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Reprocessing of Reflection Seismic Lines R111 and R102, Risha Gas Field, Hashemite Kingdom of Jordan

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CONTENTS

ILLUSTRATIONS

TABLES

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ABSTRACT

In response to a request from the Natural Resources Authority (NRA) of Jordan the USGS reprocessed two multichannel seismic lines that were recorded over the Risha Gas field in eastern Jordan. The purpose of the reprocessing was to be able to better interpret the upper Ordovician Risha member of the Dubaideb formation, which produces gas in this area. Seismic data in this area are highly contaminated by coherent noise and require extensive f-k filtering to suppress these noise trains. We verified the validity of the f-k filter parameters used by an industry contractor, hired previously by the NRA to reprocess these data. We then used these parameters in our pre-stack processing and improved the sections by detailed residual statics analysis and by applying a Karhunen-Loeve transform technique after stacking. By using the Karhunen-Loeve transform, we were able to minimize any processing artifacts that may have been created by post-stack f-k filtering and signal enhancement algorithms used by the contractor.

We also analyzed the sources of noise and determined that the optimum method of suppressing coherent noise before stacking was to apply 3 passes of f-k filtering, first in the common-shot domain, second in the common-receiver domain, and third in the common-midpoint domain.

INTRODUCTION

In the spring of 1992 the Natural Resources Authority (NRA) of Jordan requested the assistance of the U. S. Geological Survey (USGS) in exploiting the non-conventional gas reservoirs that are known to exist in eastern Jordan. We were asked to investigate two seismic lines that were recorded over the Risha Gas field in eastern Jordan (lines R102 and R111, Figure 1). Our task was to reprocess these data, the goal of which was to be able to better interpret the upper Ordovician Dubaideb formation, Risha member, which produces gas in this area (NRA brochure, undated).

The seismic data quality in the area varies from good to extremely poor. Prior to our efforts, lines R102 and R111 had been reprocessed by a number of industry contractors who generally agreed that the poor data quality was the result of coherent noise, generated by variations in the near surface conditions.

It was known that this area contained karst deposits which can sometimes give rise to severe scattering and static anomalies. We knew little other information about the geology of this area when we began our reprocessing. Further, we had no examples of any industry contractor's reprocessing against which to compare our results. We started the reprocessing using a minimal, conventional processing sequence. Additional processing resulted in marginal improvement. We had already determined that the signal strength in some areas was dependent on the range of source-receiver offsets that were stacked when we received from the NRA (as requested), copies of their best industry-processed sections. We also received well logs, synthetic seismograms and VSP data from two wells located on line R102.

The industry-processed sections had more reflectors than our sections and many of those reflectors were more laterally continuous than ours. The contractor's processing approach was to use 2 passes of pre-stack f-k (frequency-wavenumber, or velocity) filtering to eliminate the coherent noise; the first pass was performed in the shot domain, the second pass was performed in the receiver domain. They also limited the range of source-receiver offsets used in stacking by "muting", or setting to zero, the amplitudes of portions of the data below 1.2 s. This technique was called an "inside" mute and eliminated more near (inside) source-receiver offsets with progressively increasing travel time (e.g. on line R111, at 1.5 s, offsets < 1,350 m were muted; at 4 s, offsets < 3,475 m were muted). After stacking, they used a signal enhancement technique (algorithm not known) and another pass of f-k filtering to produce their final section. They limited the frequency bandwidth to 10-35 hz.

We incorporated the industry contractor's technique of pre-stack f-k filtering into our reprocessing and by using parameters as similar as possible to those of the contractor, we were able to duplicate the quality of their sections. We were able to improve upon their results in the following ways:

1. We applied pre-stack f-k filtering, but used a broader frequency bandwidth (10-45 hz).
2. On line R111, we varied the offset ranges used in stacking, based on an analysis of stacks using subsets of the full offset range. We found that in some areas, it was possible to use a larger range of offsets than that used by the industry contractor.
3. We analyzed and applied surface-consistent residual statics based on the offset ranges of the "inside" mute zones.
4. After stacking, we rejected much of the remaining random noise by means of a Karhunen-Loeve transform (KLT) algorithm. No post-stack f-k filtering was necessary.

We also analyzed the sources of coherent noise and determined that in future processing the coherent noise could be more effectively suppressed by additional f-k filtering, applied in the common-midpoint (CMP) domain. We recommend that this technique be used in future reprocessing, but in this study we applied the CMP domain f-k filter to a test section of the data only.

This report describes our reprocessing effort and gives an analysis of the sources of noise present, and an optimum method for eliminating the noise from lines R102 and R111, which should be useful if additional seismic data from this area is reprocessed.

ACKNOWLEDGEMENTS

The authors wish to thank the Natural Resources Authority of the Hashemite Kingdom of Jordan for providing, and granting permission to publish, the seismic data used in this study. We also thank David Taylor and William Stephenson for their valuable reviews of the manuscript.

RECORDING PARAMETERS

The data were recorded by Geophysical Service Inc. in the late spring of 1987. The data were recorded using 120 recording channels (asymmetric split-spread), Vibroseis energy sources, 50-m group intervals, and 100-m source intervals, giving 30-fold CMP coverage. The data were crosscorrelated in the field, resulting in maximum record lengths of 5s. Details of the recording parameters are given in Table 1.

INITIAL USGS REPROCESSING

Initial reprocessing was performed using a minimal, conventional processing sequence that included datum statics, spectral whitening, stacking velocity analysis, surface-consistent residual statics analysis and bandpass filtering. Details of the processing sequence and pertinent parameters are given in Table 2. The result of this initial processing for representative portions of both lines is shown in Figure 2 (a-c).

Line R111 was of much better quality than R102. Three main bands of relatively continuous reflectors can be seen at about .5, 1.8, and 3.1 s Two-way Traveltime (TWTT) (Figure 2a,b). Equivalent reflectors on line R102 were much less continuous (Figure 2c). Surface consistent-residual statics analysis on line R111 was successful in improving the continuity of the reflector at 3.1s, but the reflector continuity on line R102 was much less than that of line R111 and this made residual statics analysis difficult.

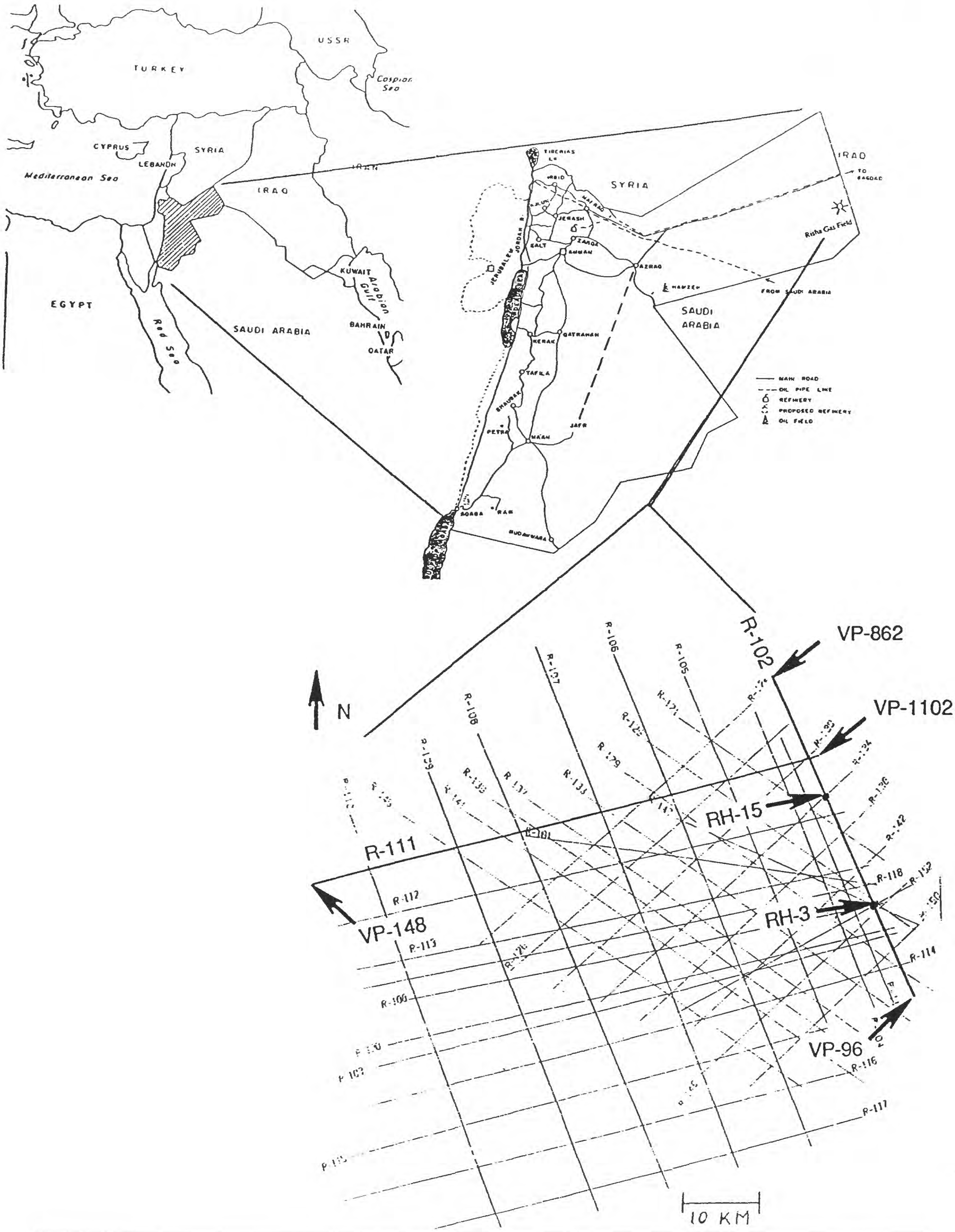


Figure 1. Sketch Map showing study area and location of seismic lines and wells. Because portions of this map are reductions of the only maps available, some type may be illegible; it is not needed to convey the information intended.

Parameter	Line R111	Line R102
Date Shot	June 3-7, 1987	May 2-6, 1987
Instrument	DFS-V	DFS-V
Analog Filters	low: OUT; high: 90Hz, 72dB/Oct	low: 8Hz; high: 90Hz, 72db/oct
No. of Channels	120	120
Record Length	5s after correlation	5s after correlation
Group Interval	50 m	50 m
No. Phones/Group	36	36
Pattern	3 parallel strings of 12 phones (in-line), 1 m apart, staggered by 2m	3 parallel strings of 12 phones (inline), 1 m apart, staggered by 2 m
Length	70 m	70 m
Connection	12 phones in series, 3 strings in parallel;	12 phones in series, 3 strings in parallel
Spread	Asymmetrical Split 24:96 Chan1 -1275 m Chan24 -125 m Chan25 +125 m Chan120 +4875 m	Asymmetrical Split 40:80 Chan 1 -2045 m Chan 24 -125 m Chan 25 +125 m Chan 120 +4075 m
Source	Vibroseis	Vibroseis
Sweep Length/taper	10 s / .75 s	10 s /.75 s start 1.5 s end
Sweep Freq/type	6-50 Hz / Linear	8-70 Hz Linear (.15 db/Hz)
# Sweeps per VP / # of Vibrators	8 / 4	8 / 4
Source array	Type: Parallelogram Length: 125 m Width: 45m Lateral Spacing: 15m Stagger: 12.5 m Move-up: 12.5 m	Type: Parallelogram Length: 125 m Width: 45 m Lateral Spacing: 15 m Stagger: 12.5 m Move-up: 12.5 m
Source Interval	100 m	100 m
Subsurface fold	30	30
Tie points	Line R102; SP 1084	Line R111; SP 662

Table 1. Recording parameters for Lines R111 and R102

Processing Step	Parameters, Line 111	Parameters, Line 102
Automatic Gain Control (AGC)	1 s sliding window	1 s sliding window
Spectral Whitening	5-10 / 45-55 Hz	3-6 / 50-70 Hz
Datum Statics	Velocities from Field Calculations	Field Supplied Statics
Velocity Analysis	CVA's (2 passes)	CVA's (2-passes)
Surface-consistent Residual Statics	2 passes	1-pass
Normal Moveout		
First Break Mute	Offsets: 175, 750, 4000, 4875 m Times: 0, .7, 1.8, 2.3 s	Offsets: 0, 75, 750, 2075, 2375, 4025 m Times: .025, .05, .7, .95, 1.35, 1.9 s
Stack		
Bandpass Filter	0-1 s: 12.5-35 Hz 1.6-5 s: 10-35 Hz	5-10 / 35-45 Hz
Time-Variant Scaling	Window Lengths: .4, .4, .8 s	None

Table 2: Initial USGS processing sequence and pertinent parameters for Lines R102 and R111

At this point in the study, we had no way of knowing whether the result of our reprocessing was an improvement over that of the industry contractor. We began to test alternate processing schemes and at the same time we requested copies of the original sections and geologic information available from the NRA. We were sent copies of their best reprocessed sections as well as Vertical Seismic Profiles (VSP), well logs, and synthetic seismograms for two wells located on line R102: RH-3, which produces gas, and RH-15, which is non-productive (Figure 1). Some additional geologic information was also sent in a letter, and that information was presented in the introduction of this report. Representative portions of the contractor-processed sections are shown in Figure 3 (a-c).

Although our reprocessed sections had a wider bandwidth, the contractor-processed sections had resolved more reflectors. Furthermore, most reflections on the contractor-processed sections were more laterally continuous, especially in the area of the target zone at 1.7-2.0 s TWTT. This target-zone reflector was noticeably absent on the east end of line R111 (Figure 2b) and was weak or absent everywhere on line R102 (Figure 2c).

INDUSTRY CONTRACTOR PROCESSING

The data were reprocessed by contractor in March, 1988. As mentioned under the section entitled Recording Parameters, the data were crosscorrelated in the field. Table 3 gives the processing sequence and as many of the parameters as could be determined from the side label of the sections provided to us by the NRA. We could not determine the exact parameters for some of the processing steps. For example, the residual statics step stated that there were 2 passes of 5 iterations performed; there is no information about the algorithm used, the time windows analyzed, or maximum static shifts that were allowed. Similarly, the signal enhancement step gives no information about the algorithm used.

Processing Step	Parameters, Line 111	Parameters, Line 102
True Amplitude recovery	2.5 dB/sec 0-2 s	2.5 dB/sec; 0-2 s
F-K (Velocity) Filter, Shot Domain	+9 / -4 ms/trace	+9 / -4 ms/trace
F-K (Velocity) Filter, Receiver Domain	+18 / -8 ms/trace	+18 / -8 ms/trace
Gapped Deconvolution	Oper Length: 228 ms Gap: 28 ms Single Window Design	Oper Length: 228 ms Gap: 28 ms Single Window Design
Time variant Scaling	Window lengths: .3, .4, .5, .9. .7 s Start: .1, .9, 1.75 s Offsets: 125, 1700, 4875 m	Gate Len: .3, .4, .5, .9, 1.0 s Start: 0, .9, 1.4 s Offsets: 75, 1700, 4025 m
Datum Statics	Field Statics	Field Statics
Velocity Analysis		
Normal Moveout		
Datum Shift	+800 m, V = 2200 m/s	+800 m, V=2200 m/s
Residual Statics	2 passes, 5 iterations	2 pass, 5 iterations
First Break Mute	Offsets: 175, 750, 4875 m Times: 0, .7, 1.6 s	Offsets: 75, 750, 4025 m Times: .8, 1.0, 1.4 s
"Inside" Mute	Offsets: 0, 1350, 3475 m Times: 1.2, 1.5, 4.0 s	Offsets: 0, 660, 2500, 2600 m Times: .8, 1.0, 3.0, 5.0 s
Stack	30-fold	30-fold
Signal Enhancement	Algorithm Unknown; 55% of input added back	Algorithm Unknown; 40% of input added back
F-K Filter	Reject: +5.2 - +12.5 ms/trace	Reject: +6/+9 ms/trace
Bandpass Filter	0-1 s: 12.5-35 Hz 1.6-5 s: 10-35 Hz	0-1 s: 12.5 - 35 Hz 1.6-5 s: 10 - 35 Hz
Time-Variant Scaling	Window Lengths: .4, .4, .8 s	Window Lengths: .4, .4, .8 s

Table 3: Contractor processing sequence and pertinent parameters for Lines R102 and R111

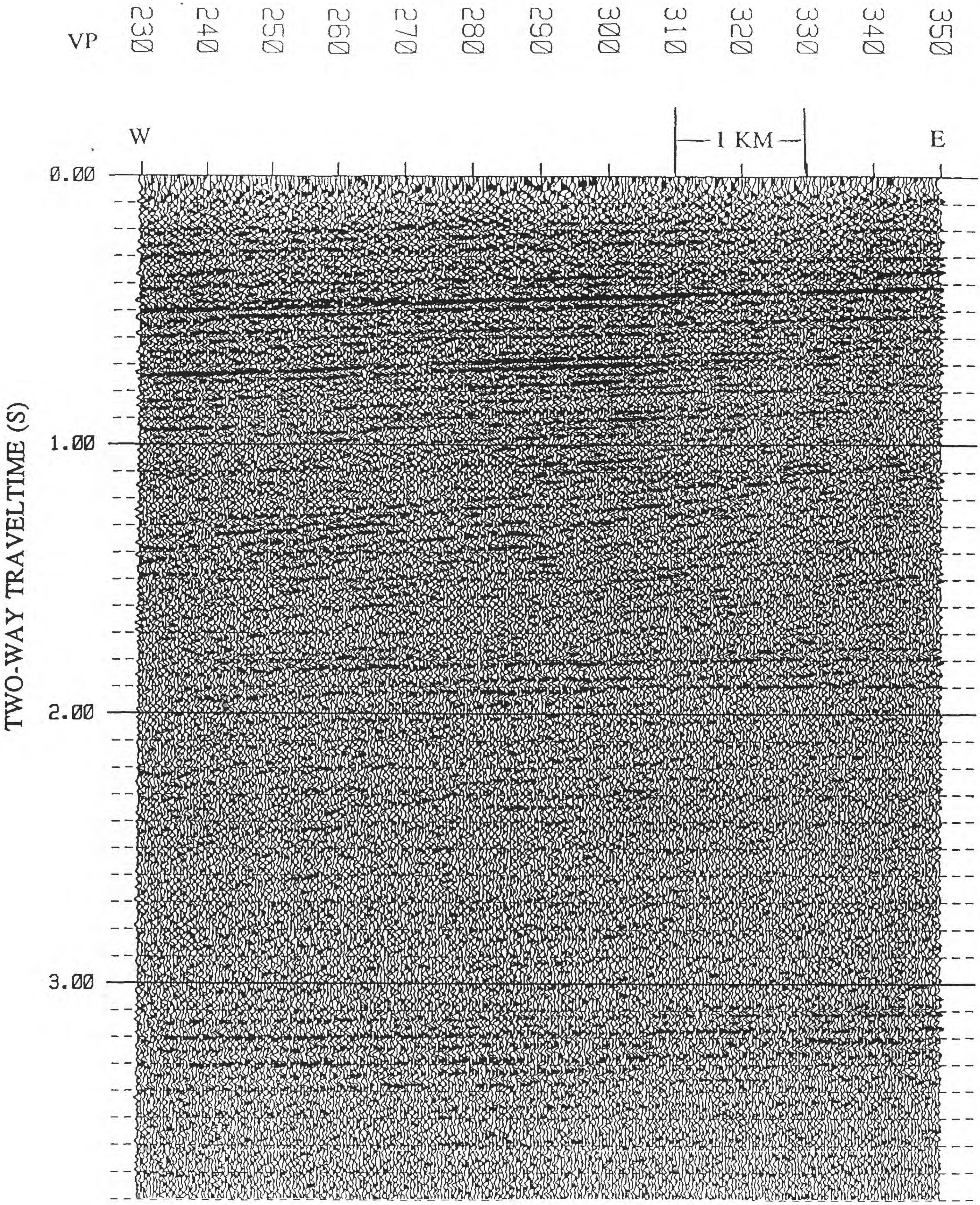


Figure 2a. USGS initial reprocessing (west end) of line R111

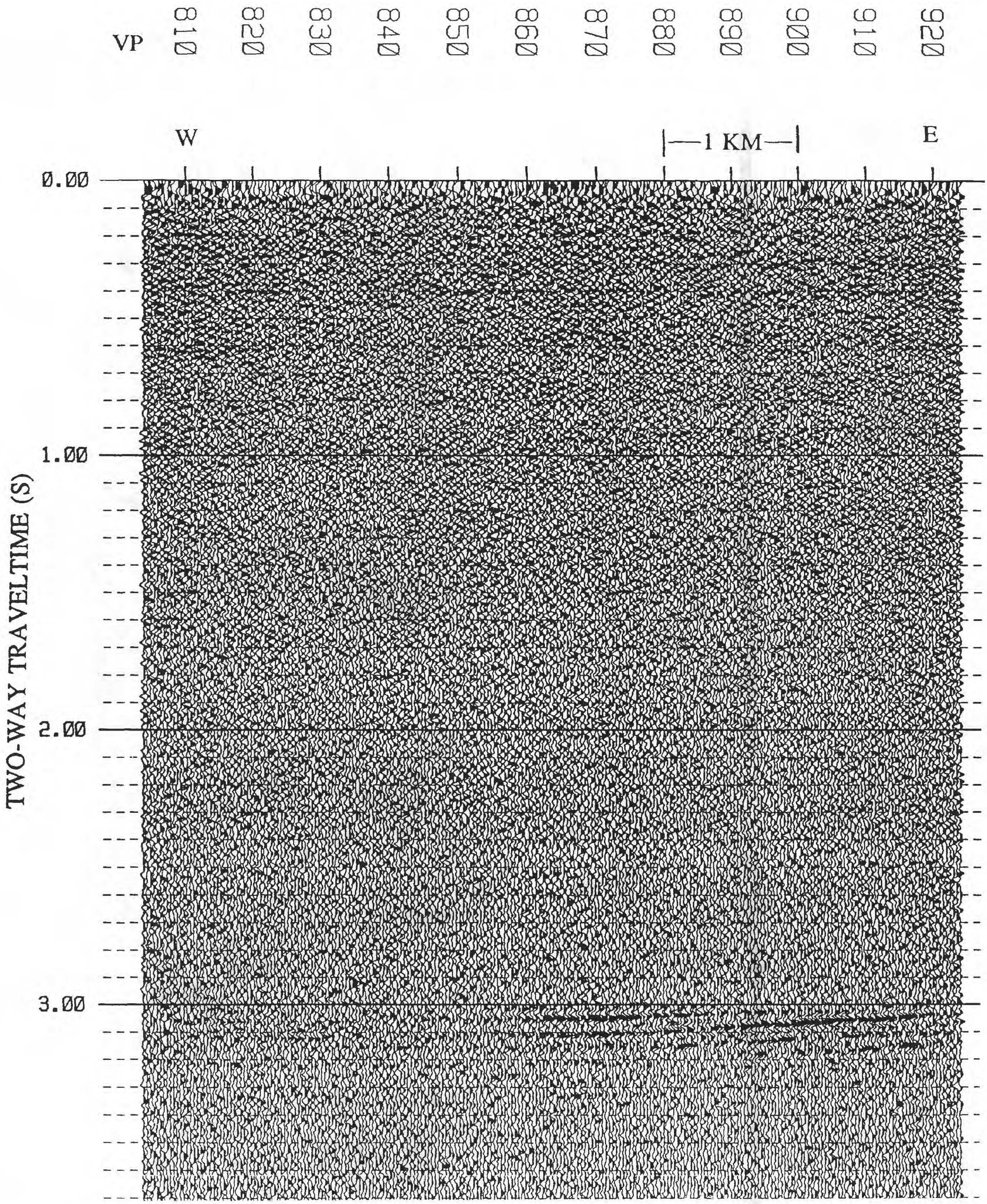


Figure 2b. **USGS initial reprocessing (east end) of line R111**

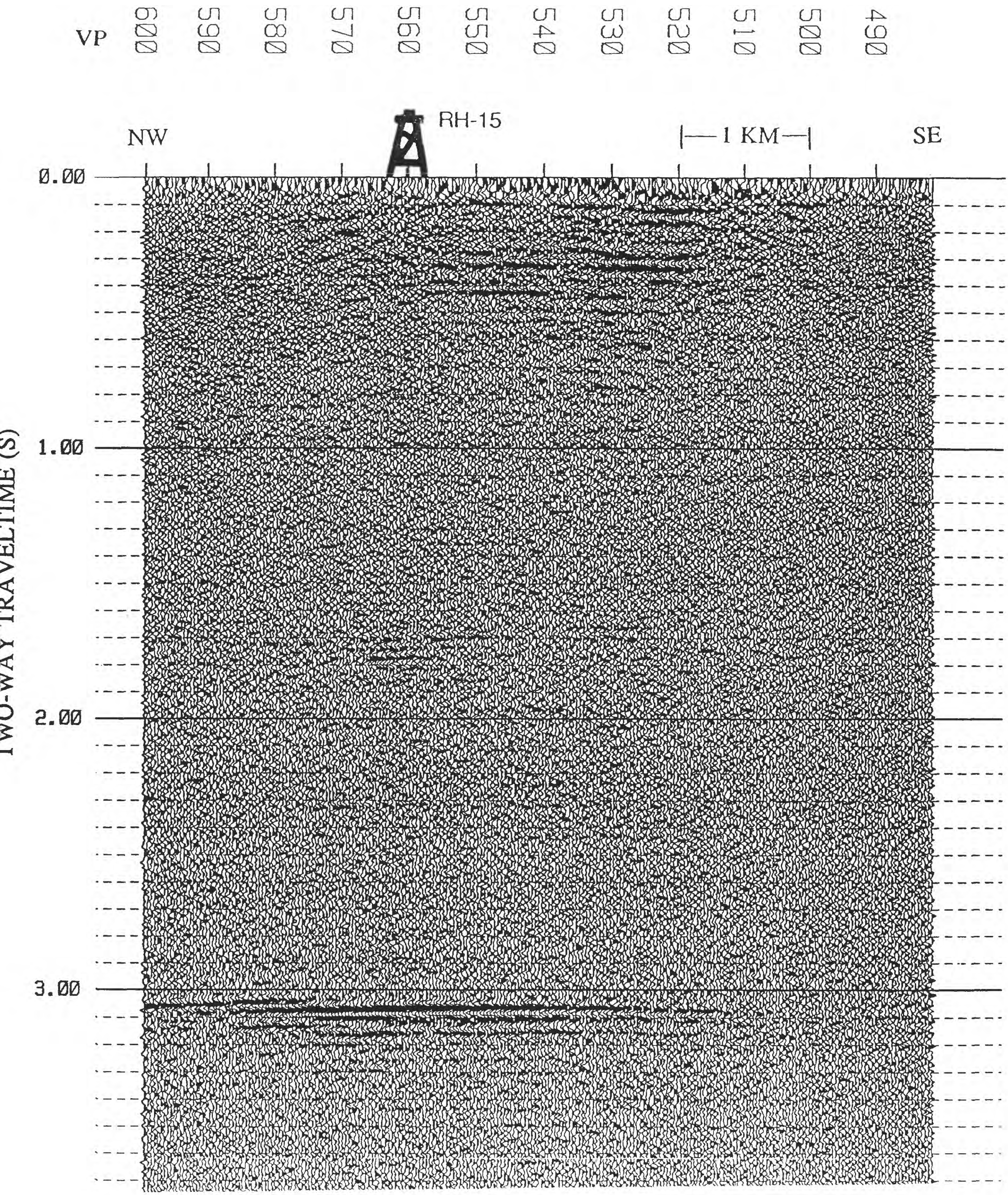


Figure 2c. USGS initial reprocessing (central portion) of line R102

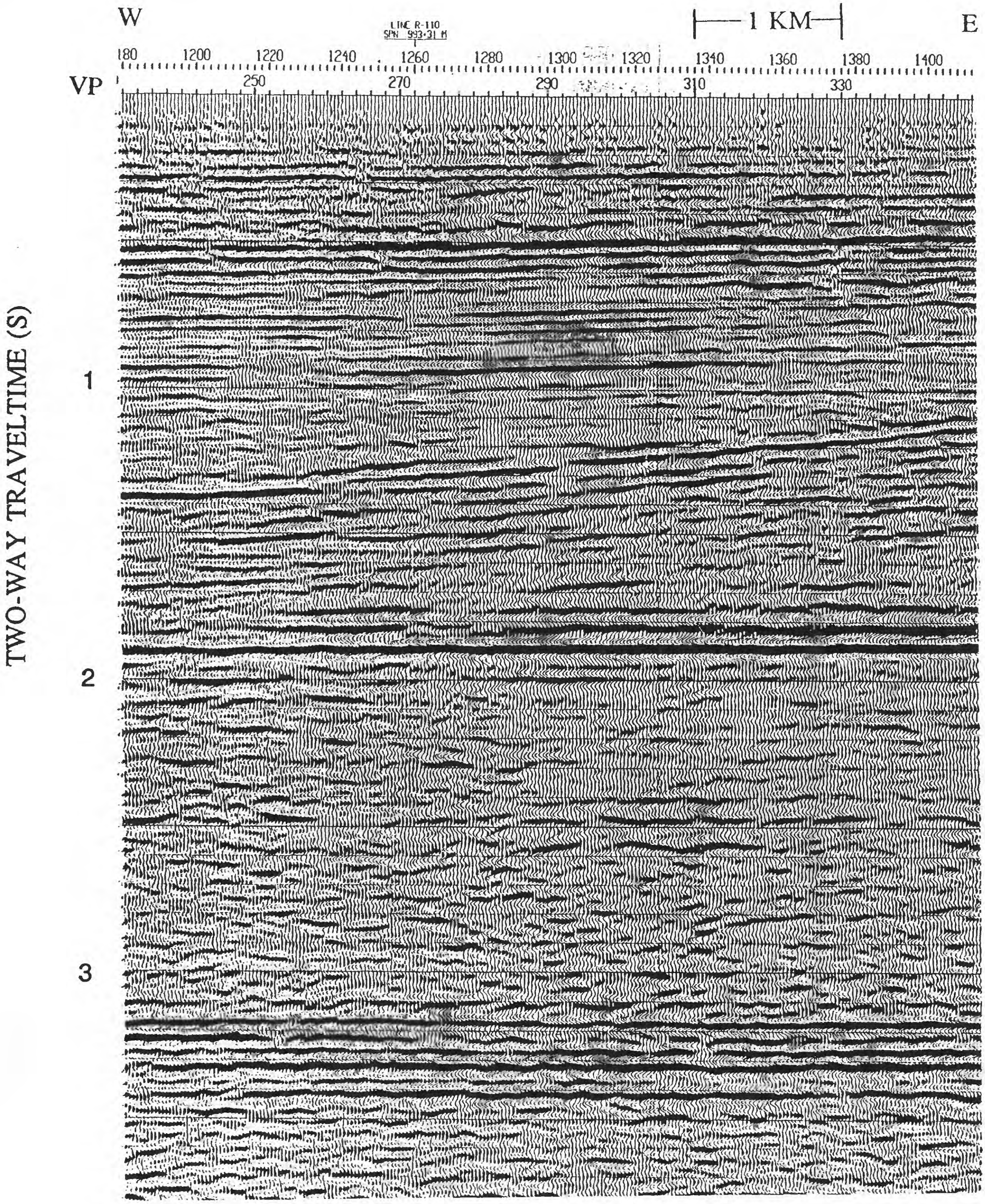


Figure 3a. Portion of contractor's reprocessing of line R111 (west end)

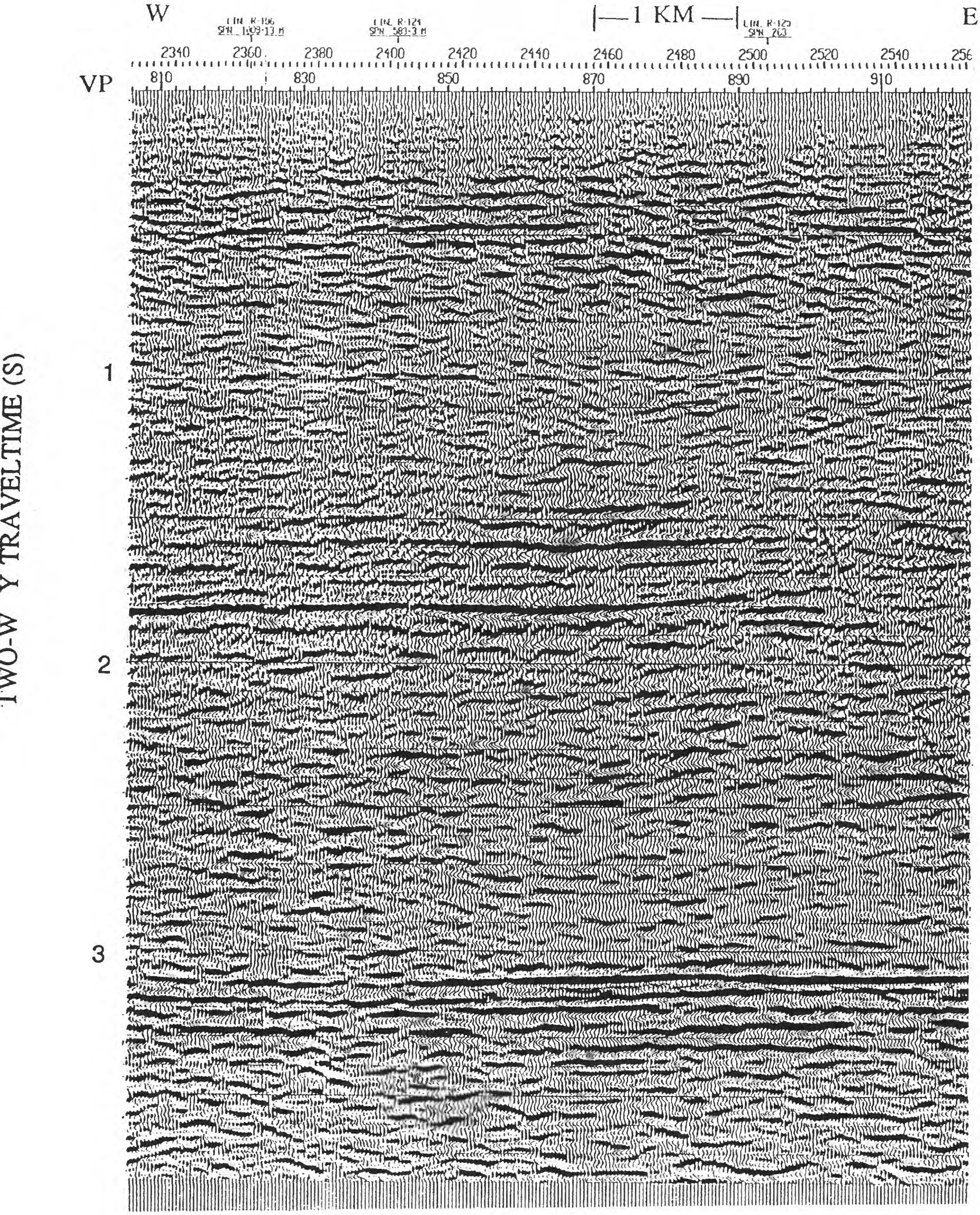


Figure 3b. Portion of contractor's reprocessing of line R111 (east end)

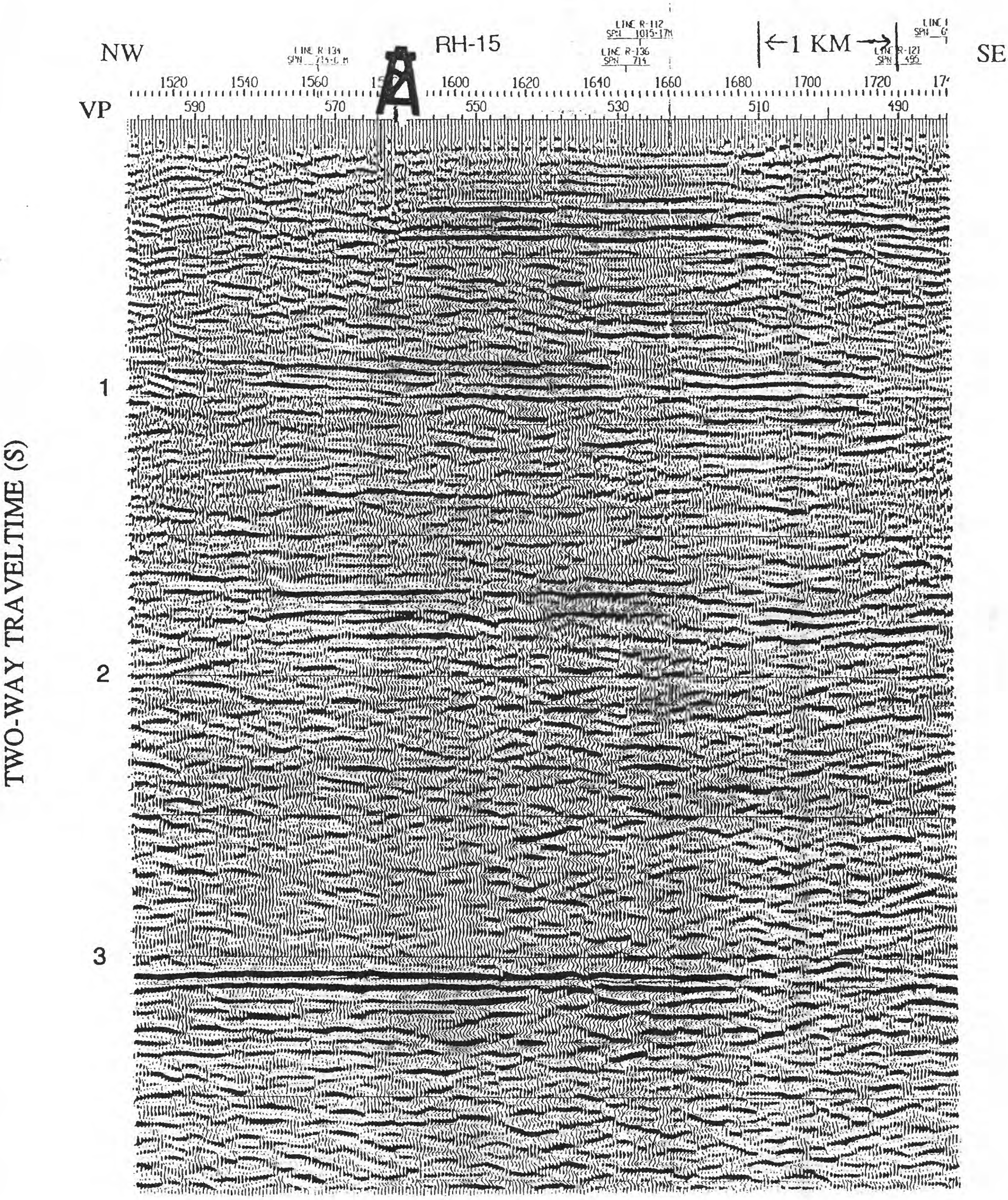


Figure 3c. **Portion of contractor's reprocessing of line R102 (central)**

There were two main differences between the contractor's processing sequence and our initial processing sequence. The first was that the contractor performed pre-stack F-K filtering in both the shot- and receiver-domain, and f-k filtering was also performed after stacking. The second was that the contractor preformed a so-called "inside" mute prior to stacking. The effect of this inside mute was to eliminate from stacking those traces that had small source-receiver separation (near offsets). More near-offset traces were eliminated with increasing travel time. For example, at 1.2 s all offsets were stacked, at 1.5 s only offsets greater than 1350m were stacked and at 4 s, only offsets greater than 3475 m were stacked.

USGS REPROCESSING: 2ND PASS

It was apparent that an intensive effort was carried out by the industry contractor to analyze and eliminate the noise that was contaminating the data. Rather than duplicate the contractor's effort, we adopted the following approach: we would attempt to create sections equivalent to those of the contractor, using parameters as similar to theirs as possible and then concentrate our efforts upon making further improvement to the data.

We applied f-k filtering using the same dip ranges as those of the contractor in both the shot and the receiver domains. We verified that these f-k parameters were correct and present this verification below in the section entitled Noise Analysis. Prior to stacking we applied the contractor's "inside" mute (Table 3). After stacking, we applied a signal enhancement program and f-k filter to obtain a result very similar to that of the contractor.

We were able to improve upon the contractor's result by changing some of the processing steps and parameters as described below. The way in which we varied the amplitude balance, deconvolution and "inside" mute contributed somewhat to the improved result. However, we feel that our residual statics and post-stack processing approach (#'s 4 and 5, below) were responsible for most of the improvement. Our complete processing sequence and parameters used are given in Table 4.

1. Amplitude Balance: We used automatic gain control (AGC) by means of a 1 s long sliding window to balance the amplitudes. The contractor used a programmed gain curve (Table 3) before deconvolution and then a number of fixed-size windows after deconvolution to balance amplitudes.

2. Deconvolution: We used a spectral whitening algorithm (Lee, 1986) in place of the contractor's gap deconvolution. This algorithm does not make the minimum phase assumption as does gap-deconvolution, and thus is theoretically more appropriate for Vibroseis data, which is assumed to be zero phase.

3. "Inside" Mute: For velocity analysis on both lines, and for stacking line R102, we used the same mutes (NMO-stretch, and "inside") as those of the contractor; on line R111, we varied the NMO-stretch and inside mutes based on offset-dependent stacking tests (discussed below).

4. Residual Statics: On the contractor's section, the side-label stated only that two passes of 5 iterations were used; no information regarding time windows analyzed, maximum time shifts allowed, algorithm used, etc. was given. We therefore made our own decisions regarding residual statics analysis and application. We tried both surface-consistent and non-surface consistent residual statics algorithms and decided to use the surface-consistent algorithm.

For line R111 we made two passes of residual statics: The first pass used 600 ms and 450 ms windows centered at 1.9 s and 3.1 s TWTT, respectively. A maximum static shift of +-32ms was allowed. Four iterations were performed. The second pass used a 450 msec window centered at .25 s. A maximum shift of +- 20 ms was allowed. Because of the "inside" mute applied before statics analysis, we applied the first pass of statics to traces whose source-receiver offsets were greater than 750 m and the second pass to those traces whose offsets were less than or equal to 750 m.

On line R102, reflector continuity in the shallow section (<1s TWTT) was poor. For this reason, only one pass of residual statics was applied to this line using a time window of 600 ms centered at 3 s TWTT and applied to offsets greater than 2125 m only. Four iterations and a maximum shift of +- 48ms were used.

Processing Step	Parameters, Line 111	Parameters, Line 102
Automatic Gain Control	1 s sliding window	1 s sliding window
F-K (Velocity) Filter, Shot Domain	+9 / -4 ms/trace	+9 / -4 ms/trace
F-K (Velocity) Filter, Receiver Domain	+18 / -8 ms/trace	+18 / -8 ms/trace
Spectral Whitening	5-10 / 45-55 Hz	3-6 / 50-70 Hz
Datum Statics	Flat Datum = + 800 m Vcorr = Variable, from field calculations	Flat Datum = +800 m Static values from field calculations
Velocity Analysis	Constant Velocity Stack Method. "Inside" mute applied.	Constant Velocity Stack Method. "Inside" mute applied.
Normal Moveout		
Residual Statics	4 iterations: Pass #1: offsets >750m Trace Mix: 21, 17, 13, 11 Time windows: .6 s centered @1.9s; .4 s centered @3.1s Max Shift: 32 ms Pass #2: offsets<=750m Time window: .45 s centered @.25 s Max Shift: 20 ms	4 iterations: Trace Mix: 21, 17, 13, 11 Time Window: .6 s centered at 3 s Max Shift: 48 ms Statics applied to offsets > 2125 m only
First Break Mute	Offsets: 175, 750, 4000, 4875 m Times: 0, .7, 1.8, 2.3 s	Offsets: 0, 75, 750, 2075, 2375, 4025 m Times: .025, .05, .7, .95, 1.35, 1.9 s
"Inside" Mute	Variable, based on stacking tests of offsets 0-1, 1-2, 2-3, 3-4, 4-5 km	Based on inside mute used by industry contractor (GSI)
Stack	30-fold	30-fold
Post Stack Balance	1s windows overlapped at increments of .75s	None
Predictive Deconvolution	2nd zero crossing filter length: 220 ms % white noise: .5 Design: .1-2.2s; 1.5-4s	2nd zero crossing filter length: 140 ms % white noise: 3 Design: .1-2.2s; 1.5-4s
Bandpass Filter	5-10 / 45-55 Hz	5-10 / 45-55 Hz
Random Noise Reduction	KLT transform method	KLT transform method

Table 4: Final USGS Processing sequence and pertinent parameters for Lines R102 and R111. This sequence was used to produce the sections shown in Figures 4a, 4b, and 4c.

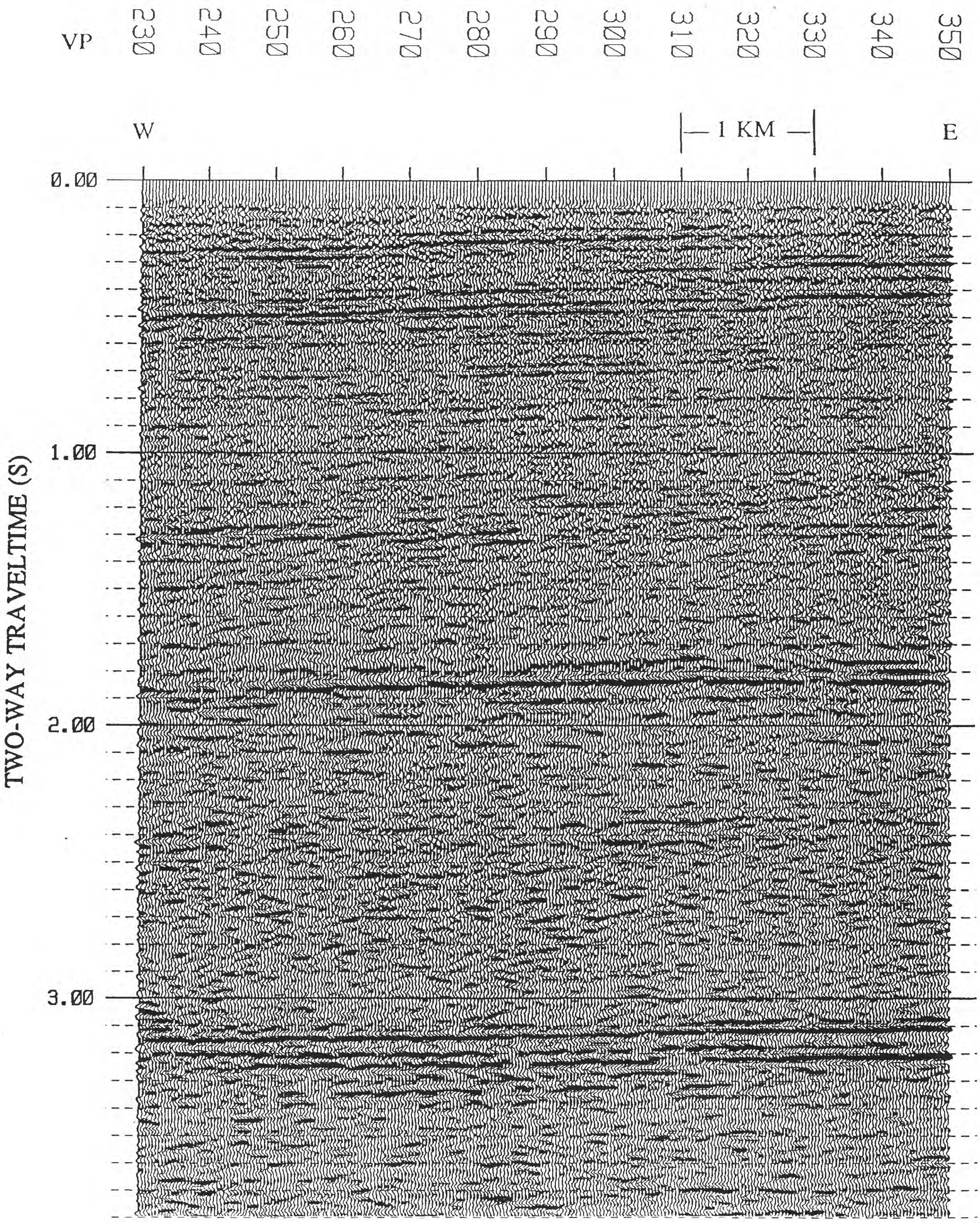


Figure 4a. **Portion of USGS final reprocessing of line R111 (west end)**

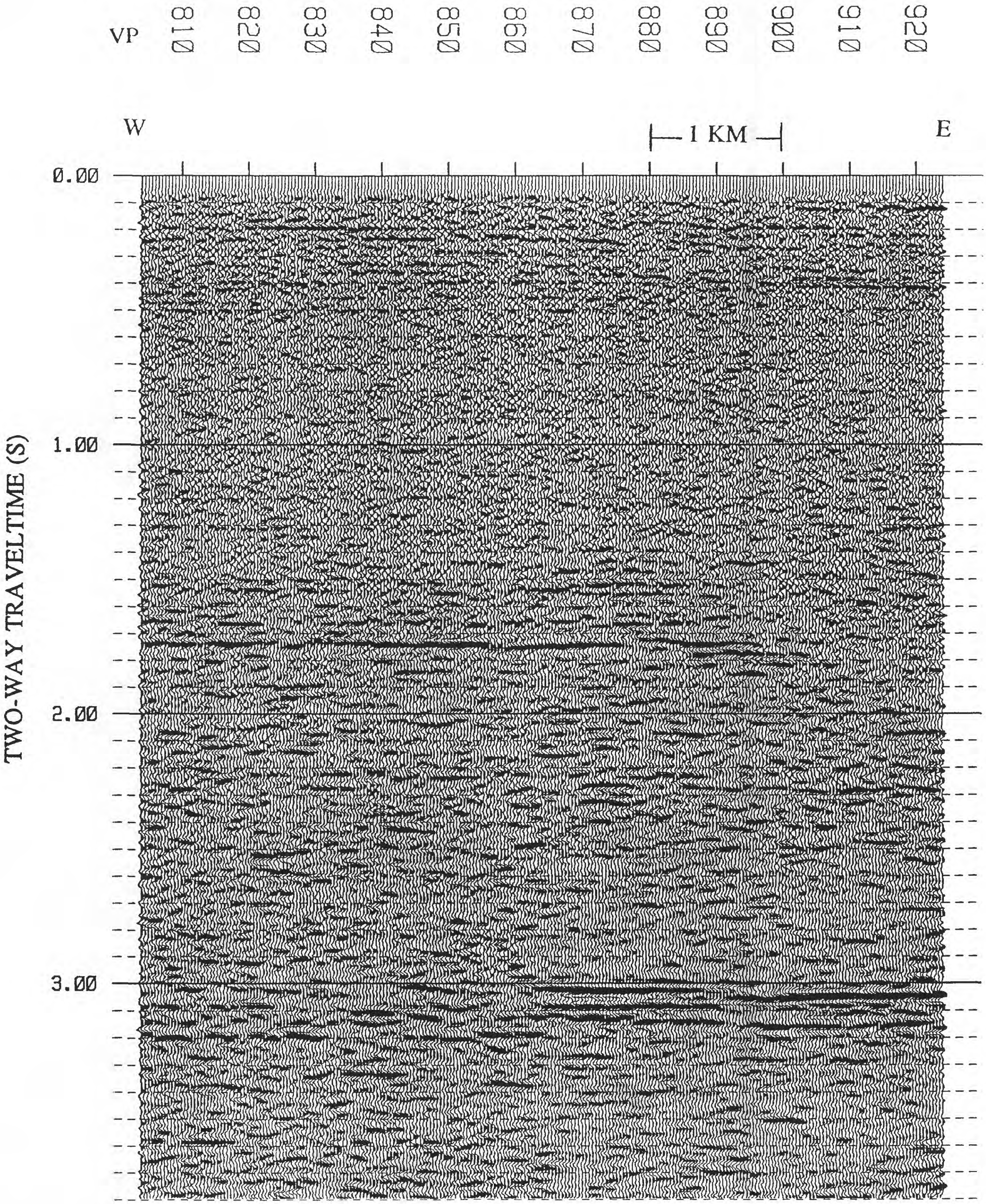


Figure 4b. **Portion of USGS final reprocessing of line R111 (east end)**

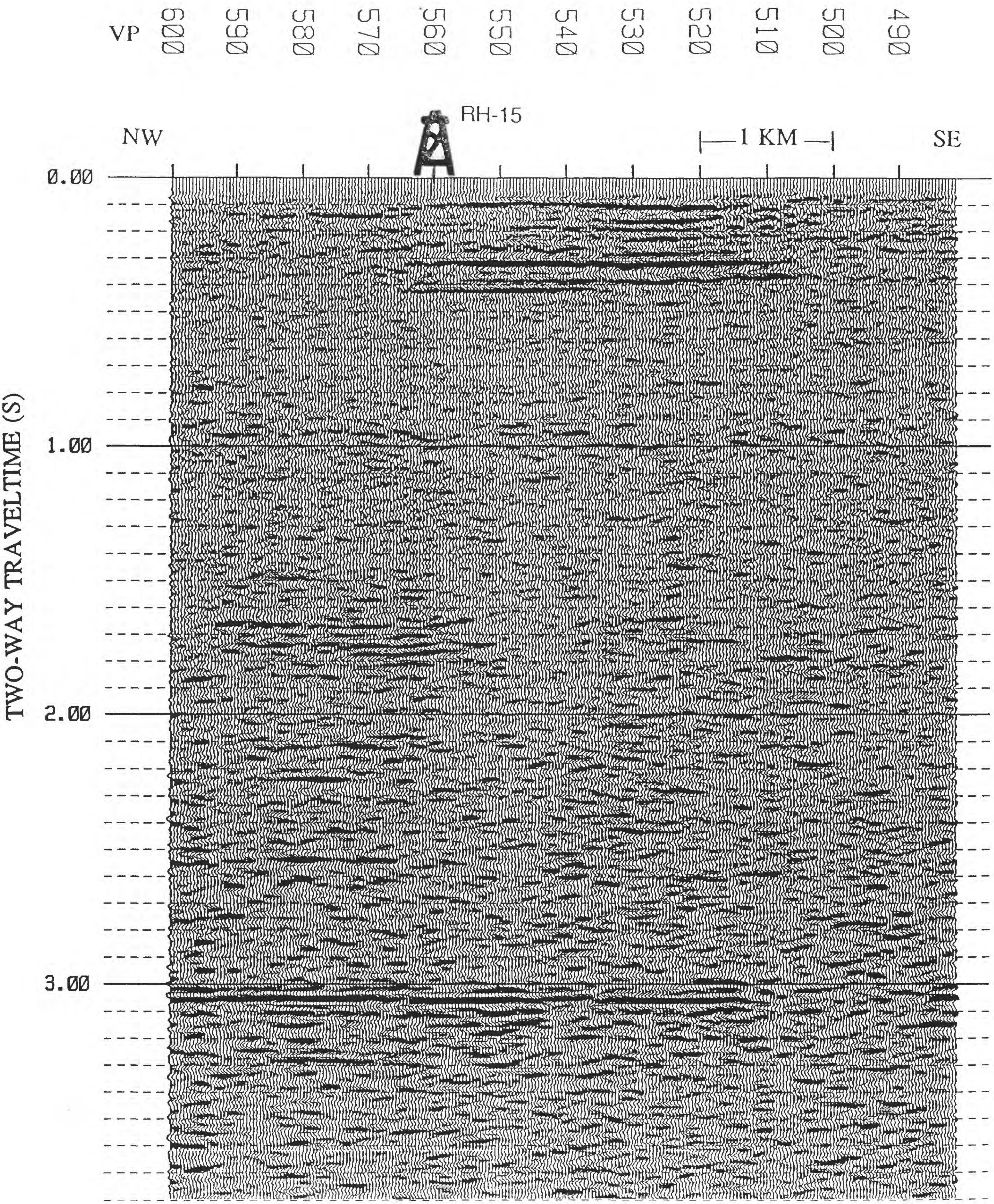


Figure 4c. Portion of USGS final reprocessing of line R102 (central)

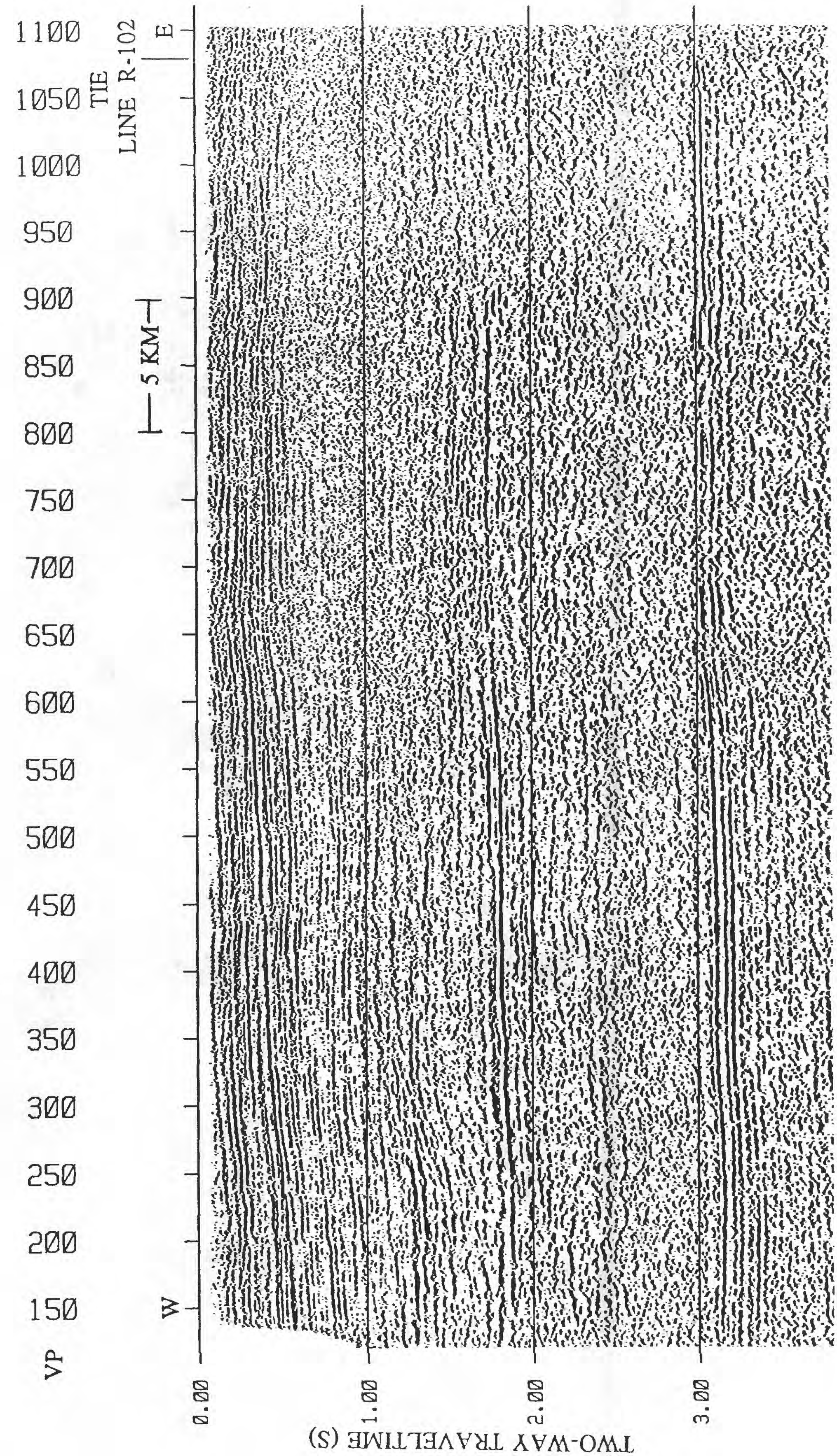


Figure 4d. **Total of line R111 after final USGS reprocessing (amplitude adjustment and 2:1 vertical stack applied for display purposes). The data quality deteriorates from west to east and the loss of reflector coherency at 1.7s between VP 900 and VP 1000 may indicate a fracture zone.**

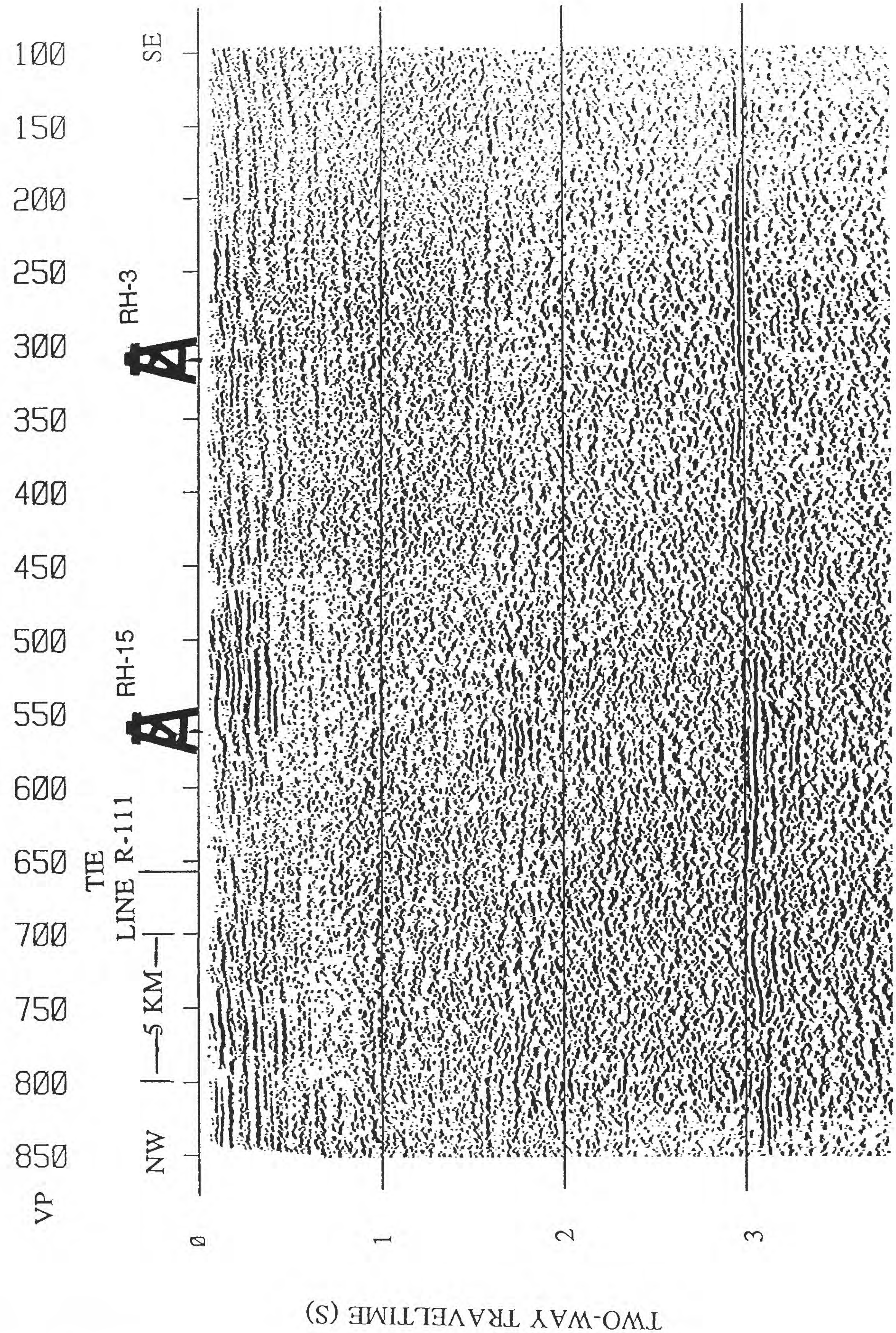


Figure 4e. Total of line R102 after final USGS reprocessing (amplitude adjustment and 2:1 vertical stack applied for display purposes). The poor data quality is comparable to that of the east end of R111 (Figure 4d).

5. Post-stack Processing: The exact algorithm used by the contractor for post-stack signal enhancement was unknown. However, their side label stated that they used a 55% add back of the original section after signal enhancement, which indicated to us that they used a standard algorithm that searched laterally along a range of dips to determine the most coherent signal. We applied this type of algorithm and a post-stack f-k filter and obtained a result similar to that of the contractor.

For our final section however, we did not apply the signal enhancement and f-k filter but instead applied predictive deconvolution, the design of which was based on the second zero crossing of the autocorrelation function, a bandpass filter, and finally, an algorithm which implemented the Karhunen-Loeve Transform (KLT) method (Hemon and Mace, 1978, Jones and Levy, 1987). The KLT technique provided the ability to separate the random-noise from the coherent signal, and then to eliminate the random noise. This method of applying the Karhunen-Loeve transform (KLT) minimizes processing artifacts that could result from post-stack signal enhancement and f-k filter techniques. We feel that our final stacked sections are superior to those of the contractor. Representative portions of those sections are shown in Figures 4a, 4b, and 4c. These can be compared directly with the contractor's sections shown in Figures 3a, 3b, and 3c. The complete sections for lines R111 and R102 are shown in Figures 4d and 4e, respectively. In order to display the complete sections at such a small scale we applied an amplitude adjustment program and performed a 2:1 vertical stack prior to display. Figures 4d and 4e are shown for qualitative purposes only and should not be used for any detailed analysis or interpretation.

ANALYSIS AND DISCUSSION

OFFSET DEPENDENT STACKING

The "inside" mute used by the contractor (mentioned above), had the effect of limiting the range of source-receiver offsets (SRO's) used in stacking. For line R111, the minimum and maximum SRO's were 125m and 4875m, respectively (Table 1). At 1.2 s, the full range of SRO's were stacked; at 1.5 s, only SRO's greater than 1,350m were stacked; at 4.0 s, only SRO's greater than 3475m were stacked. Between 1.2-1.5s and 1.5-4.0s, the range of SRO's stacked were determined by linear interpolation.

On line R111 we investigated the stacking response of different source-receiver offset ranges to determine if the inside mute used by the contractor was justified and if so, whether it could be modified to yield a better stacking response. We stacked the following SRO ranges: 0-1km, 1-2km, 2-3km, 3-4km and 4-5km. On these test stacks no "inside" mute was performed; the NMO stretch mute was the same as that used by the contractor.

From these tests, we found that we could vary the "inside" mute laterally and slightly improve the quality of the resulting stack. In some areas, more traces could be included in the stack at greater travel times, thereby improving the signal to noise ratio of the result. These tests were extremely time-consuming in terms of both computational time, and man-hours needed to analyze the tests. The improvements that we obtained were too slight to justify performing this type of testing on a production basis.

NOISE ANALYSIS

Variations in near surface conditions and the presence of known karst deposits gave rise to areas of extremely poor data quality. Fortunately some of the noise could be eliminated using conventional frequency-wavenumber (f-k) filtering. To better understand the nature of the noise, we analyzed the data in both the common-shot point (CSP) and common-receiver point (CRP) domains. Figures 5 is a distance-time (x-t, top) and f-k (bottom) display of a CSP from line R111. In the top part of Figure 5, the noise train marked as "a" consists mainly of guided waves and has an apparent dip of about 10 milliseconds per trace. The receiver domain representation of the same area is shown in Figure 6 and the noise train marked as "b" (top), has an apparent dip of about 19 milliseconds per trace. Frequencies in both the receiver and shot domains ranged from about 8 Hz to 45 Hz. This analysis verified that the dip ranges used by contractor were correct. The contractor limited the frequency range to 10-35 hz; from our analysis, we increased the frequency range to 8-45 hz.

We applied f-k filters using the above determined parameters, first in the common shot domain, and second in the common receiver domain. Experience has shown that f-k filtering of both common-shots and common-receivers generally results in better stacks than f-k filtering in the CMP domain alone (Yilmaz, 1987). However, the added trace smearing resulting from a second f-k filter, and the added processing time (cost) resulting from the second pass of filtering and from having to sort the data into the CSP and CRP domains, and then back to the CMP domain, does not always warrant using the dual f-k filter approach.

F-K FILTERING: SHOT, RECEIVER, AND COMMON MIDPOINT

We tested whether CMP domain f-k filtering could be used in place of 2 passes (CSP and CRP) of f-k filtering. One of the drawbacks with using f-k filtering in the CMP domain is that side-scattered noise does not manifest itself as well in the CMP domain as in the CSP or CRP domains and thus cannot be removed as effectively (Yilmaz, 1987).

For our tests, we created super CMP gathers (supergathers) from 4 consecutive CMPs. The reason for creating a supergather is to avoid spatial aliasing that can result from the large trace spacing present in the CMP gather, relative to a CSP or CRP gather (Yilmaz, 1987). For example, each CSP gather contains 120 channels at a trace spacing of 50 m; each CRP gather contains 60 traces at a trace spacing of 100 m. Because of the shooting geometry, each CMP contained only 30 channels at a trace spacing of 200 m. Thus, the first CMP in a set of 4 would contain channels 1, 5, 9, . . .; the next would contain traces 2, 6, 10 . . ., etc. By combining 4 consecutive CMPs and sorting the traces by offset, we could create a supergather having 120 traces at a trace spacing of 50 m. The dip range used in filtering the supergathers was the same as that used in the CSP-domain f-k filter which was warranted because the supergathers have the same number of traces and trace spacing as the CSP gathers.

A supergather from line R111 with both CSP and CRP f-k domain filtering and its associated f-k plot is shown in Figure 7. Shown in Figure 8 are the associated plots of the same supergather using only CMP domain f-k filtering. There are some differences between these two results. The source-receiver distance (offset) for each trace in Figures 5-8 are annotated at the top of each display. In the CMP domain f-k filter (Figure 8, top), the reflectors on the traces with offsets less than 1000 m are better resolved than those on Figure 7, especially above 2s TWTT. On the CSP and CRP f-k version (Figure 7, top) the reflections on the traces with offsets >1000m are better resolved, especially below 2s TWTT.

A stacked segment from line R111 processed using the two-pass (CSP and CRP) f-k filtering approach is shown in Figure 9. A stack of the same segment using f-k filtering in the CMP domain only is shown in Figure 10. As with the unstacked data (Figures 7 and 8), the shallow reflectors are better resolved after CMP f-k filtering and the deeper reflectors are better resolved after CSP and CRP f-k filtering. This result indicates that side-scattered noise might be the dominant noise below 2s.

A stacked segment from line R111 processed using CMP-domain f-k filtering **after** CSP and CRP f-k filtering is shown in Figures 11. Both the shallow and the deep reflectors are well-resolved.

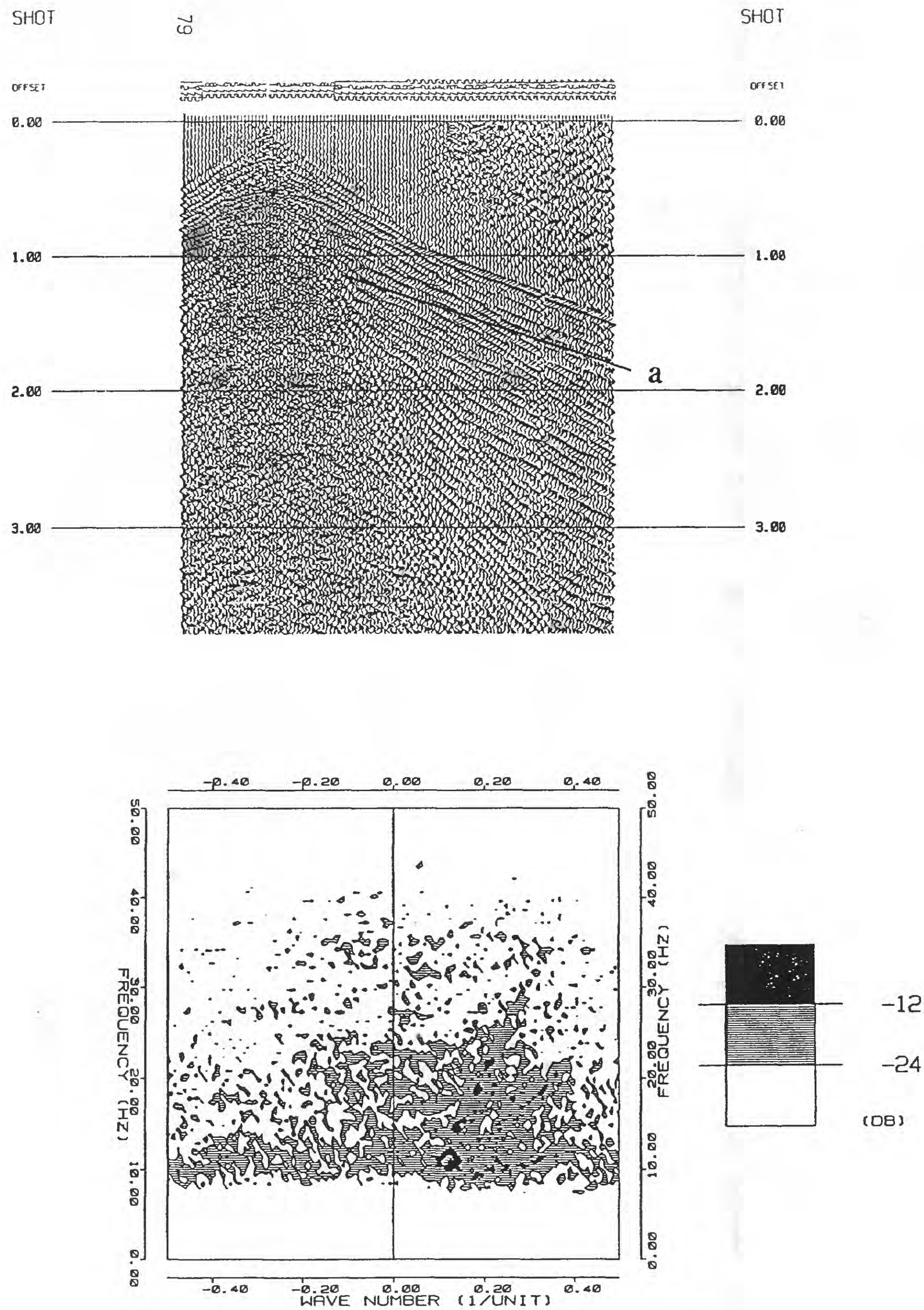
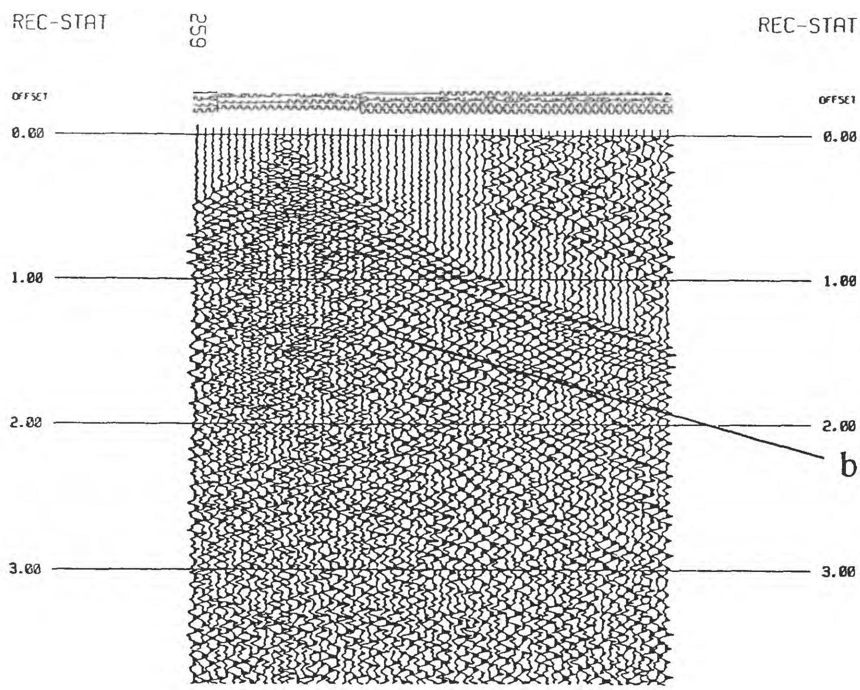


Figure 5. **Common shot gather (CSP) from line R111**
Top: Distance-time (x-t) domain
Bottom: Frequency-wavenumber (f-k) domain



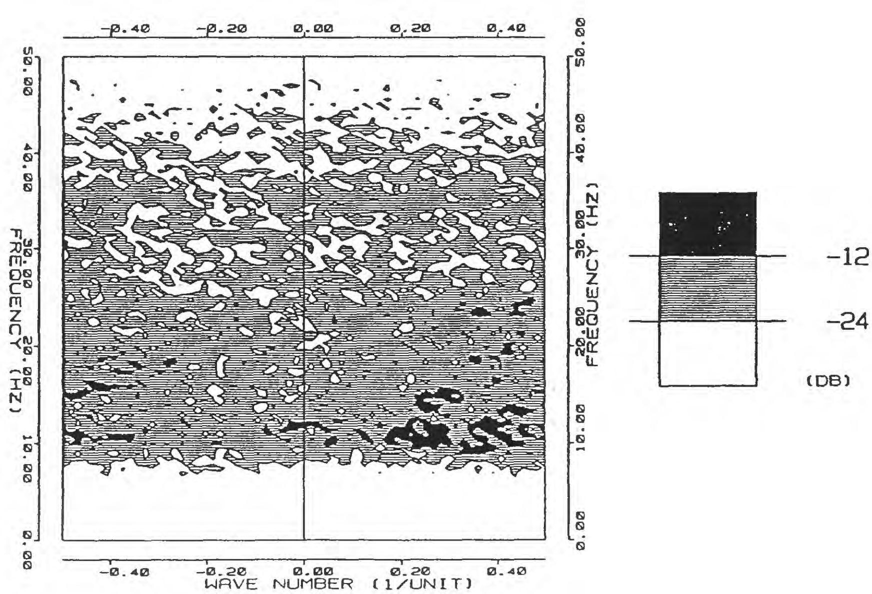
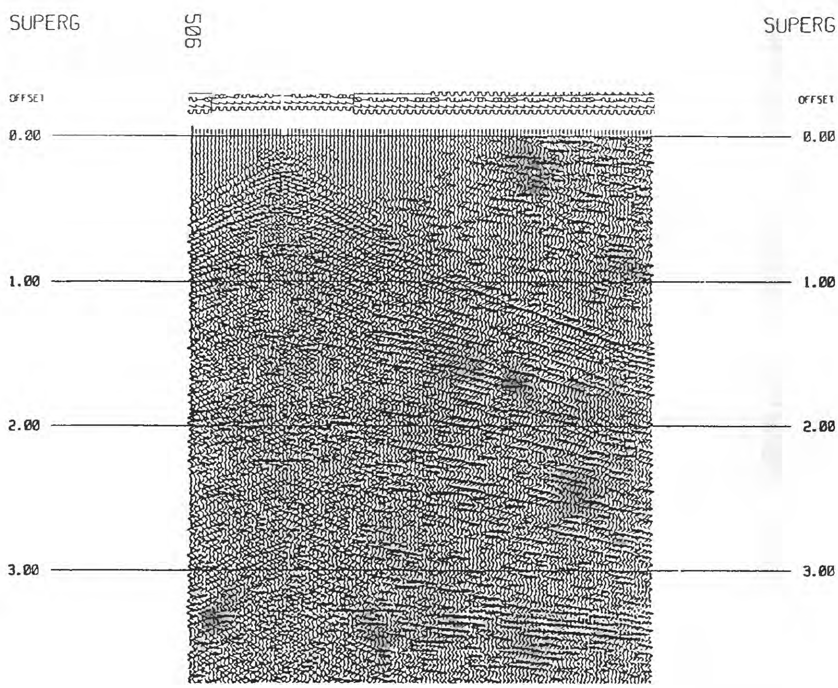


Figure 6. Common receiver gather (CRP) from line R111
Top: Distance-time (x-t) domain
Bottom: Frequency-wavenumber (f-k) domain



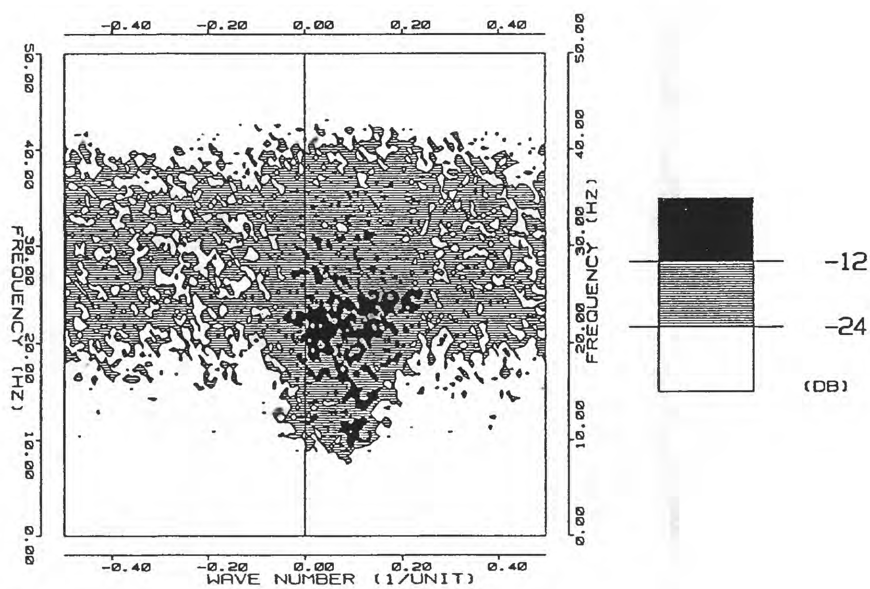


Figure 7. **Supergather after CSP and CRP f-k filter has been applied.**
Top: Distance-time (x-t) domain
Bottom: Frequency-wavenumber (f-k) domain

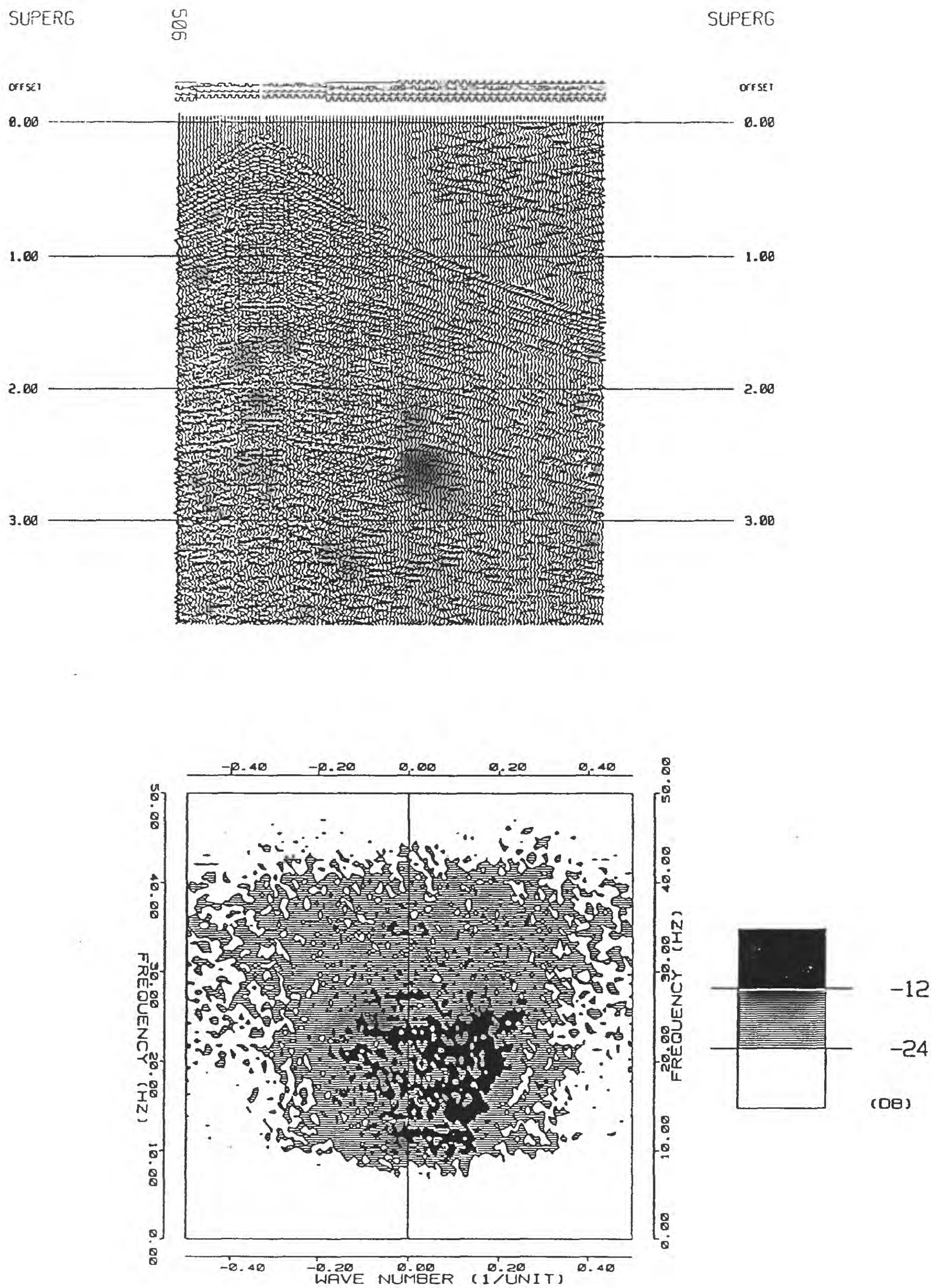


Figure 8. Supergather after CMP f-k filter has been applied.
Top: Distance-time (x-t) domain
Bottom: Frequency-wavenumber (f-k) domain

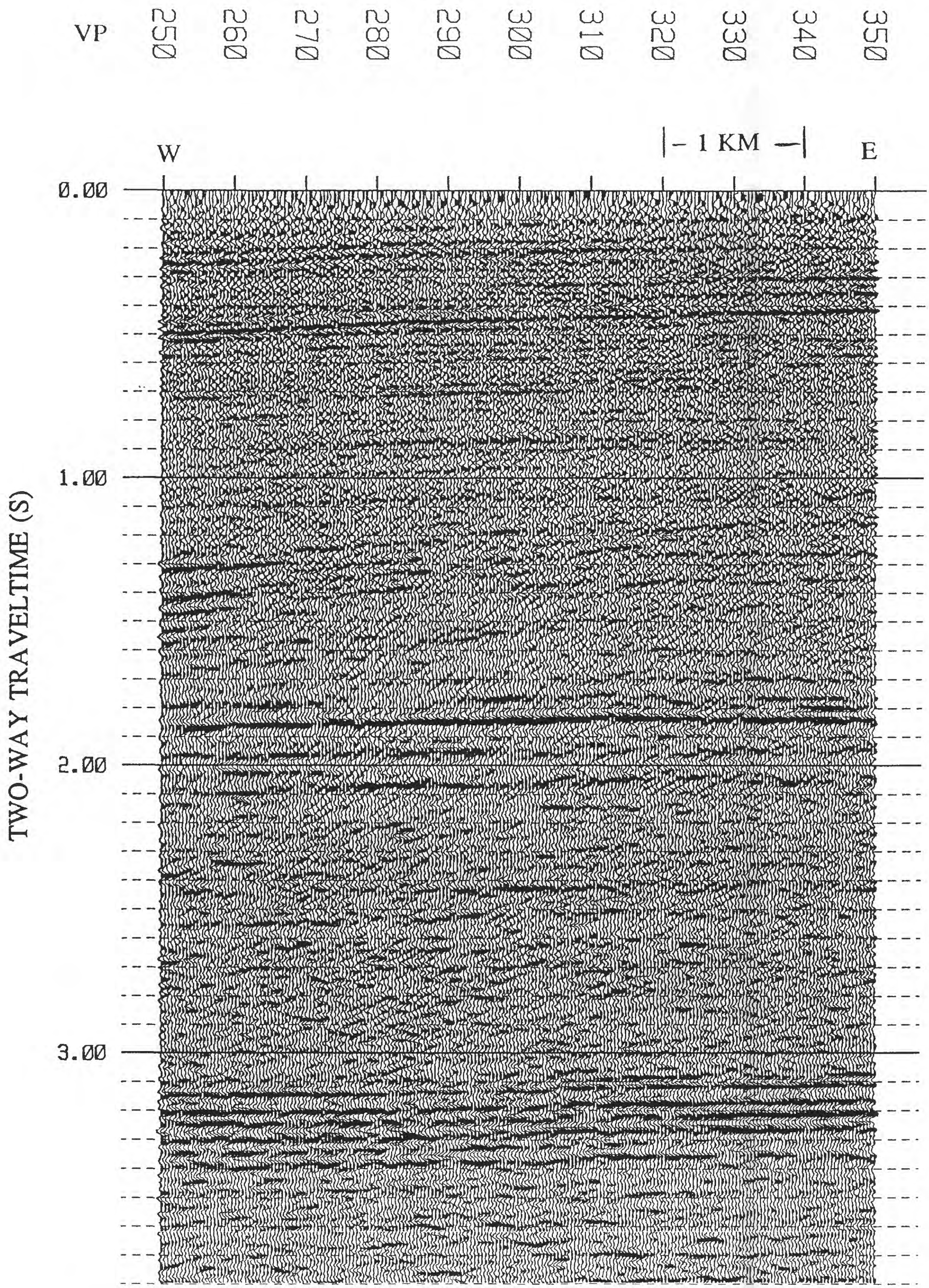


Figure 9. **Stacked section of line R111 after CSP and CRP f-k filter has been applied.**

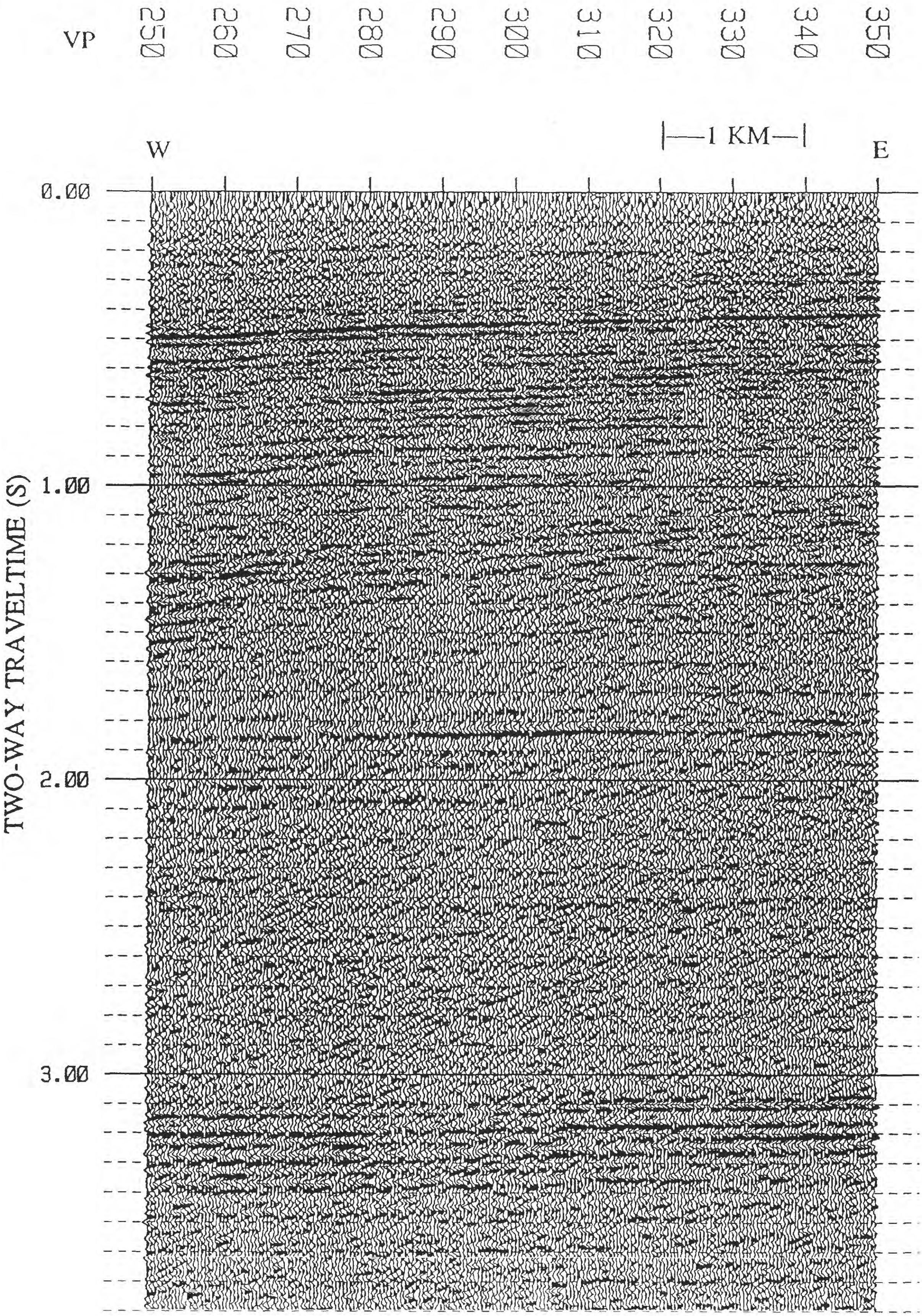


Figure 10. Stacked section of line R111 after CMP f-k filter has been applied.

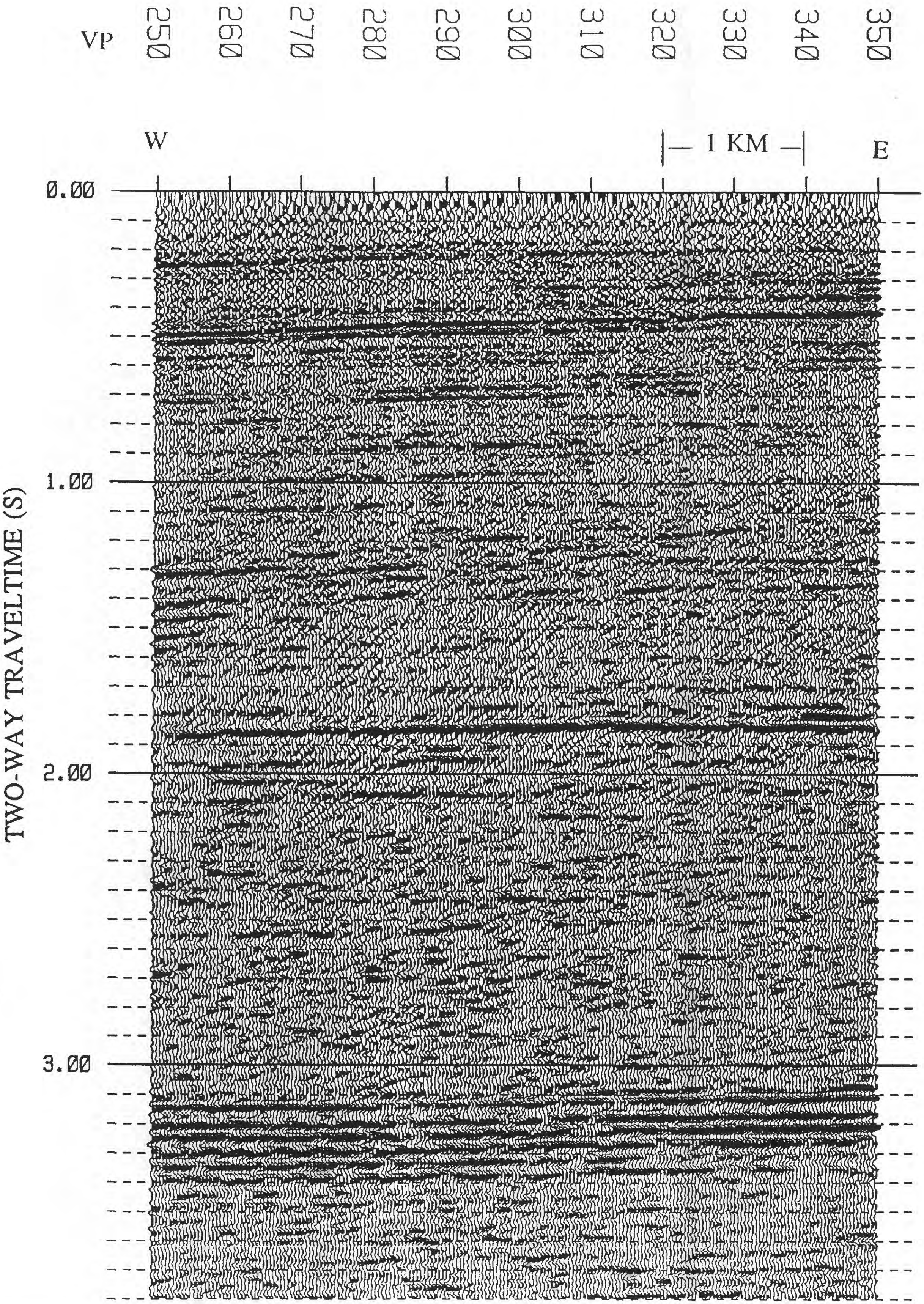


Figure 11. **Stacked section of line R111 after CMP f-k filter has been applied after CSP and CRP f-k filter.**

DISCUSSION

Although we feel that our results give a more realistic image of the subsurface in the Risha area, they do not differ greatly from those of the industry contractor. In some areas, the contractor's sections show more apparent continuity in the reflectors. However, we feel that this apparent continuity may be an artifact of their processing.

As mentioned above, the side label of the contractor's section gives little information about their residual statics method. It is possible that the contractor used a non-surface-consistent algorithm; such a method can have the effect of "forcing" continuity in reflectors when in reality, that continuity does not exist. Our surface-consistent residual statics analysis did not make the reflectors appear as continuous as in the contractor's sections. However, we cannot state for certain whether this lack of reflector continuity is a function of the geology, or the limitations in our residual statics program.

Furthermore, the apparent reflector continuity in the industry-processed sections could also have been enhanced by their post-stack signal enhancement and f-k filter. We feel that our method of applying the Karhunen-Loeve transform (KLT) minimized processing artifacts because the transform was designed to eliminate random noise, rather than to enhance coherent signal.

CONCLUSIONS AND RECOMMENDATION

In reprocessing two multichannel seismic lines from the Risha area, Jordan, we incorporated an industry contractor's technique of applying pre-stack f-k filters and "inside" mutes, after verifying the necessity of these two techniques and the accuracy of the parameters used. We further improved the ability to interpret the data over that of the industry processing, by increasing the frequency bandwidth of the data from 10-35 hz to 8-45 hz, applying surface-consistent statics analysis, and rejecting much of the remaining random noise by means of a Karhunen-Loeve transform (KLT) algorithm.

Processing artifacts were minimized by using a known surface-consistent statics algorithm (the contractor's algorithm was unknown and might have been non- surface consistent), and by applying the Karhunen Loeve transform after stacking, which eliminated the need for post-stack f-k filtering and signal enhancement used by the contractor. We also determined that an additional pass of f-k filtering, performed before stacking in the CMP domain, is an optimum method for suppressing the coherent noise present in data from this area.

We recommend that this processing sequence be used as a starting point when reprocessing other data from the Risha area.

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