Application of Inverse-Q Filtering

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Inverse-Q Filtered Data

Elsewhere in this report (Hale,1981), we described an efficient method for reducing non-stationarity due to attenuation by "inverse-Q filtering". This sequel illustrates the application of this inverse filtering to twenty traces of a common-midpoint (CMP) gather. The first three seconds of this gather are plotted in Figure 1a. Although four seconds of data were processed throughout this study, a three second window is about the longest that can reasonably be plotted in one figure. A spherical divergence correction has been applied to roughly equalize amplitudes with respect to time. The data was recorded offshore by Teledyne Exploration and was made available to the SEP by the Continental Oil Company. The source was an array of 7 airguns fired at a depth of 25 ft; the cable depth was also 25 ft, and the temporal sampling interval is 4 msec.

The feature of interest in this study is the gradual broadening of seismic events with increasing traveltime which we assume can be described by our model of attenuation. [Throughout this paper, we will refer to models, filters, symbols, etc. described in *An Inverse-Q Filter* (Hale, 1981).] This broadening with traveltime implies that the traces are non-stationary; and to reduce this non-stationarity, we applied an inverse-Q filter (IQF) to the traces of Figure 1a. A constant value of $Q_0 = 250$ was used to derive the initial, two-term, approximate inverse-filter $p^1 = (1+\varepsilon,-\varepsilon)$ where $\varepsilon \approx 0.00255$. Recall that subsequent inverse filters p^i are obtained by convolving p^1 with itself $i-1$ times. The filtered data are shown in Figure 1b. Notice that the filter has little effect on the events at early traveltimes, while the events at later traveltimes are sharpened considerably, giving the traces of Figure 1b a more "spectrally balanced" appearance. To preserve the relative amplitudes of events with respect to time, an exponential dampening was applied to compensate for the exponential gain of the IQF.

The reader may wonder how the value of $Q_0 = 250$ was chosen. Several values were tested, Fourier amplitude spectra were computed from early and late traveltime windows and then compared, and $Q_0 = 250$ was subjectively chosen as producing the most spectrally balanced output traces. A more objective, programmed method of determining Q_0 was unavailable to us at the time of this study.

To obtain a better understanding of how IQF may affect the final, processed section, we corrected for normal moveout (NMO) and then stacked both the "raw" and IQF gathers to obtain Figures 2a and 2b, respectively. Because (1) we wish to compare raw and IQF traces and (2) the effect of IQF is most notable at late traveltimes, the last (rather than the first) three seconds of the two gathers are plotted in these figures. Traces 1 through 20 are the NMO corrected traces; trace 22 is the stacked trace. Comparing the two stacked traces, IQF has enhanced the resolution of events at late traveltimes. The frequency content of the IQF stack appears relatively invariant with respect to traveltime, while the raw stack demonstrates a progressive loss of high frequencies with traveltime. In other words, the IQF data are more stationary than the raw data.

"Deconvolved" Data

Prior to CMP stacking, most seismic data processors would attempt some deconvolution of the unstacked traces. If we believe that the IQF traces are more stationary than than the raw traces, then we might expect statistical deconvolutions to be improved by a pre-decon application of IQF; recall that statistical deconvolutions perform best when applied to stationary data. To test this notion, we applied two statistical deconvolution processes to the pre-NMO gathers of Figures 1a and 1b.

The first deconvolution applied was a conventional, "spiking" deconvolution. For the raw gather of Figure 1a, the autocorrelation of a seismic wavelet was estimated by averaging the twenty autocorrelations of the twenty traces. A four-second window of data (not just the three seconds shown in Figure 1a) was used to compute each autocorrelation. Then, assuming the wavelet to be minimum-phase, a single, minimum-phase inverse operator was derived by spectral factorization of the mean autocorrelation. This operator was convolved with the raw traces, then NMO and stacking yielded the traces of Figure 3a. Again, trace 22 is the stack of traces 1 to 20. An operator of the same length (~160 msec), but designed from (and then convolved with) the IQF traces of Figure 1b produced the traces of Figure 3b.

Neither of these "deconvolved" gathers is particularly appealing. The stack of the deconvolved raw traces still exhibits a lack of high frequencies at the later traveltimes.

The time-invariant deconvolution operator can only be the inverse of some *average* wavelet in the raw traces; and while this inverse may be quite appropriate for traveltimes of about 2 sec, it has little effect on events at late traveltimes (and has likely over-amplified the high frequencies at early traveltimes). The undeconvolved, IQF stack of Figure 2b may be more desirable than the deconvolved, raw stack of Figure 3a.

In contrast, the stack of deconvolved, IQF traces suffers from an over-abundance of high frequencies. The stack's noisy appearance at late traveltimes probably results from the decreasing signal-to-noise ratio at *all* frequencies with traveltime; the high-frequency components of noise are just the first to appear. The signal-to-noise ratio of this stack may be improved by summing all of the sixty traces in the actual CMP gather rather than just the twenty traces used in this study; one might also consider (1) using a Q_0>250, thereby only partially compensating for attenuation or (2) using a bandlimited IQF (Hale, 1981).

Another approach to the noise problem is to use a different, statistical deconvolution method. Recognizing that IQF compensates for a dominant, time-variable, spectral trend, we applied the spectral-smoothing deconvolution process described by Godfrey and Claerbout (1978) which, briefly stated, preserves trends but removes rapid variations in a trace's power spectrum. (This process is somewhat analogous to the application of a "gapped" deconvolution operator.) For the raw data, a minimum-phase, deconvolution operator was designed from the average power spectrum of the twenty traces. This operator was convolved with the raw traces; then NMO and stacking were applied, resulting in the gather of Figure 4a. The same processing applied to the IQF traces yielded the gather of Figure 4b.

As expected, this deconvolution method is even less effective than spiking deconvolution in restoring the higher frequencies of the raw data at late traveltimes. The stack of *deconvolved*, raw traces (Figure 4a) is quite similar to the stack of the *undeconvolved*, raw traces (Figure 2a). But this method also prevents over-amplification of high-frequency noise at late traveltimes; the stack of deconvolved, IQF traces (Figure 4b) appears to provide a reasonable balance between the two goals of high resolution and low noise.

To enable closer examination of the stacked traces in Figures 2 through 4, these traces are plotted separately on an expanded scale in Figure 5.

Summary

The inverse-Q filter has proven to be effective as a time-variable, spectral balancing process. Whether or not the process leads to a noticeably improved, final, processed section is certainly data-dependent; and even for the data of this study, the value of IQF remains uncertain for we have looked at only one stack of twenty traces. The more

exercise of processing an entire line, both with and without IQF, is "left to the reader"; but the results of this study indicate that the exercise may well be worthwhile.

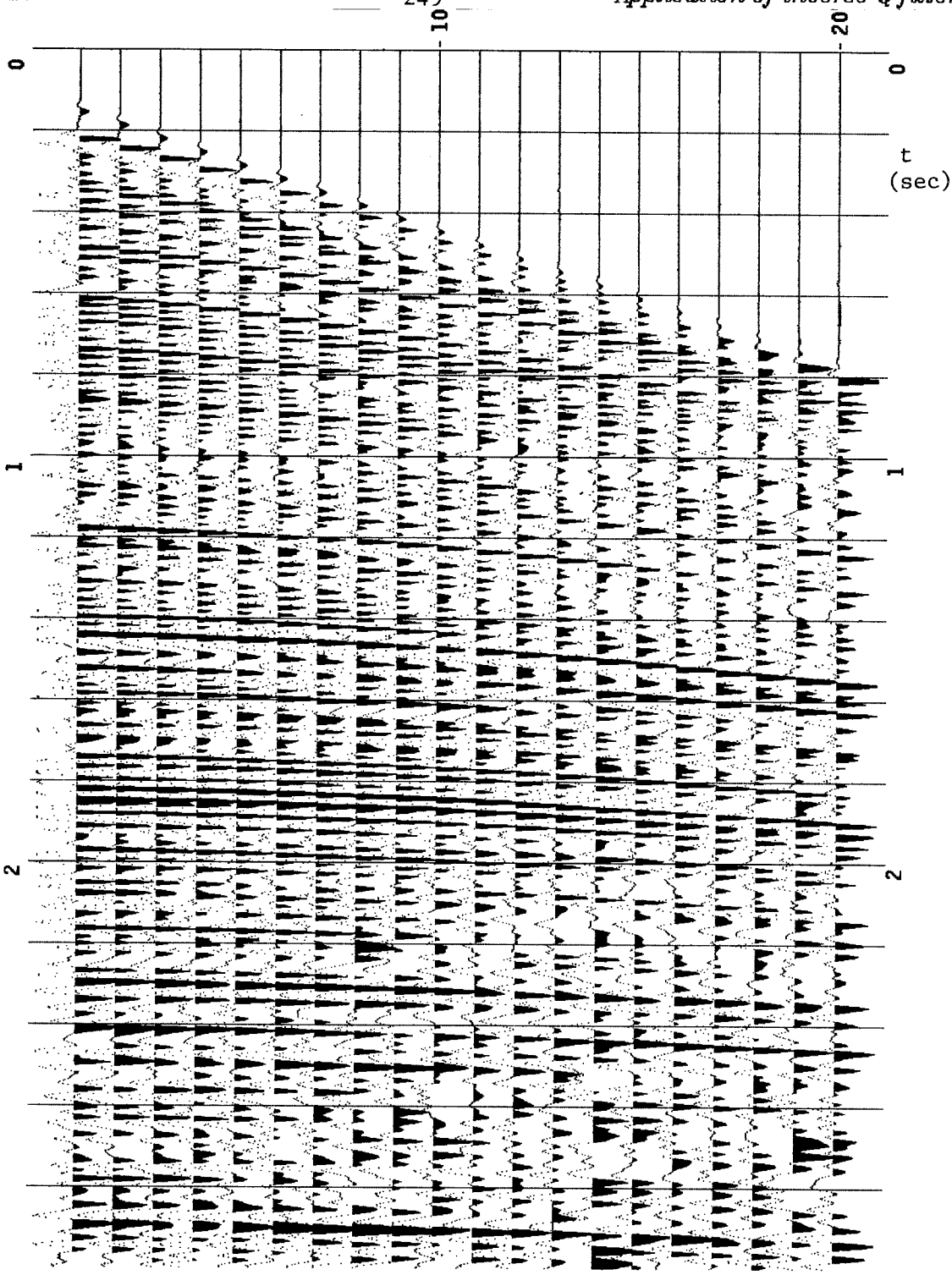

FIG. 1a. The first three seconds of the twenty-trace, "raw", CMP gather used in this study. A spherical divergence correction has been applied.

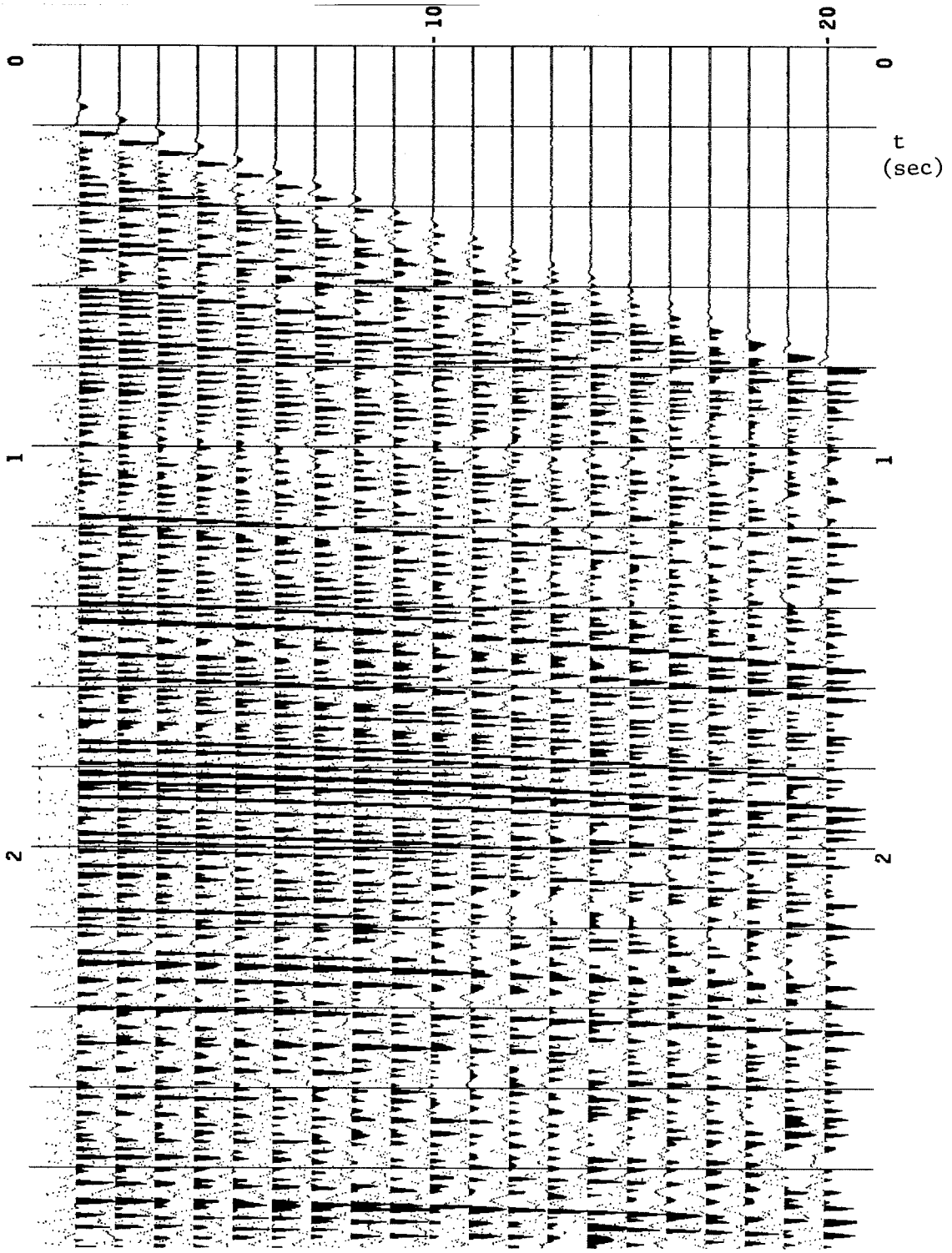

FIG. 1b. The result of inverse-Q filtering the gather of Figure 1a. A constant $Q_0 = 250$ was assumed in the inverse-filtering process.

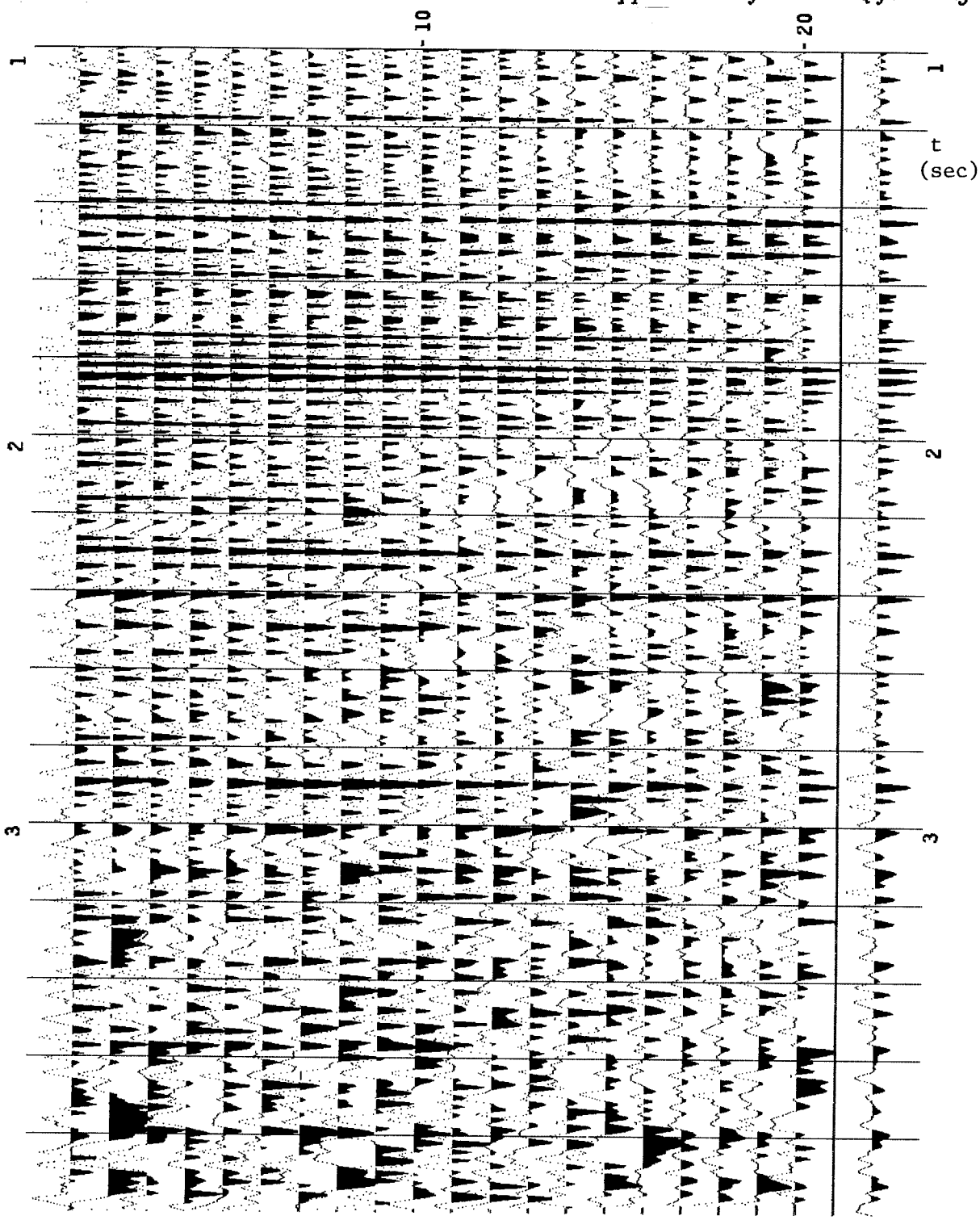

FIG. 2a. The *last* three seconds of the raw gather after correcting for normal moveout. Trace 22 is the stack of traces 1 through 20.

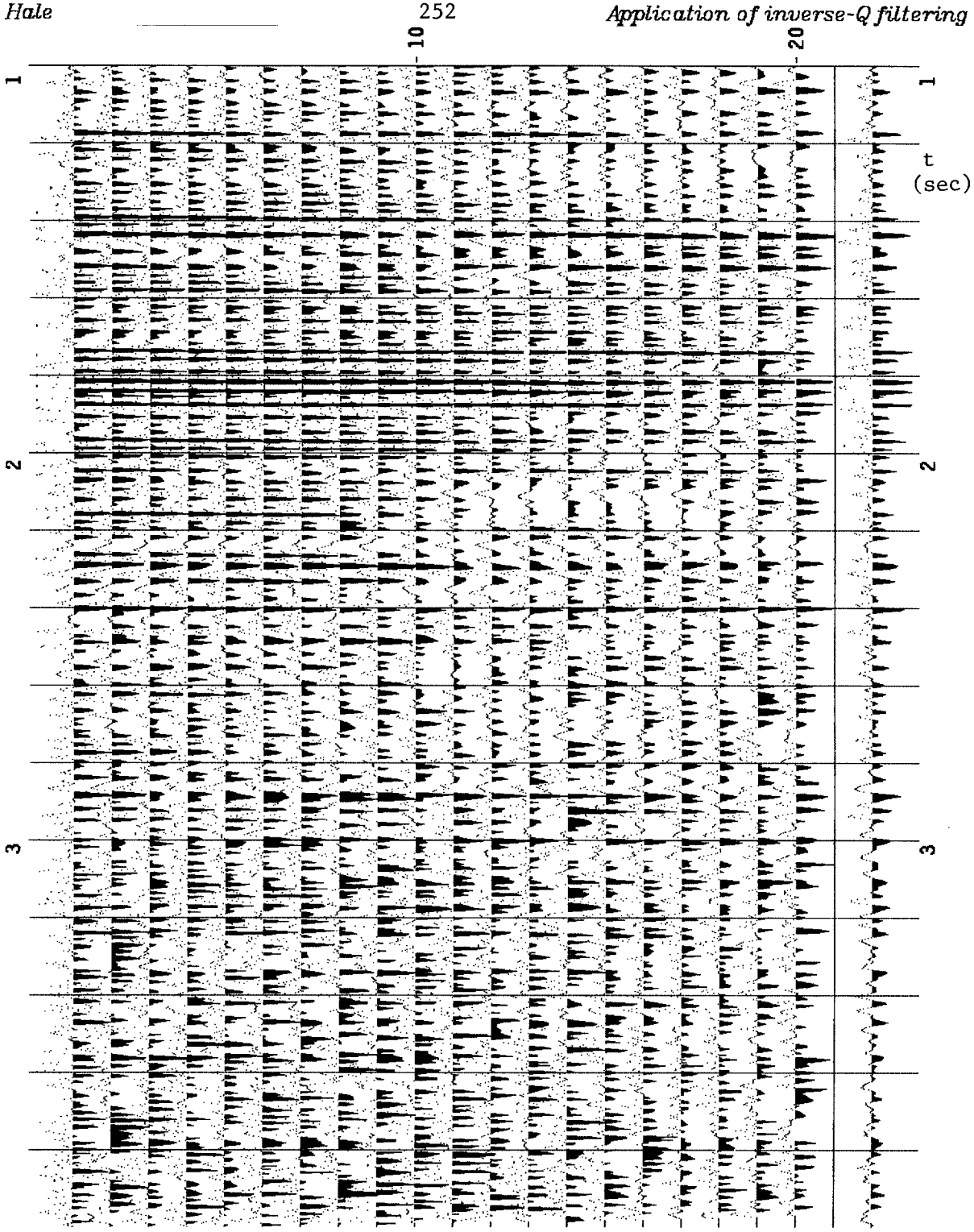

FIG. 2b. The last three seconds of the inverse-Q filtered gather after correcting for normal moveout. Trace 22 is the stack of traces 1 through 20.

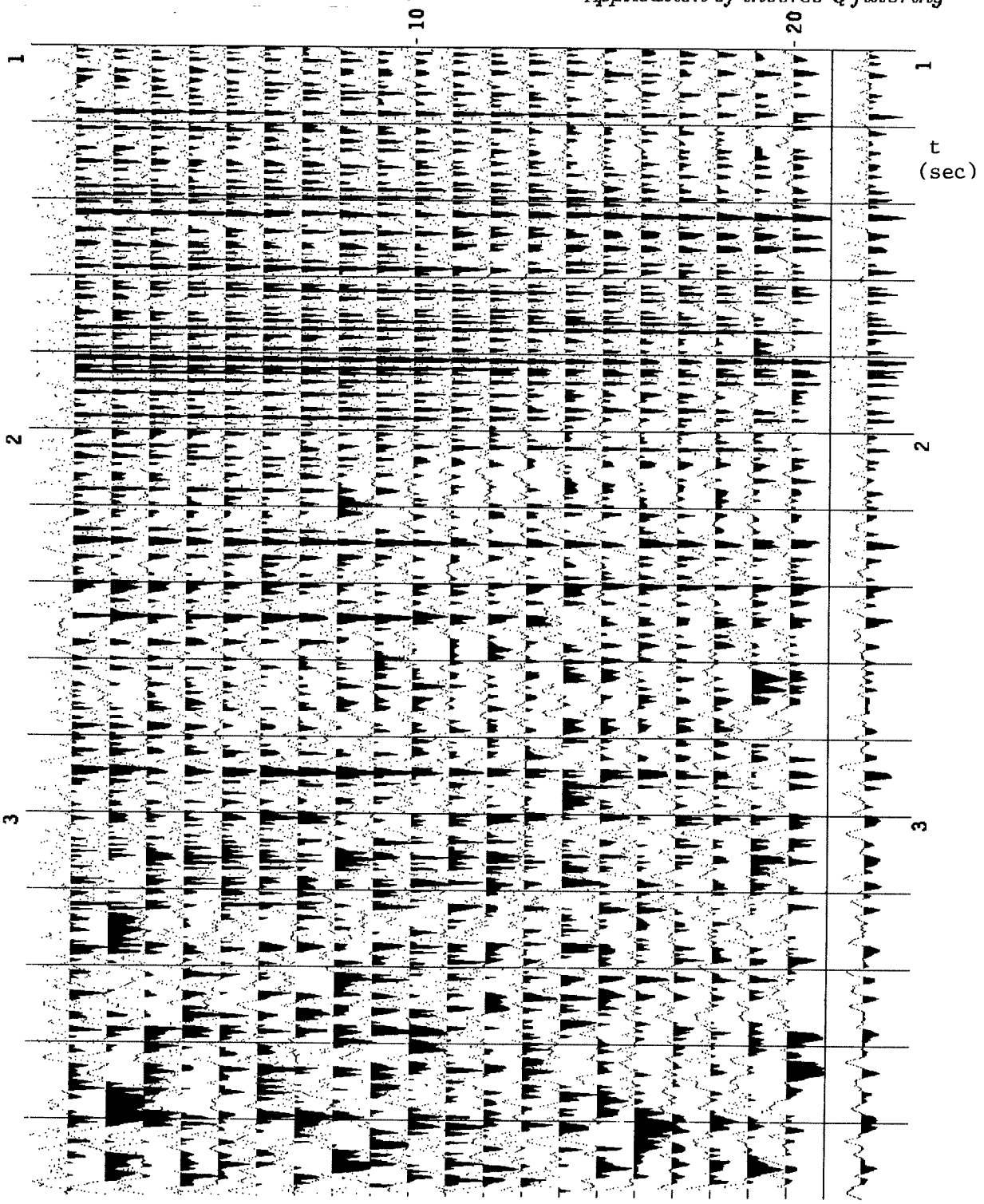

FIG. 3a. The result of applying spiking deconvolution to the raw gather. Trace 22 is the stack of the NMO-corrected traces 1-20.

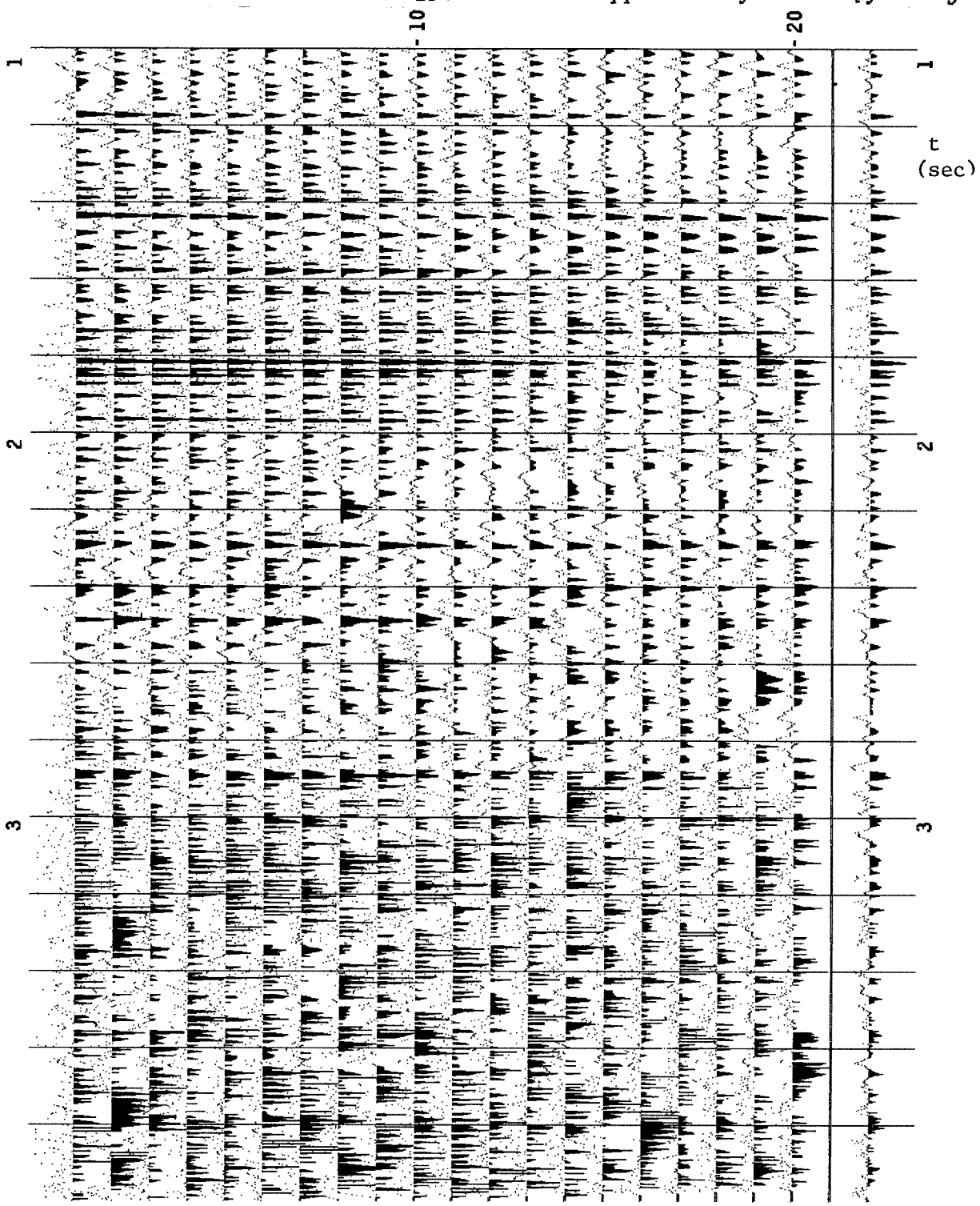

FIG. 3b. The result of applying spiking deconvolution to the inverse-Q filtered gather. Trace 22 is the stack of the NMO-corrected traces 1-20.

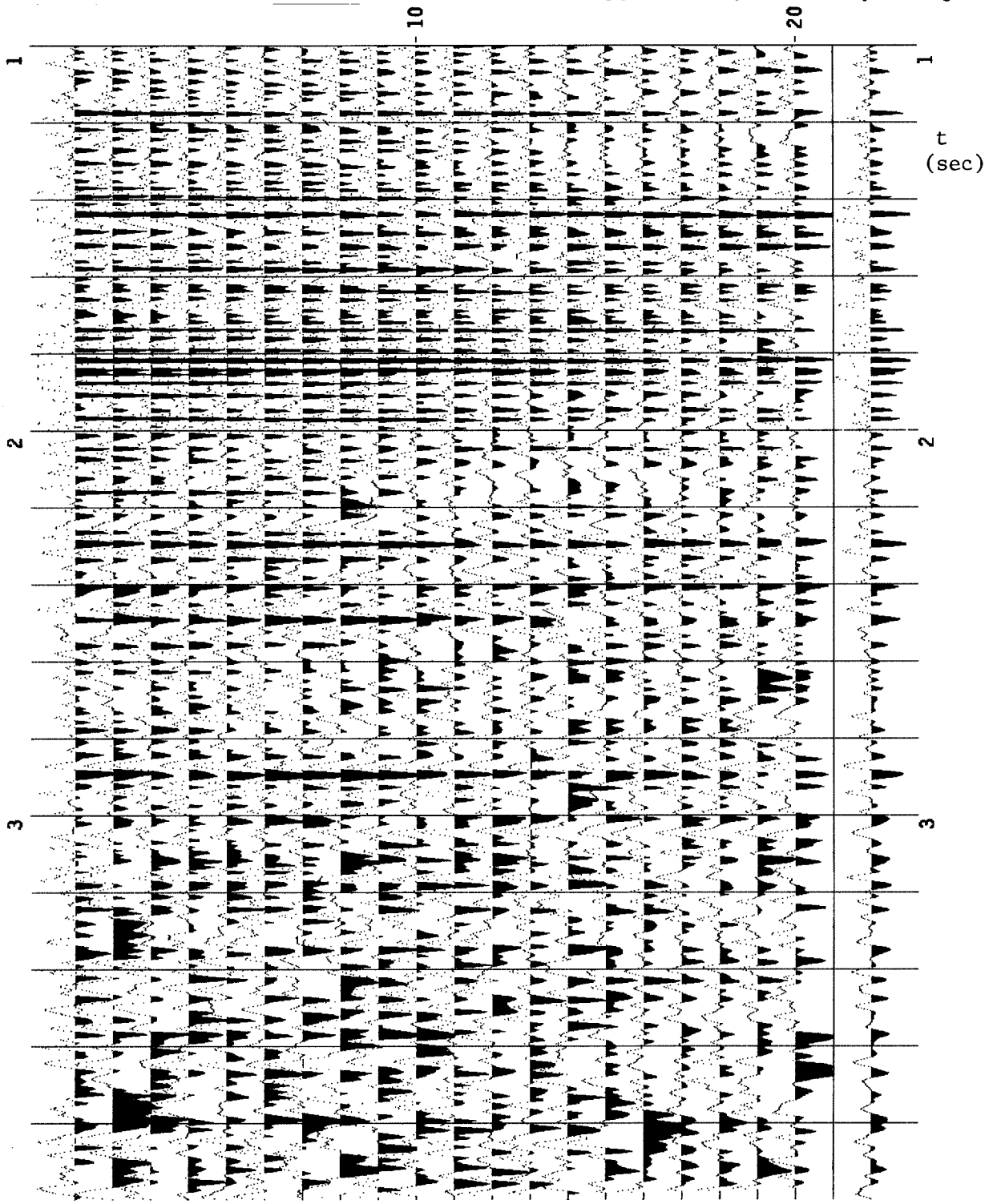

FIG. 4a. The result of applying spectral-smoothing deconvolution to the raw gather. Trace 22 is the stack of the NMO-corrected traces 1-20.

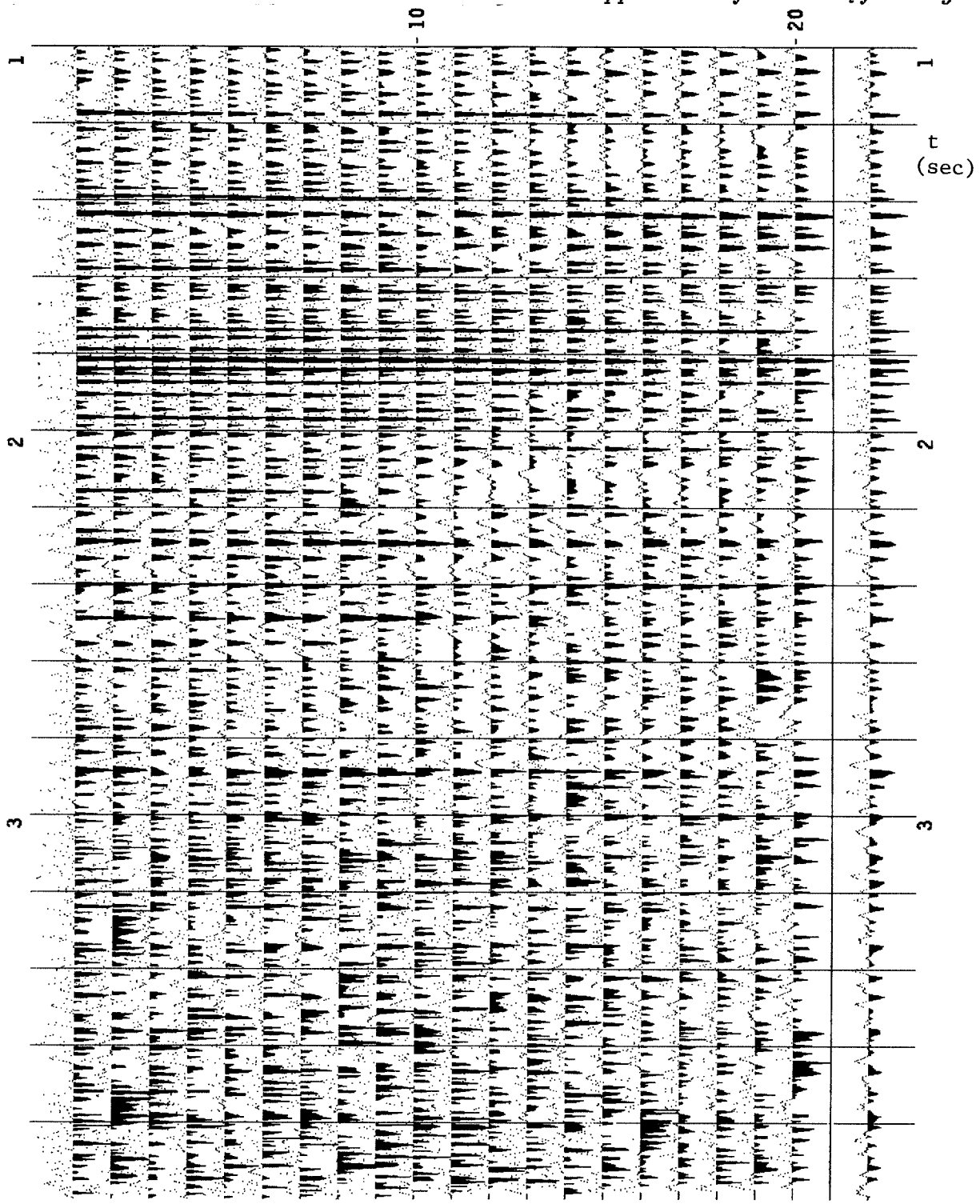

FIG. 4b. The result of applying spectral-smoothing deconvolution to the inverse-Q filtered gather. Trace 22 is the stack of the NMO-corrected traces 1-20.

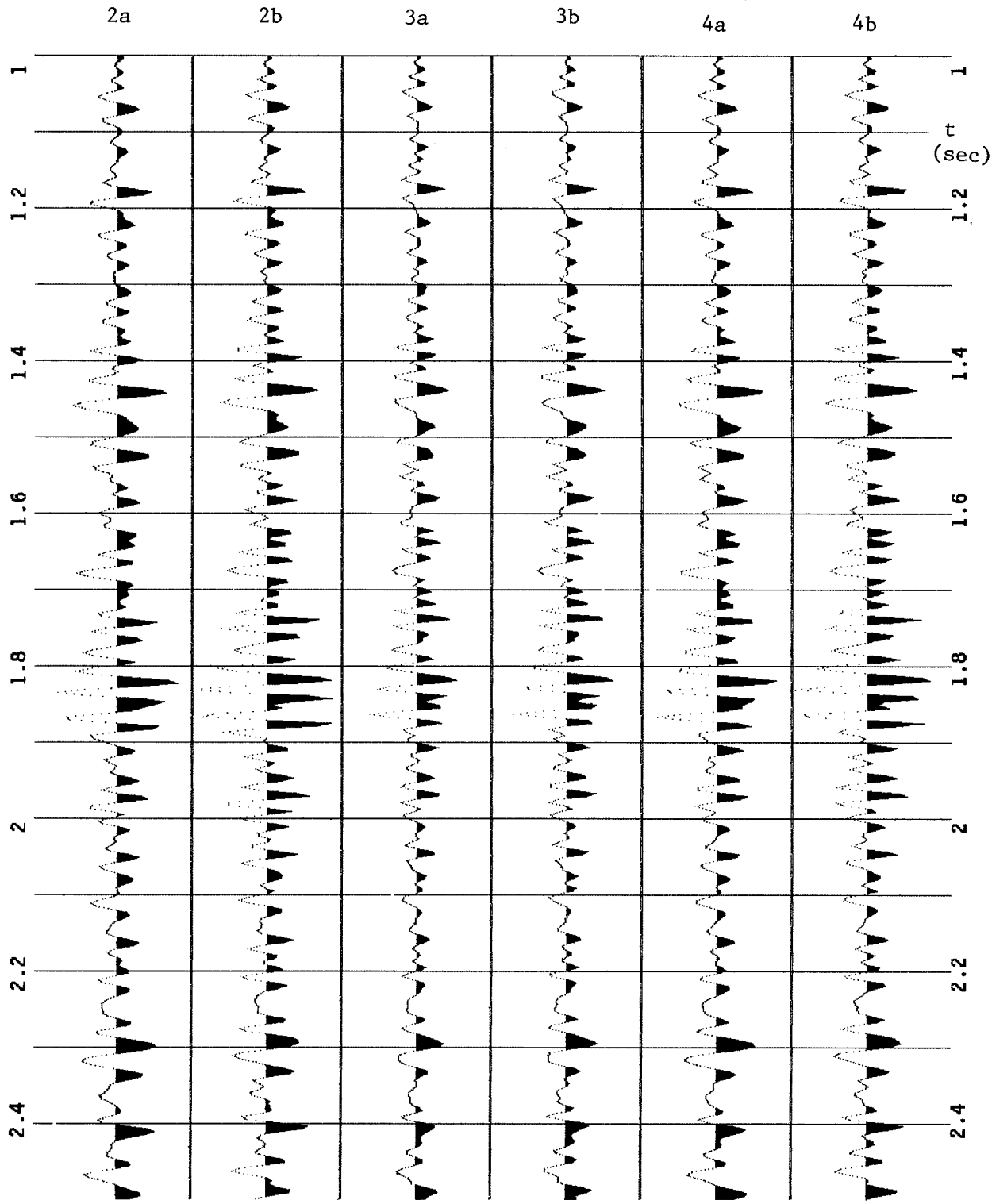

FIG. 5. The stack traces from Figures 2 through 4. 2a is the stack of raw traces; 2b is the stack of IQF traces; 3a is the stack of spiking-deconvolved, raw traces; 3b is the stack of spiking-deconvolved, IQF traces; 4a is the stack of spectral-smoothing-deconvolved, raw traces; 4b is the stack of spectral-smoothing-deconvolved, IQF traces.

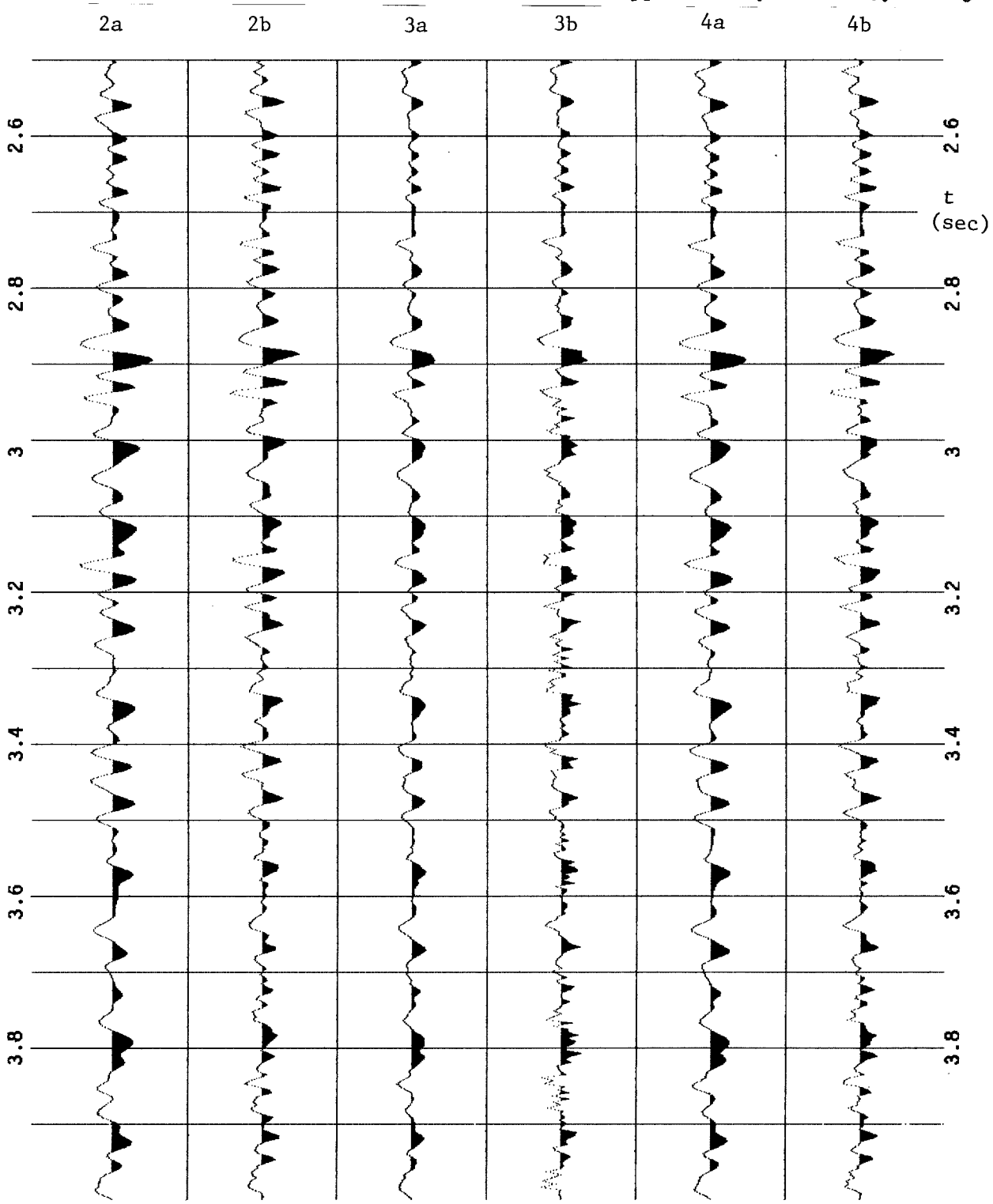

FIG. 5. (continued)

ACKNOWLEDGMENT

The author is particularly thankful for the guidance of Francis Muir during this study.

REFERENCES

Godfrey, B., and Claerbout, J., Two methods of deconvolution: power spectrum smoothing and parsimonious deconvolution: SEP-14, p.207-226.
Hale, D., 1981, An inverse-Q filter: SEP-26.

There is a great discovery still to be made in Literature: that of paying literary men by the quantity they do NOT write.

Keep grandma off the streets -- legalize bingo.

Democracy is also a form of worship.
It is the worship of Jackals by Jackasses.
-- H. L. Mencken

Don't cook tonight -- starve a rat today!

My love runs by like a day in June,
And he makes no friends of sorrows.
He'll tread his galloping rigadoon
In the pathway or the morrows.
He'll live his days where the sunbeams start
Nor could storm or wind uproot him.
My own dear love, he is all my heart --
And I wish somebody'd shoot him.

Violence is the last refuge of the incompetent.
Salvador Hardin

Birth: The first and direst of all disasters.

Lysistrata had a good idea.

Please ignore previous fortune.

God isn't dead, he just couldn't find a parking place.

If bankers can count, how come they have eight windows and only four tellers?

Death is life's way of telling you you've been fired.
-- R. Geis

"Now the Lord God planted a garden East of Whittier in a place called Yorba Linda, and out of the ground he made to grow orange trees that were good for food and the fruits thereof he labeled SUNKIST..."

Those who can't write, write manuals.