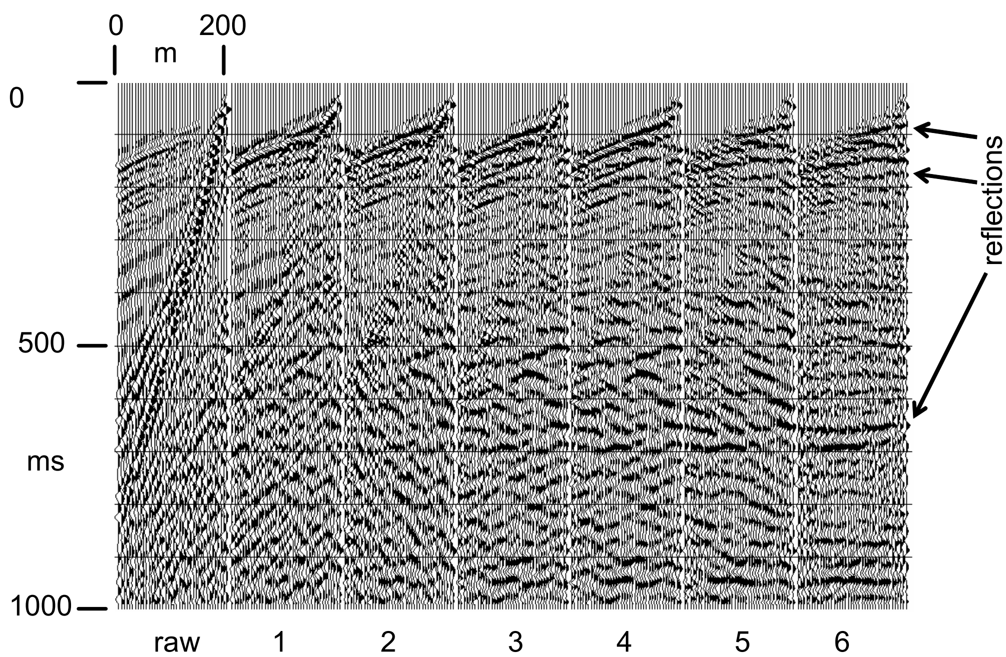

Fig. 6. Single Shaganappi shot gather showing successive passes of "new" R-T filters (noise is modelled by low-pass filter in the R-T domain, subtracted in the X-T domain).

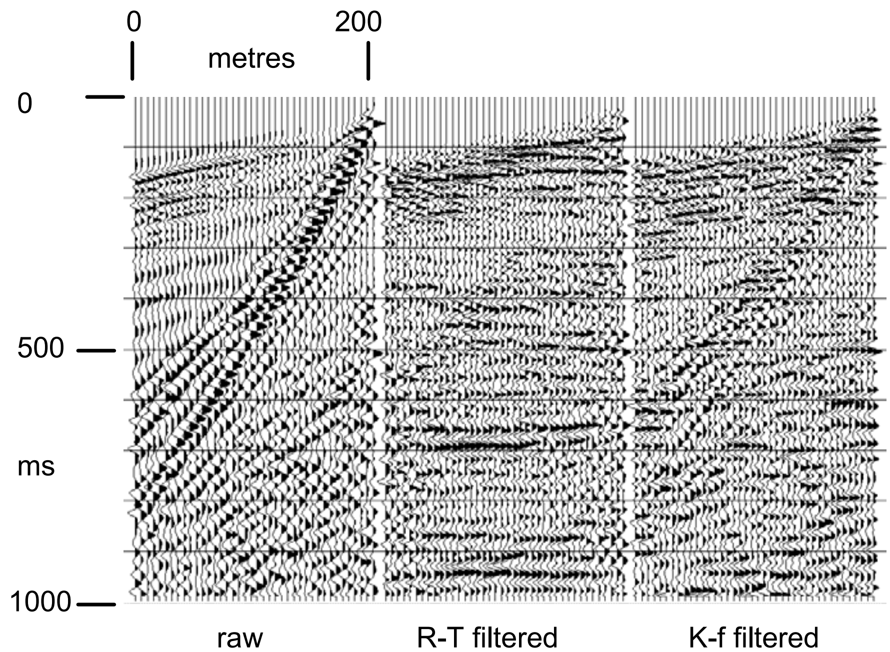

Fig. 7. Single Shaganappi shot gather showing comparison between R-T filtering and K-F filtering.

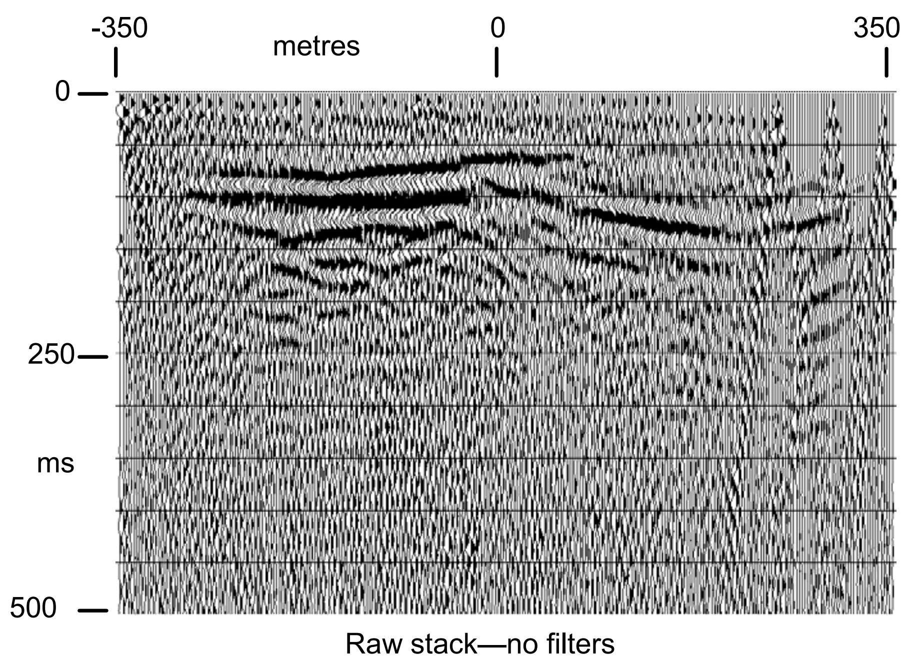

Fig. 8. Raw stack of Shaganappi seismic survey with no pre-stack filtering applied to shot gathers. Much of the visible coherent energy is fortuitously stacked refraction energy.

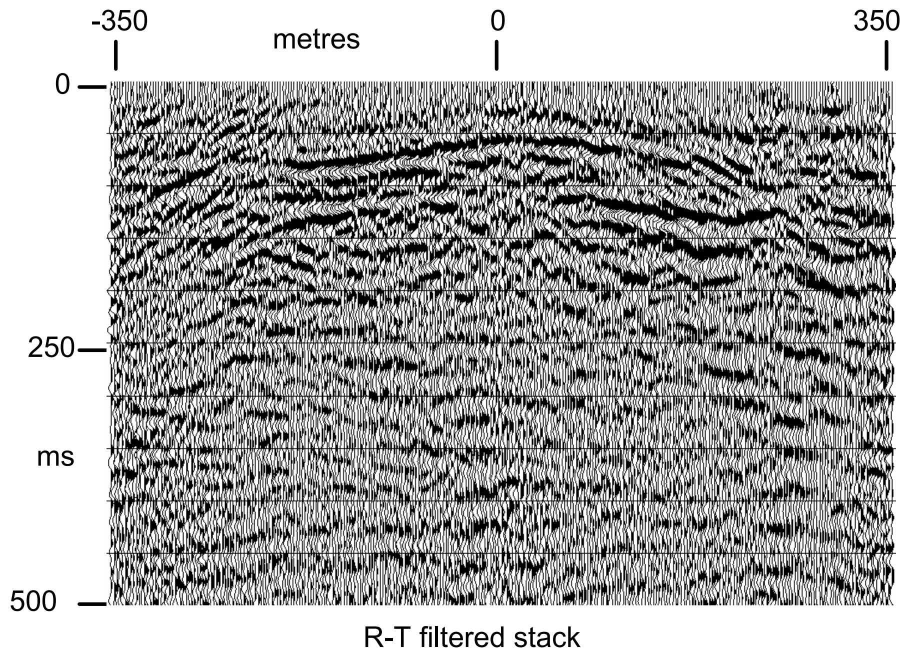

Fig. 9. Stack of Shaganappi shot gathers filtered with R-T subtraction filters.

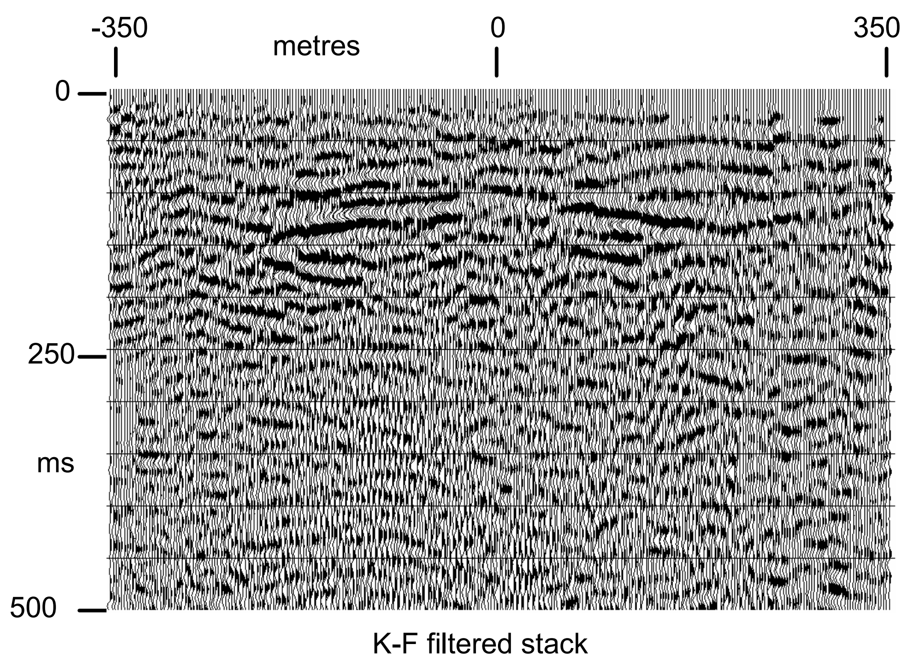

Fig. 10. Stack of Shaganappi shot gathers filtered in the K-F domain.