TWO DIMENSIONAL FILTERING OF SEISMIC DATA

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ABSTRACT

Embree, Burg and Backus (1963) introduced the concept of two-dimensional filtering to seismic processing. However, this did not become widespread because although long space operators are successful in attenuating undesirable components of data, they also distort signal character and often obliterate small features which could diagnose hydrocarbon accumulation.

High resolution surveys with single shots and geophones record wide spectral bands of reflection energy but the signal quality is often unacceptable due to a high content of random and organized noise. Coherency filtering of such data may provide misleading sections reflecting the bias of the processor. We have found that two-dimensional filtering with short operators handles this problematic situation satisfactorily in many cases.

Instead of more common f-k filters with bands radiating from origin, we worked with straight spatial-wavelength and time-frequency filters. After some experiments we devised an optimum truncation operator to enable the design of short symmetric two-dimensional operators, seven traces long and eleven samples wide for 110 ft. subsurface spacing and 2 msec sample rate. If the spatial-wavelength and time-frequency parameters are selected carefully from two-dimensional spectrum, these filters are effective in preserving signal character and random and organized noise is considerably attenuated.

The process is normally recommended after stack. A case is discussed where it was applied before stack in order to compute better normal moveout and static corrections, thereby improving the final stack.

In addition to allowing more confident and detailed interpretation, data filtered by two-dimensional operators provide better inversion. It is also possible to amplify particular frequency bands and thus increase resolution. This would not be possible on normal seismic data because of inadequate signal/noise ratio at higher frequencies. We have also been able to compute seismic regional and residual sections, the residual sections display local anomalies in greater detail than normal seismic sections.

INTRODUCTION

Smoothing, filtering, regional, residual, derivatives, continuation, be it upward or downward, are commonplace terms to potential field geophysicists. All these terms imply the use of two-dimensional operators and these operators have been used with some understanding and much misunderstanding in gravity and magnetic maps for several years (Henderson and Zietz, 1949). First application of two-dimensional operators in seismic processing was by Embree, Burg and Backus (1963). They introduced the f-k domain filters with pass- and reject-bands passing through the origin. The operators are quite successful in attenuating random and organized noise and enhancing particular dips. However, these operators have to be quite long in the space domain. Consequently, the signal character is

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invariably distorted and small features which may be diagnostically important are attenuated. Worse still, the reflection energy in any particular dip direction may be enhanced and the rest attenuated at the processor's will. Thus, any structure may be created by a determined processor.

In the last two years, high resolution seismic reflection surveys with a single geophone per channel and single shots have become quite common. The purpose of these recordings is to record wider spectral band than is possible with multiple geophone and/or shot arrays. Unfortunately, random and organized noise-trains like wind noise, hole-blast, distant traffic movement are also recorded most faithfully. Some of this extraneous noise may be attenuated by using frequency band limiting filters which defeats the purpose of high-resolution surveys. Five or seven trace mix with constant or variable weights has had some success in attenuating wind noise but the discrimination between signal and noise is very crude.

This paper discusses straight two-dimensional filtering using short-operators which overcome the objections outlined above. Significant improvement in the signal/noise ratio makes it possible to further refine the data to aid interpretations. These refinements are also discussed in this paper.

METHOD

For one dimensional case, if the spectrum of the desired filter is F(f), the filter operator is given by

$$F(t) = \int_{f=-\infty}^{\infty} F(f) e^{-i\,2\pi\, ft}\, df \qquad (1)$$

and the filtered trace S(t) is

$$S_f(t) = \int_{\tau=-\infty}^{\infty} S_0(t-\tau) F(\tau)\, d\tau \qquad (2)$$

S_0 being the input trace.

In two-dimensional case, we include the profile direction x as well as the time t. The equation of the operator F(x,t) for given spectral distribution $F(f_x, f_t)$ is

$$F(x,t) = \int_{f_x=-\infty}^{\infty} \int_{f_t=-\infty}^{\infty} F(f_x f_t) e^{-i\,2\pi f_x X}\, e^{-i\,2\pi f_t t}\, df_x df_t \qquad (3)$$

and the filtered trace $S_f(x,t)$ is

$$S_f(x,t) = \int_{\tau_x=-\infty\, \tau_f=-\infty}^{\infty} S_0(x-\tau_x, t-\tau_f) F(\tau_x, \tau_f)\, d\tau_x d\tau_f \qquad (4)$$

Equations (1) and (3) show that the operator must be infinitely long to be exact. Very long operators are, however, impractical for reasons of cost as well as the fact that the data to be filtered are finite themselves. Therefore, it is desirable to restrict the operator to a manageable size. This is done by truncating the operator, i.e. multiplying the operator by a curve which is zero beyond the desired operator dimension. This curve is designed such that the influence on the response of the operator in the desired interval is within tolerable limits. There are several standard truncators to choose from. We experimented with various truncation operators and eventually settled on a hybrid truncator as the most optimum for two-dimensional seismic filters. One example of such filters is shown in Figure 1. The actual values of filter points are contoured. Since the filter is symmetrical in both time and space, only one quarter of the filter is shown.

Once the operator is designed, it is applied to each sample on the data as given in equation (4). The array processors make the operation very efficient in terms of computer costs.

f-k Plots and Box-car filter:

Figure 2 shows a frequency-wave number plot as described by Embree, Burg and Backus (1963). Wave-number, i.e. the reciprocal of wavelength is plotted on the x-axis and frequency on the y-axis. On this plot, various

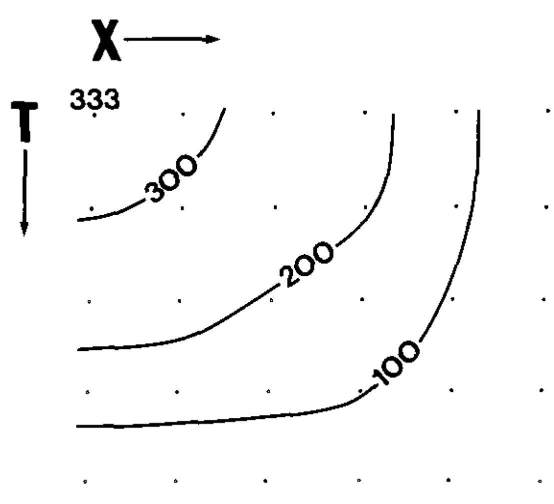

Fig. 1. Impulse response of two-dimensional filter, passband 83hz and 10 traces.

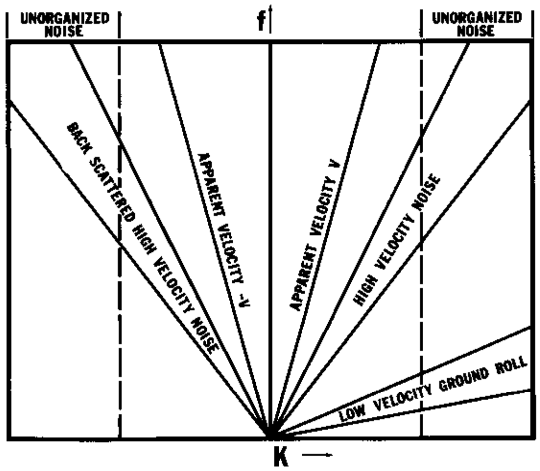

Fig. 2. Distribution of various patterns on a frequency-wave number plot (after Embree et al, 1963).

kinds of organized noise patterns fall into separate radial zones emanating from the origin, their slope depending on the apparent velocity or the dip of the event. Unorganized noise covers all ranges of seismic frequency and since it is unorganized, i.e. unrelated from trace to trace, it has a high wave number and plots on the right or the left fringe of the plot. Note that we differentiate between 'random' and 'unorganized' in the sense that unorganized noise is sporadic in the section and its spectrum is not white.

Normal practice of velocity filtering involves specifying a 'V-shape' in the frequency-wavenumber plot where signal is retained. In other words, the maximum allowable dips are specified. This approach is quite successful provided the operators are quite large in terms of number of traces. However, these large operators have been known to attenuate small features which are often crucial to correct interpretation. On the other hand, efficient box-car pass-band filters for frequencies o-f_{max} and wave-numbers o-k_{max} can be designed for seven to nine traces. It is clear from Figure 2 that these box-car filters attenuate unorganized high wave-number events, almost all of low-velocity noise and a substantial proportion of high velocity noise while retaining almost all of signal energy. Thus, these filters provide sections which retain stratigraphic information and significantly improve signal to noise ratio.

Determination of filter parameters:

The highest frequencies, both in time and in space, are determined from the inspection of two-dimensional spectrum. The spectrum is usually computed from 42 stacked traces, window for each trace being one second. Figure 3 illustrates such a spectrum. Vertical axis is the time frequency in hertz, horizontal scale is spatial wavelength (reciprocal of wave-number) in units of trace-interval. The computer plots numbers ranging from 0-9 for each spatial and time-frequency, 9 being the highest power (0 db), 0 being the lowest (-54 db).

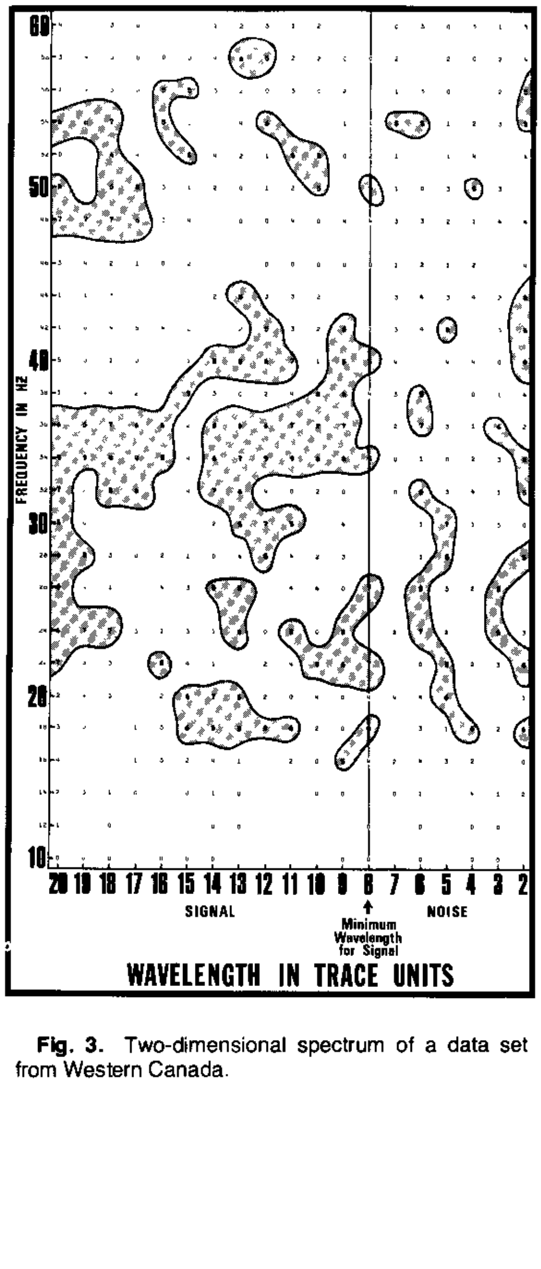

Fig. 3. Two-dimensional spectrum of a data set from Western Canada.

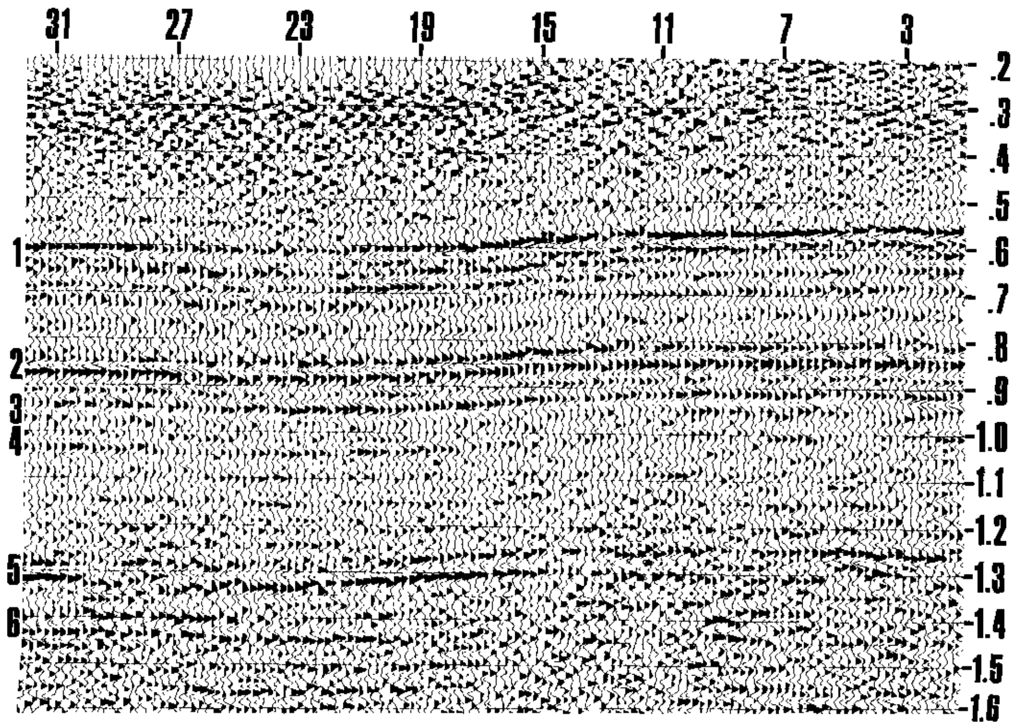

Fig. 4. A 12-fold stack section from Western Canada.

Values less than -54 dbs are left blank. The 30 db down points are contoured by hand. These contours indicate the possible existence of two bands of energy, one from 10 hz to 60 hz, with spatial wavelengths of 8 traces and greater and the other band with similar frequencies but spatial wavelengths of 8 traces or less. It is quite possible that the first band (spatial wavelengths of 8 or greater) is mainly signal energy and the other band is mainly noise. Therefore, for the given data, a two-dimensional filter of passband 80 hz and 8 traces will pass most of the signal energy, while discriminating against noise.

Our program to design and apply these short two-dimensional operators is called Enhance. For the rest of the paper, we will use this term to describe the two-dimensional filter as programmed by us.

Enhance after stack:

Figure 4 shows a stacked section from Western Canada. The data is 12-fold stack, nine geophones per trace and a small dynamite charge. The poor continuity and absence of character in reflectors 5 and 6 between 1.2 and 1.4 seconds makes the stratigraphic interpretation of the reef zone very difficult.

Figure 5 shows the same data after Enhance. A 125 hz and 8 trace (spacing 110 ft.) wavelength operator was applied. Not only has the noise been attenuated, significant character and continuity improvements have been made.

Enhance before stack:

In another region of Western Canada, inter-bed multiples are a serious problem. The interpretation of the main gas-bearing horizon is often complicated by these multiples. Figure 6 is the normal 12-fold stack of some of these data. Continuity of the main event, reflector 5, is very questionable at critical points. If we look at some corrected CDP gathers (Figure 7) it becomes obvious that the multiple interference is acute. Figure 8 shows the same CDP gathers

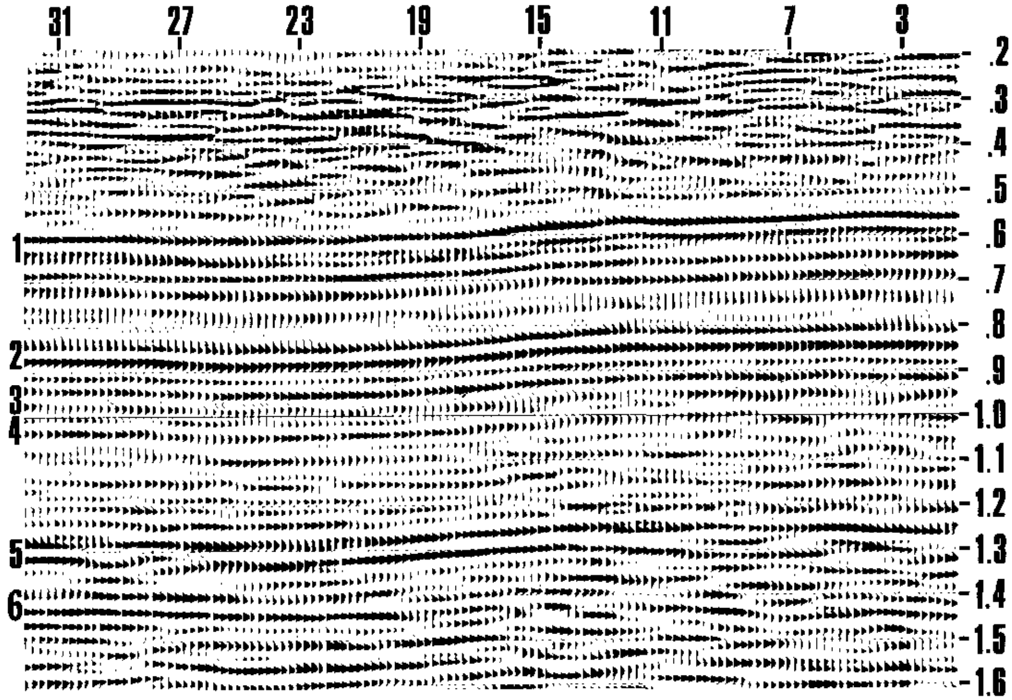

Fig. 5. Section in Figure 4 after two-dimensional (125 hz* 8 traces) filter.

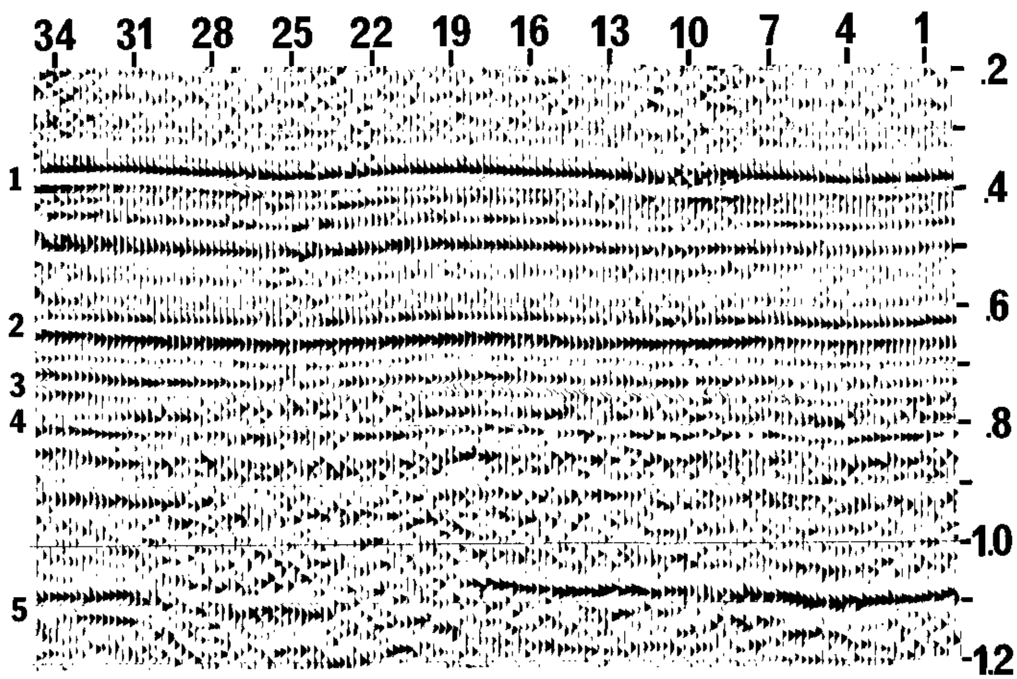

Fig. 6. A 12-fold stack section from Western Canada.

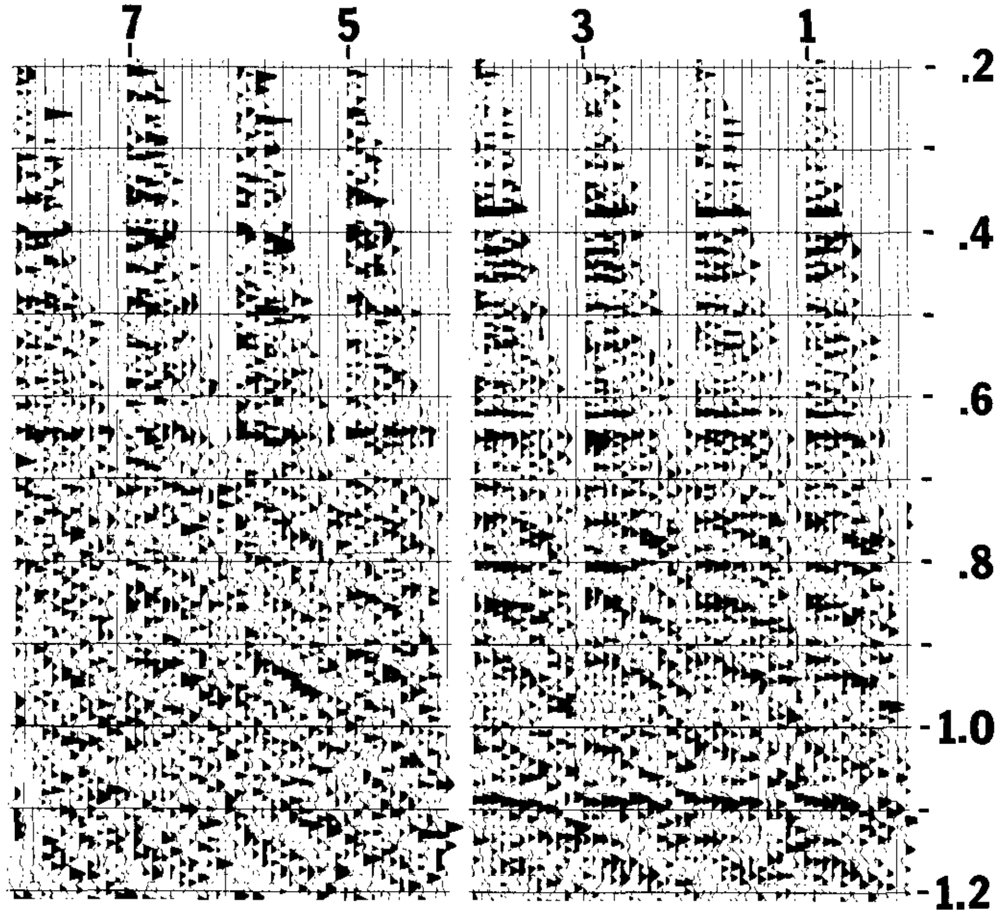

Fig. 7. An example of CDP gather of data for section in Figure 6.

after Enhance. Multiples have been suppressed, primaries appear to be more reliable. The stack after Enhance (Figure 9) is a definite improvement over the previous stack (Figure 6) and reflector 5 can be interpreted with some confidence even if it is not as continuous as one would wish.

Inversion and Two-Dimensional filtering:

Figures 10 and 11 show the comparison of the same set of seismic traces after inversion with actual sonic logs. Data in Figure 10 were processed normally and those in Figure 11 through Enhance before stack. Resolv, which incorporates two-dimensional filter design and application followed by high-frequency enhancement, was applied after stack in both cases since the stacked data by themselves were not considered good enough for inversion. The figures also show the low-velocity function applied in inversion. The inversion technique, Soniseis, described by Jain and Wren (1977, 1978) was applied.

Careful comparison shows that Enhance before stack has improved the similarity between inverted traces and the sonic logs. This is due to general improvement in signal/noise ratio between .5 - 1.0 sec and substantial attenuation of multiples at about 1.2 sec.

Seismic Regional and Residual Sections:

Once the signal/noise ratio has been increased to a high level, it is practical to compute regional and residual seismic sections.

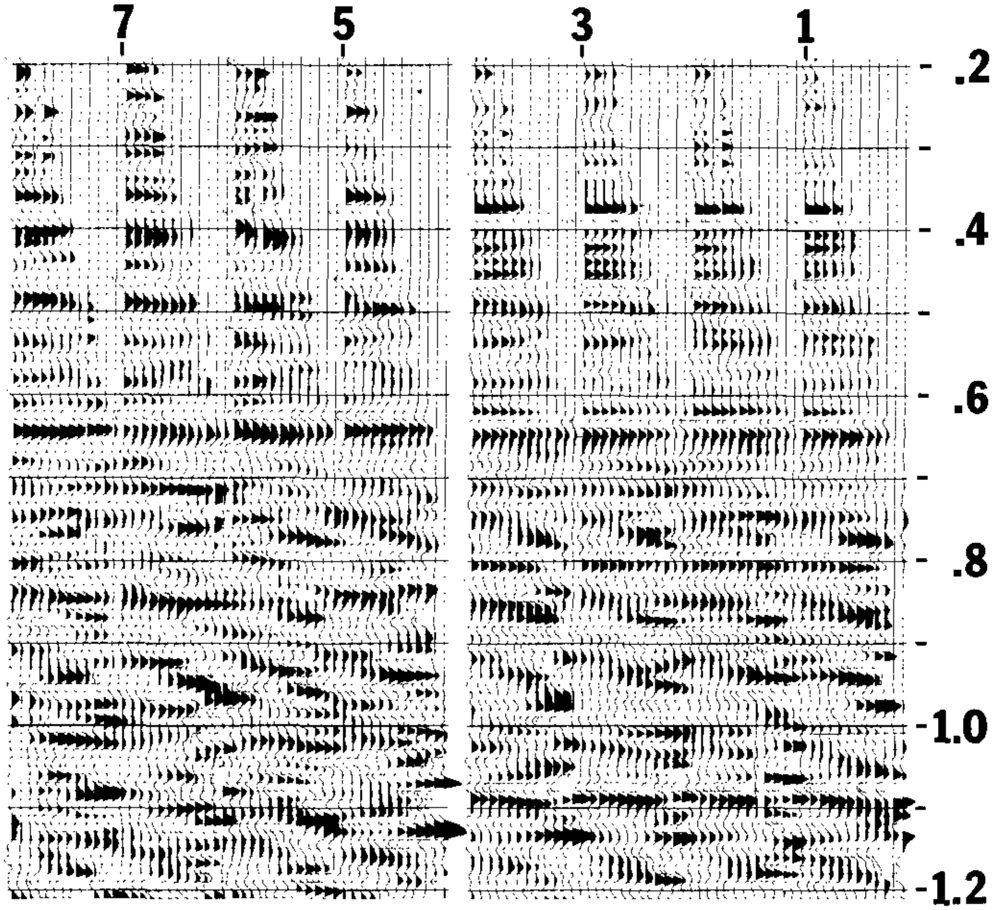

Fig. 8. Data in Figure 7 after two-dimensional filter.

The regional section displays the reflection character changes over larger distances and the residual section shows changes lasting a few traces. Major reflections on the stacked section which do not change laterally are not prominent on the residual section. Regional sections are obtained by applying a two-dimensional filter that passes most frequencies in the seismic section but only high wavelengths in horizontal direction. Residual section is obtained by subtracting regional section from the stacked section. If signal/noise ratio is poor, residual section consists mostly of noise and is not useful.

Figure 12 is a seismic section from Western Canada. Figures 13 and 14 are respectively the regional and residual sections computed by applying a 33 trace 17 msec rectangular operator. The regional section shows many features of the stacked section. As expected, these features are smooth compared to those in stacked section even if the reflection amplitudes are relatively similar in both sections.

On the residual section (Figure 14) reflectors have no general relationship to amplitudes and polarity in the stacked section. The major reflectors at 0.7 and 0.9 sec on the stacked section are almost absent on the residual section while the weak reflector at 0.810 to 0.820 sec appears prominently and continuously. On the stacked section (Figure 12), this

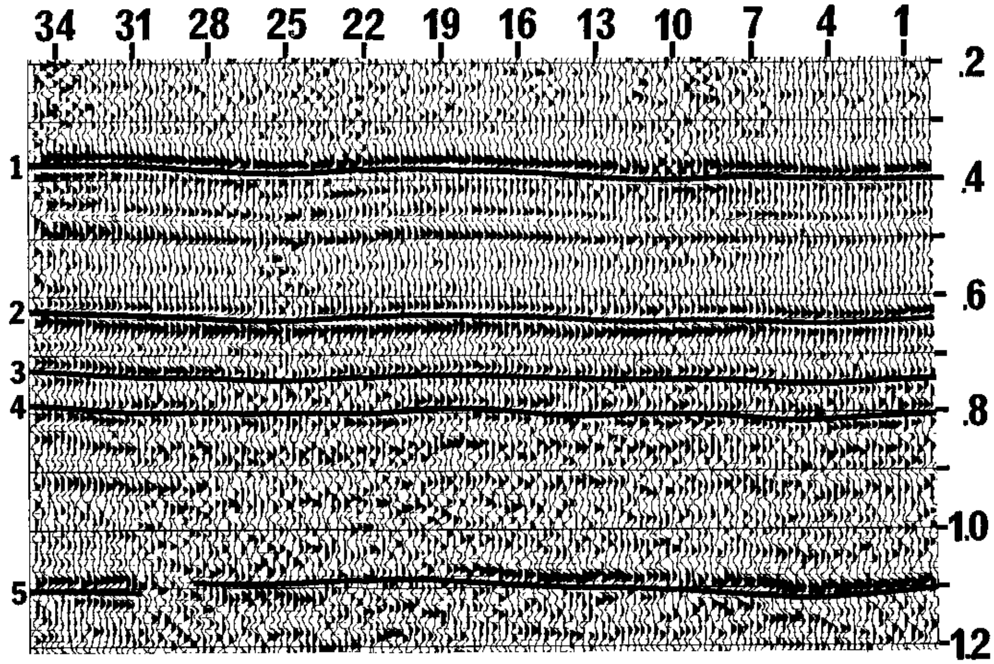

Fig. 9. Same data as in Figure 6 except that CDP gathers were processed through a two-dimensional filter before stack.

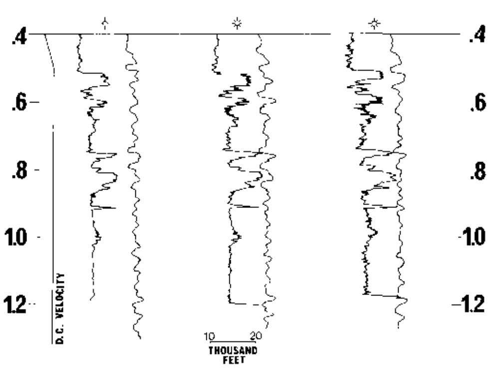

Fig. 10. Comparison of Sonic logs and inversion traces near three wells.

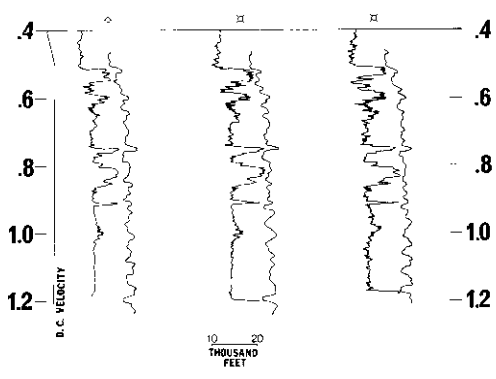

Fig. 11. Comparison of same data as in Figure 11 except that Enhance was applied before stack and subsequent inversion.

thin sand bed shows as a peak only when it is 18 msecs (approximately 120 ft) or more away from the main unconformity above. When the bed is any nearer to the unconformity, the main reflection (due to unconformity) is distorted and the sand reflection loses its identity. When the regional character of the reflections is subtracted from the distorted event, the thin bed appears as a continuous reflector, thus establishing continuity and structural closure of the sand bed.

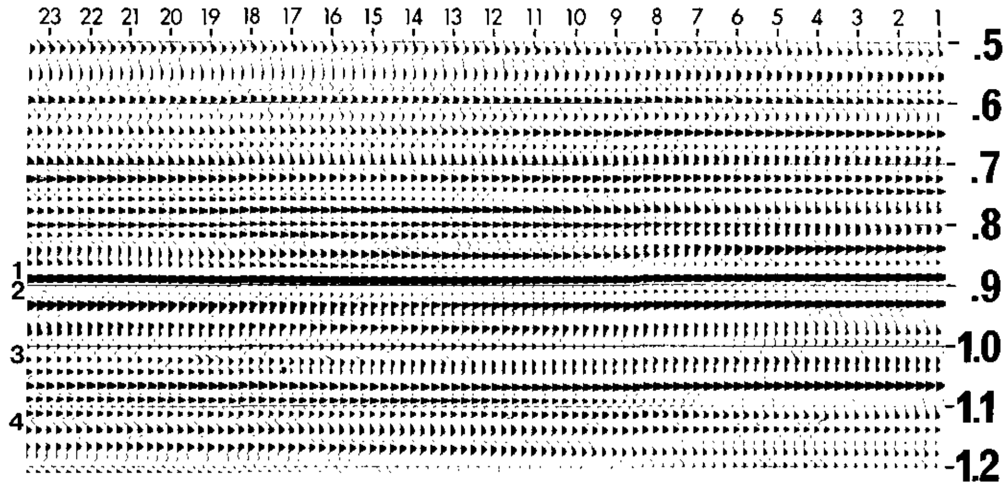

Fig. 12. A 12-fold high-resolution section from Western Canada after stack and Enhance.

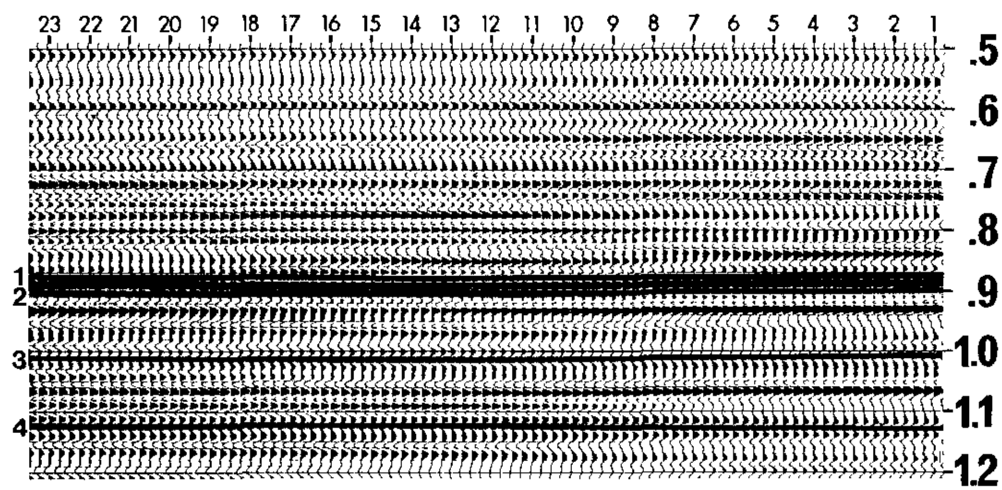

Fig. 13. The regional section computed from data in Figure 12.

The residual sections identify local anomalous features prominently, if only because of the near absence of major reflectors. It should be pointed out that when a thin bed is spaced uniformly from the major reflector, the residual section will not identify either of the reflections.

Conclusion

We have shown some examples of straight two-dimensional filtering in improving continuity and interpretability of seismic sections. The major advantage of this process over coherency enhancement processes is that the

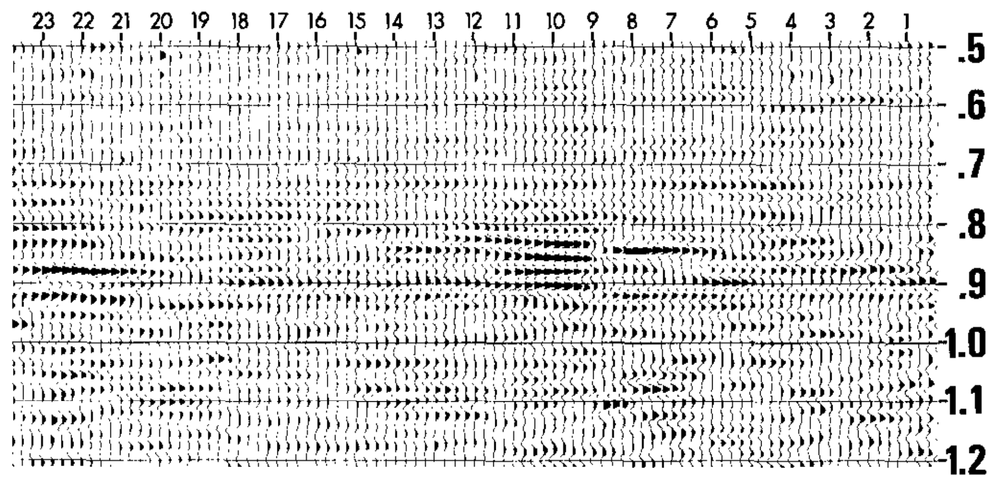

Fig. 14. The residual section computed from data in Figures 12 and 13.

same operator is applied to all samples of the data, thus the probability of enhancing particular events beyond their appropriate significance level is low. The process is simple in design and application and has proved effective on data all over Canada.

The concept of two-dimensional filtering has been extended to compute seismic regional and residual sections. The residual sections show much improved definition of anomalies which are barely indicated on normal sections. The regional sections have been used to compute anomaly coefficient sections which will be the subject of a separate paper.

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References

Embree, Peter, J. P. Burg, and M. M. Backus, 1963, Wide-Band Velocity Filtering, The Pie-Slice Process, Geophysics, Vol. 28, p. 948-974.

Henderson, R.G., and I. Zietz, 1949, The Computation of Second Derivatives of Geomagnetic Fields, Geophysics, Vol. 14, p. 508-516.

Jain, S., and A. E. Wren, 1977, The Application of Optimal Wavelets in Seismic Inversion, Journal of the C.S.E.G., Vol. 13, No. 1, p. 3-14.

Jain, S., and A. E. Wren, 1978, Seismic Inversion with Optimal Wavelets, The Oil & Gas Journal, Sept. 18, 1978, p. 242-254.