Spectral clipping: A ProMAX module for attenuating strong monochromatic noise

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ABSTRACT

One of the more pervasive noises encountered on raw seismic data is that due to the inductive pickup by geophones and cables of 60 Hz signals from nearby power transmission lines. The noise often completely swamps any seismic signals detected by the affected channels and appears as continuous sinusoidal waveforms of 60 Hz, or less commonly, 120 Hz or even 180 Hz. When the frequency of such noise is known exactly, it can be removed by one of several well-known techniques, though these can affect the data in adverse ways. Presented here is an algorithm that automatically detects any strong single-frequency or narrow-band noise on seismic traces and attenuates it in a relatively harmless way. A ProMAX module has been written to apply the algorithm, and its parameters and some test results are presented.

INTRODUCTION

While hardware and software can both be utilised to attenuate inductive pickup during seismic data acquisition, the magnitude of the noise is often so great that it survives this filtering and contaminates the recorded traces. Also, hardware filters often affect the phase of recorded signals adversely. There are well-known software algorithms for attenuating narrow-band or monochromatic noise, but most of them require an exact knowledge of the frequency of the noise to be attenuated. If applied aggressively, they can also affect the underlying seismic data adversely. Furthermore, while monochromatic noise is most commonly due to inductive pickup during data acquisition, there are other situations in seismic processing, notably in radial trace domain or Tau-P domain processing, where single-frequency or narrow band noise components may appear (Henley, 1999). Particularly in these situations, the frequency of a particular noise may be unknown or may change from trace to trace, rendering the application of standard notch-filtering algorithms tedious.

The technique known as ‘spectral clipping’ is a hands-off editing scheme in which components of the seismic frequency spectrum attributable to monochromatic or narrow-band noise are automatically detected and edited out of the spectrum. The method assumes that a monochromatic or narrow-band noise is strong enough that its spectral amplitude with respect to those of neighbouring frequency components deviates more from some ‘average’ spectral amplitude level than any of the peaks and valleys of the legitimate seismic spectrum. Because the success of the operation depends upon the contrast between the amplitudes of noise peaks and ordinary spectral features, spectral clipping works best on the noisiest data.

ALGORITHM DETAILS

Since the spectral clipping technique operates in the frequency domain, the first step in the algorithm is to Fourier transform an input trace to amplitude and phase. In order to detect spectral peaks and determine whether they comprise ‘noise’ or normal spectral features, an ‘average’ spectrum must be determined in some fashion. Because the amplitudes of a typical spectrum can range over several orders of magnitude, they are first converted to dB to reduce their dynamic range. A smoothed or average spectrum can be obtained using almost any smoothing operator, but it is best to use an operator that is not affected by large spikes or notches in the raw spectrum. Otherwise, some remnant of these features might appear in the smoothed spectrum, reducing the discriminating power of the algorithm against the noise represented by those very spikes and notches. Accordingly, the running median was selected for the spectral smoothing algorithm, since it is not influenced by spectral extrema whose width is less than half the length of the running median operator.

Once the smoothed amplitude spectrum has been computed, each amplitude from the raw spectrum is compared with its corresponding amplitude in the smooth spectrum. Any amplitude value that differs from its corresponding ‘smooth’ value by more than a specified amount in dB, either higher or lower, is replaced by its smooth value, while the phase of the component remains unchanged.

In order to further reduce spectral irregularity due to the editing of spikes and notches, whenever a raw amplitude value is replaced with a smooth one, several neighbouring values on either side of the edited value in the ‘wings’ of the original peak are also replaced. This recognises the fact that even very pure noise tones have some spectral bandwidth, and not all the sideband components in a noise peak may exceed the threshold value required to trigger editing.

Figure 1 is a schematic showing the first stage in the spectral clipping process: the Fourier transform of a noisy seismic trace to the polar frequency domain (amplitude and phase). The construction of the median spectrum and the upper and lower threshold is depicted in Figure 2, along with indications of the peak width and ‘wings’ for the single noise peak. Editing the raw spectrum by replacement of peak and ‘wing’ values with median spectral amplitudes is shown in Figure 3; while the inverse transform of the edited spectra to a clean seismic trace appears schematically in Figure 4.

PROMAX MODULE

A simple module has been written for ProMAX that embodies the algorithm described above. Because of the essential simplicity of the method, and the intention that it should be automatic, only three parameters are required for the module, and these may be successfully defaulted for many data sets. The parameters in the order in which they appear in the module menu are:

- *Length in spectral points of median smoother*—This parameter controls the length of the median smoothing window used to compute the median spectrum from the raw amplitude spectrum of each input trace. The default value of 101 points will work for most data traces. This parameter is not very sensitive. The main criterion is that the length should exceed twice the expected bandwidth in frequency samples of any expected monochromatic noise.

- *Width in spectral points of peaks to edit* –This parameter specifies a minimum width for noise peaks plus their 'wings', and thus the number of spectral values centred on each threshold-exceeding point, which will be replaced by their median spectral values. The default value of 21 points works well for most data. Too large a value endangers legitimate spectral details lying close to noise peaks.

- *Allowable dB spectral deviation* – This parameter specifies the threshold values, above and below the median spectrum, for which editing will occur. The default value of 12 dB is a good starting value, but this parameter should be tested for all data sets due to the variability in the magnitude of legitimate spectral details. Too small a value here will cause editing of legitimate spectral features, while too large a value will fail to trigger editing of significant noises.

The spectral clipping module examines the entire Fourier spectrum of each input trace and will thus detect and edit all monochromatic noises in a single pass, regardless of their frequency. One instance where this can be useful is when inductive pickup during data acquisition involves not only the 60 Hz fundamental, but also some higher harmonics, due to some non-linearity in the coupling of the 60 Hz into the system. Another application where this feature is of value is in the attenuation of highly dispersed linear coherent noise. Such noise is not readily attenuated in the F-K domain because it remains dispersed in this domain as well, and is not well separated from the desired seismic reflection events. The radial trace transform, however, samples the X-T domain along trajectories of constant apparent velocity, which for dispersed linear noise are trajectories of constant frequency as well. The result is that the R-T transform of seismic data contaminated with dispersed linear noise confines the noise to a very narrow band in the spectrum of each radial trace, a situation ideal for spectral clipping. The dispersion of the noise and the spatial sampling of the original X-T panel determine the frequency of the spectral noise peak for each radial trace; but that information is not needed for spectral clipping, since the algorithm automatically finds the suspect spectral peaks.

EXAMPLE

To illustrate the effectiveness of spectral clipping against monochromatic noise, an example of field data was selected from the 2000 Okotoks field school survey conducted by the University of Calgary. These data were characterised by poor S/N over most of the survey, and 60 Hz power transmission noise was prevalent on a number of channels during the survey. Figure 5 shows two typical shot gathers from the beginning of the survey line. As can be seen, nearly half the traces have been obscured by pickup noise. These traces would typically be killed during the early processing phase. An attempt to avoid trace killing by applying conventional notch-filtering is shown in Figure 6. As can be seen, this is partially successful, particularly for the traces at nearer offsets. Some traces at longer offsets remain obscured, however. Note, also, that the notch-filter appears to have significantly attenuated the higher frequencies in these data, since the useful signal band of the original data appears to extend somewhat beyond 60 Hz. The results of spectral clipping, shown in Figure 7, on the other hand, show significant differences. Every trace in each gather now contains seismic energy, even if it is just a coherent noise event. As well, the surviving data appear to have a greater bandwidth than the notch-filtered results. In the centre of the same field survey, the raw data gathers appear as in Figure 8. Figures 9 and 10 show the notch-filtered and spectrally clipped results, respectively. In this case, both techniques appear to have reclaimed the seismic traces; but the notch-filtered results are noticeably narrower in bandwidth than the spectrally clipped results. Also, the notch-filtered results exhibit what might be termed 'ringing' (especially in the centre traces of the left-most gather), while the clipped results have no such appearance (a spectral peak associated with this ringing has been clipped, in addition to that due to the prevalent 60 Hz noise). Furthermore, examination of the clipped results reveals the presence of fragments of what may be reflection events.

CONCLUSIONS

A simple automatic spectral editing technique has been introduced and implemented in a ProMAX module. In the example shown, spectral clipping appears to offer some advantages over more conventional methods for attenuating monochromatic noise. The method works best on the strongest noises.

ACKNOWLEDGEMENTS

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REFERENCES

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

FIGURES

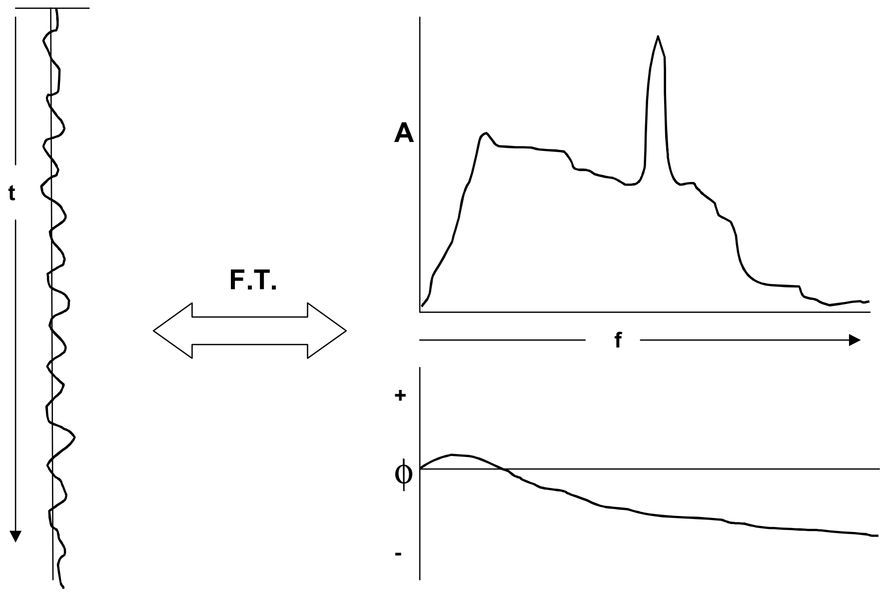

FIG. 1. Schematic showing a seismic trace contaminated with a high level of monochromatic noise transformed to the Fourier domain.

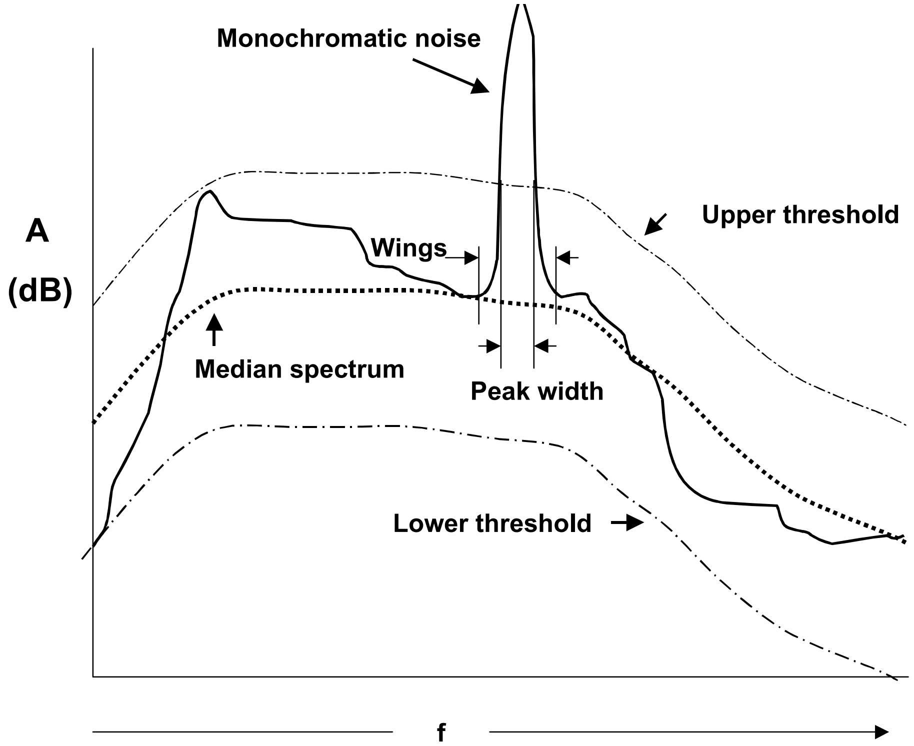

FIG. 2. Schematic showing the median spectrum computed from the raw amplitude spectrum, as well as the threshold levels above and below the median spectrum. The noise peak and its 'wings' are indicated as well.

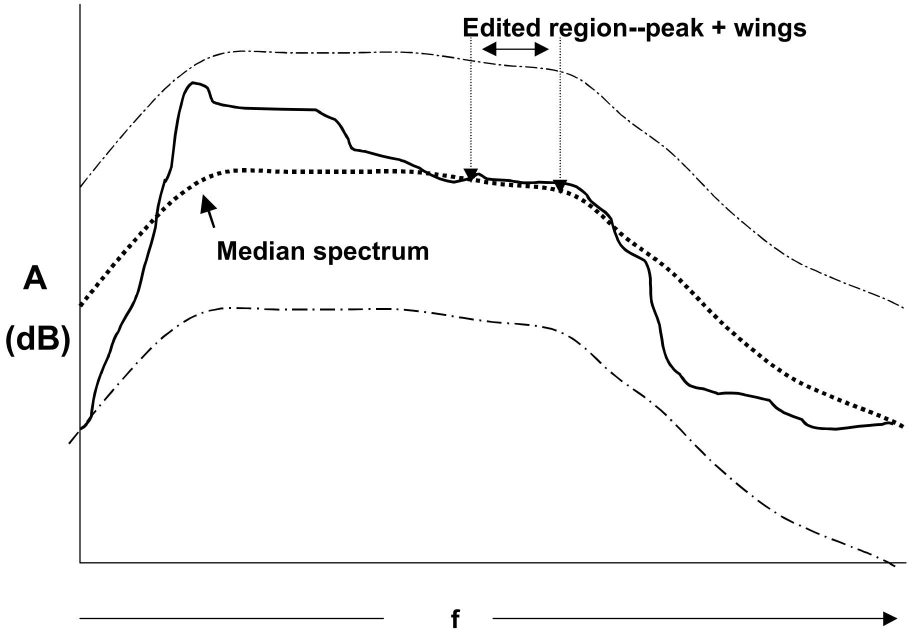

FIG. 3. Schematic showing the edited input amplitude spectrum. Spectral values in the peak and its wings are replaced by values from the median spectrum.

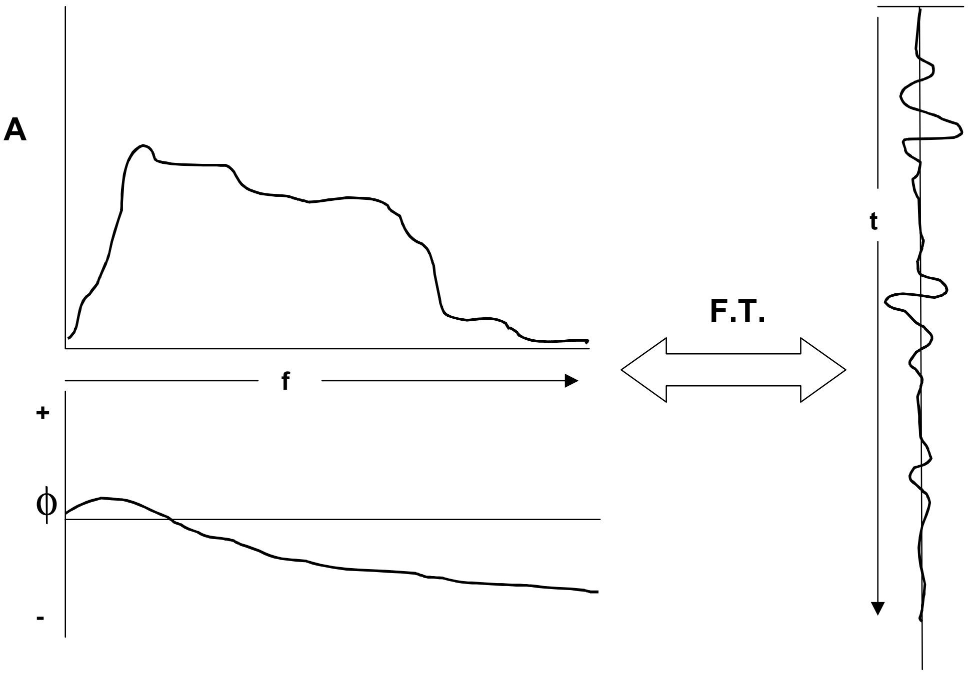

FIG. 4. Schematic showing the edited amplitude spectrum and the unchanged phase spectrum being transformed to a seismic trace without the monochromatic noise.

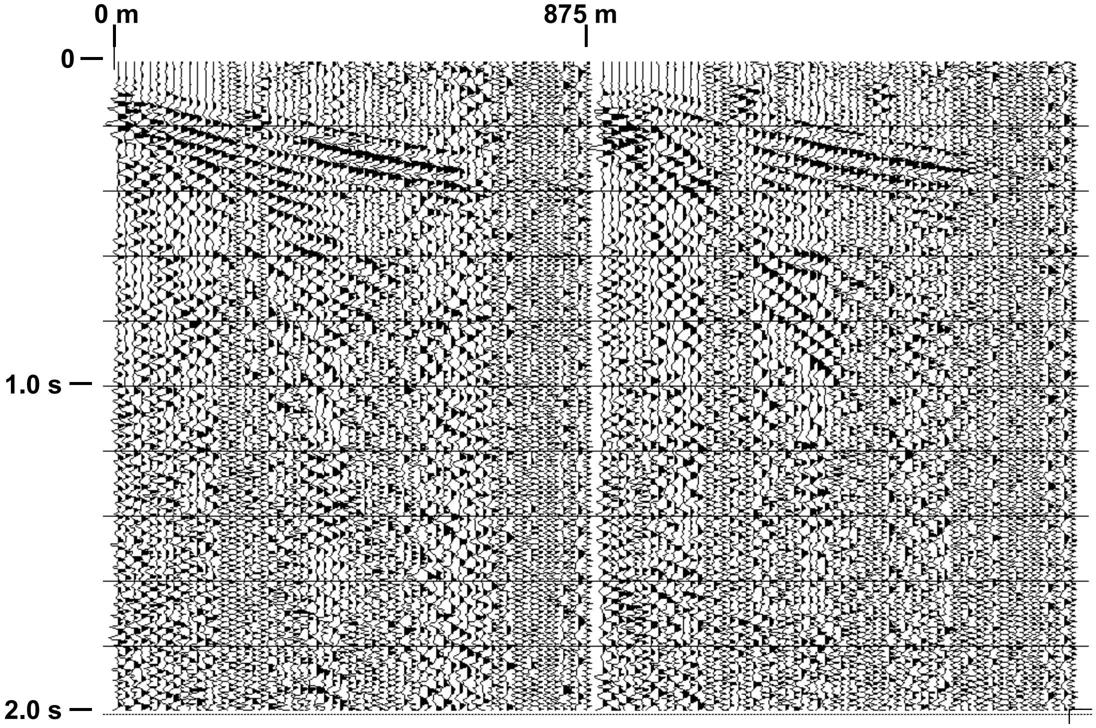

FIG. 5. Two raw shot gathers from the 2000 Okotoks field school data, after 12-15-65-80 Hz bandpass and 500 ms AGC for display.

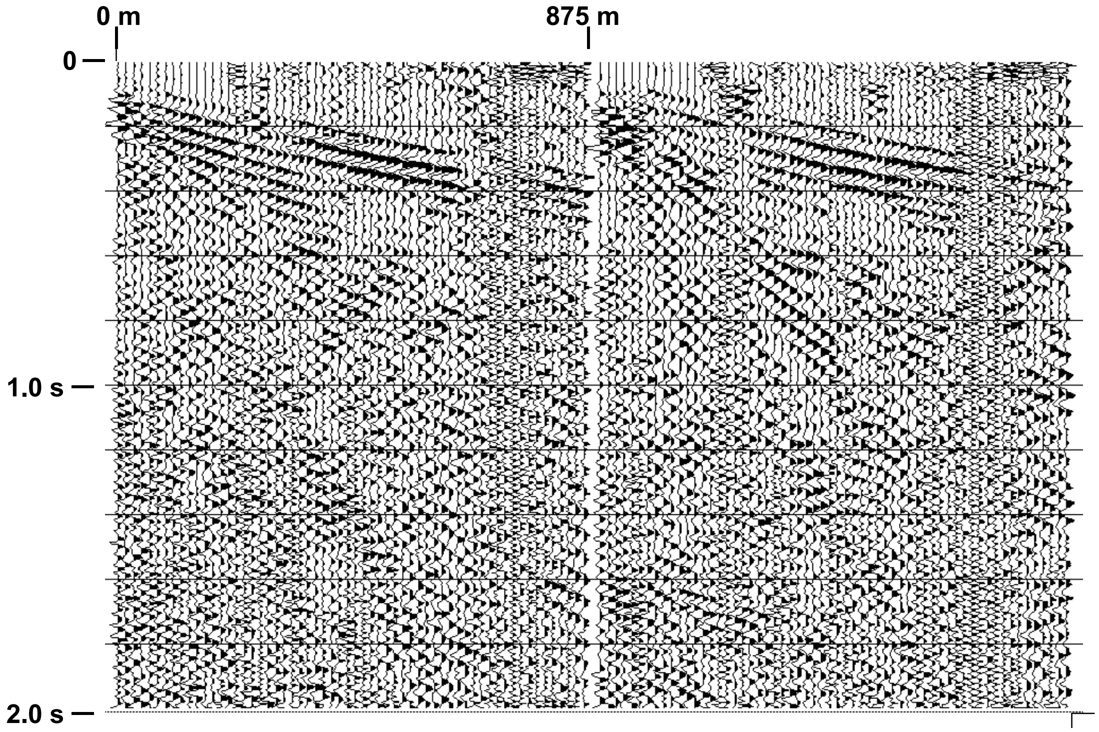

FIG. 6. Okotoks shot gathers after application of 60 Hz notch-filter, followed by bandpass and AGC.

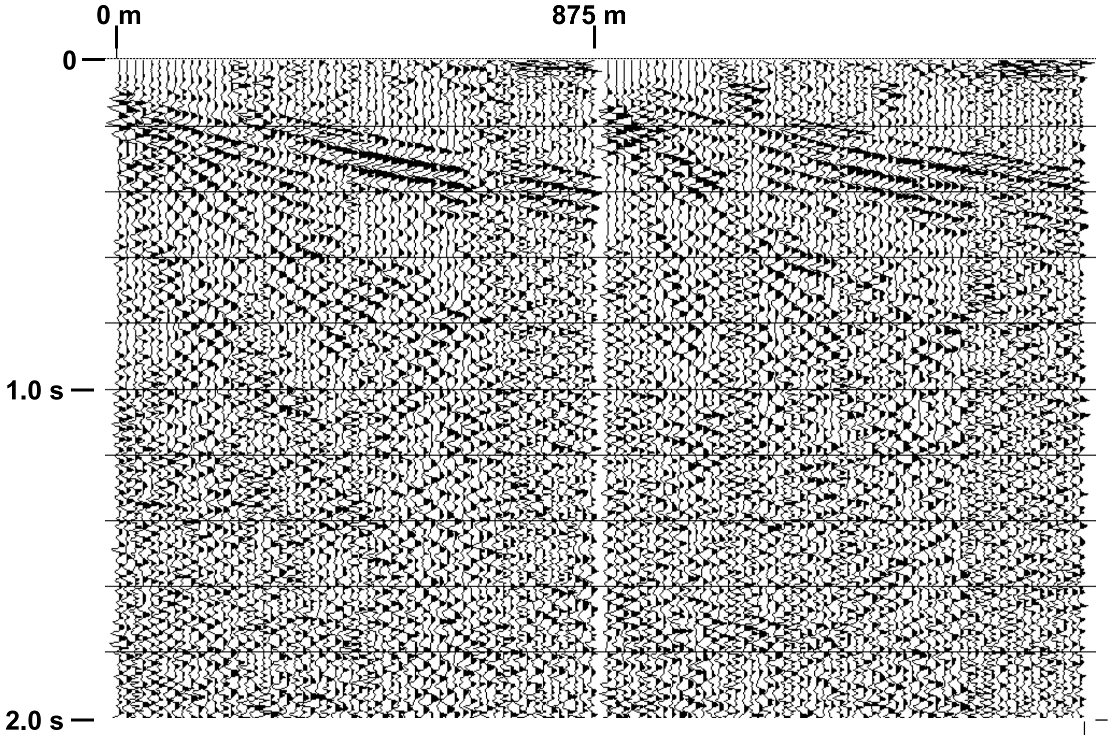

FIG. 7. Okotoks shot gathers after application of spectral clipping, followed by bandpass and AGC.

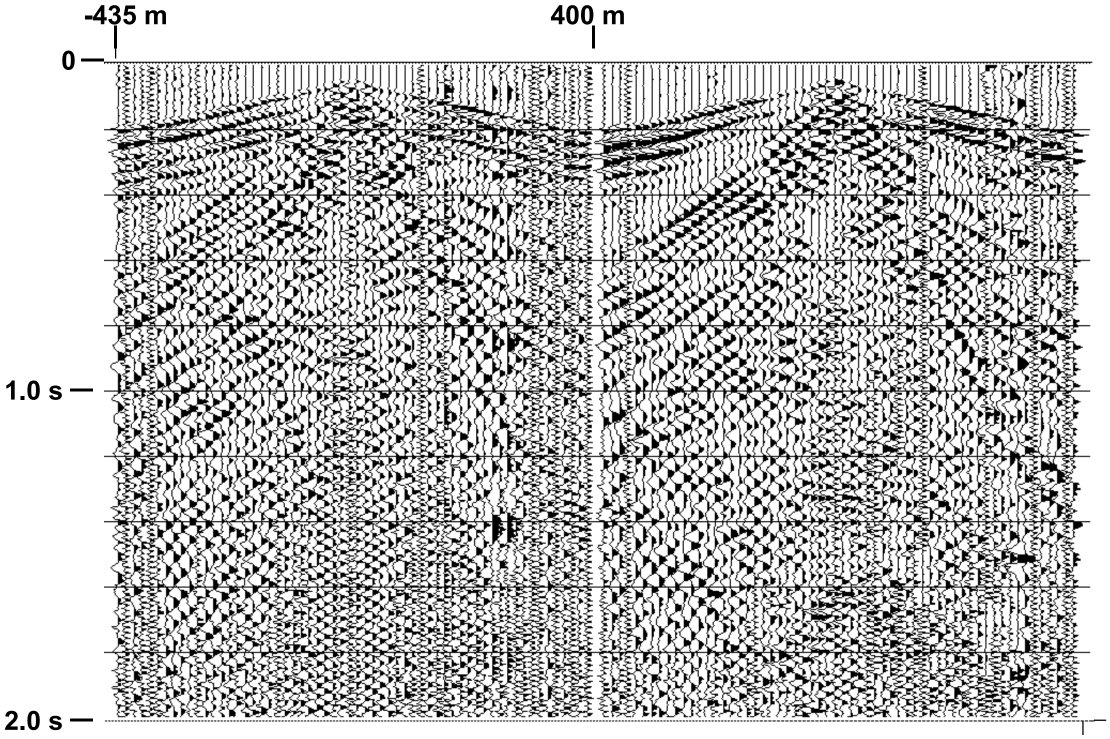

FIG. 8. Shot gathers from centre of Okotoks field school profile after bandpass and AGC.

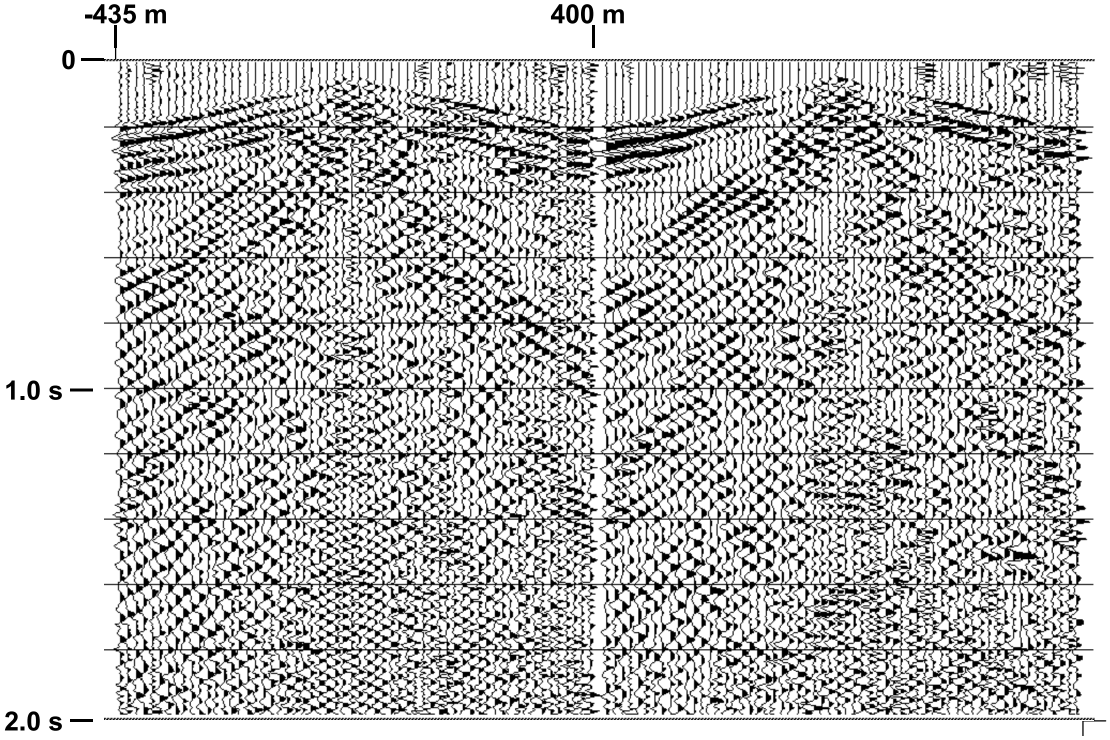

FIG. 9. Okotoks shot gathers after 60 Hz notch-filter, bandpass, and AGC.

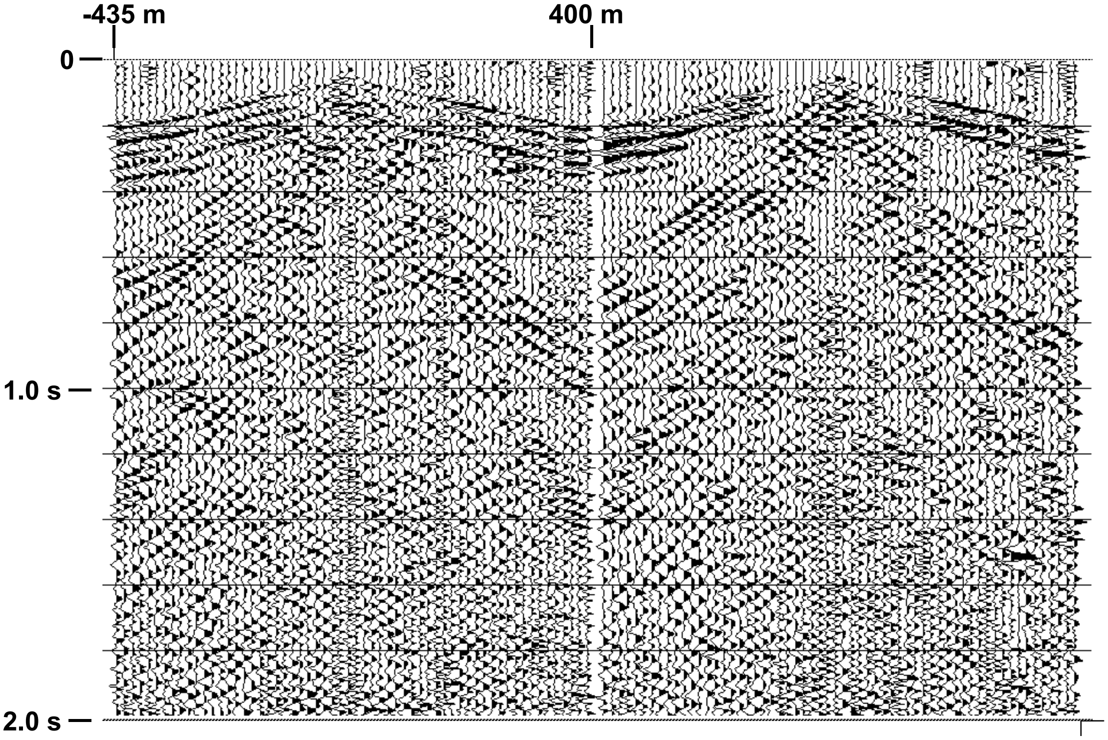

FIG. 10. Okotoks shot gathers after spectral clipping, bandpass, and AGC