Final Report for the Texas Low-Level Radioactive Waste Disposal Authority:

Preliminary Seismic Reflection Study of the Fort Hancock Area in Hudspeth County, Texas

by

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ABSTRACT

A high resolution VIBROSEIS seismic reflection study was conducted to determine the shallow geologic structure beneath the proposed Fort Hancock low-level radioactive waste disposal study area. A ten mile survey was completed with a shot/receiver group spacing of 27.5 feet using a 14 second vibrator sweep between 27-150 Hz. The study was able to detect and map 1) the angular unconformity between the Cretaceous bedrock and overlying Tertiary-Quaternary sediment (300 milliseconds two-way traveltime), 2) the top of a basal Older Bolson deposit (200 milliseconds) and 3) the base of the Younger Bolson gravel deposits (80 milliseconds). Several normal faults were also detected and mapped which appear to offset reflections as shallow as 80 milliseconds.

INTRODUCTION

Knowledge of the shallow geologic structure can be the most important factor needed to evaluate the suitability of a region for low-level radioactive waste burial. Typically, detailed information about the subsurface configuration of potential water-bearing strata, fault locations and the underlying bedrock topography is required. Currently, extensive test well drilling is the primary method for gaining such subsurface information. Unfortunately, this approach is time consuming, expensive, and provides information only at specific point locations within a selected region.

On the other hand, the seismic reflection technique is a powerful and cost effective geophysical method routinely used in oil exploration that can quickly provide detailed continuous profile-type images of the underlying geologic structures. By judicious placement of just a few test wells along selected profile lines it is then possible to correlate the seismic reflection images with well core and logging observations. This allows quantitative characterization of the geologic structure and material physical properties of the entire region of interest.

Despite the potential economic advantages of combining seismic reflection profiling techniques with selective test well drilling, the technique has not been widely used in the past to examine shallow geologic structures for engineering applications. This has resulted largely from the general belief that (i) the common depth point (CDP) seismic reflection technique as practiced in the oil exploration industry lacked the required resolution for shallow depth studies and (ii) that modification of the exploration industry techniques to make them suitable for such shallow depth engineering applications would prove prohibitively expensive as compared to the cost of test well drilling. Today these resolution and cost questions may not pose the obstacles that they did a few years ago, given the increased flexibility of modern digital seismic data acquisition system/sound sources and the marked reductions in the cost of seismic computer data processing.

The purpose of the study described in this report was to determine if conventional oil exploration-type CDP seismic reflection survey techniques could be economically adapted to provide shallow geologic structural information in the upper few hundred feet with resolution adequate for engineering evaluation applications. The area selected for the CDP survey was an area near Fort Hancock, Hudspeth County, Texas which has recently been proposed as a possible low-level radioactive waste disposal site study area (Figure 1). Although this report does not directly address the question of cost effectiveness of seismic reflection methods as compared to test well drilling, we employed the least expensive and most widely available oil exploration seismic method, VIBROSEIS. This was done in order to obtain the lowest cost likely to be encountered for seismic survey studies. Clearly, far more expensive seismic techniques such as buried explosive sound sources and buried geophone receiver methods could have been employed to obtain much higher resolution data.

REGIONAL SETTING

The proposed Ft. Hancock study area is about 50 miles (80 km) southeast of El Paso, Texas in the Rio Grande river valley. A computer-generated, geologic and topographic base shows the location of the study area in Figure 2. Kreitler et al. (1986) have previously described in detail the regional as well as local geology of the region.

Briefly, the Ft. Hancock study area lies along the eastern margin of the Hueco Bolson, a major basin and range graben structure, in the Trans-Pecos region of West Texas (Figure 3). Faulting and relative subsidence of the graben began in mid-Tertiary time as a result of east-northeast oriented extension which probably continues to the present. The graben has been filling with detritus eroded from the adjacent horst blocks. The bedrock floor of the graben consists of indurated Cretaceous limestones and sandstone formations which generally dip gently to the southwest. However, isolated outcrops of the Cretaceous bedrock along the northeastern upthrown side of the Campo Grande fault, a major southwestward dipping normal fault that extends northwest-southeast across the study area, show the Cretaceous formations to be tightly folded and overthrust to the northeast. The Tertiary and Quaternary deposits that unconformably overlie the eroded Cretaceous bedrock surface consist of two major units:

The Younger Bolson deposits are thin, unconsolidated Quaternary gravel beds that include the younger basin deposits as well as the Miser, Madden, Gills, Ramey and Ballaco formations of Albritton and Smith (1965) and are equivalent to the Camp Rice formation of Strain (1966). Test well and outcrop information indicate the depth to the base of the Younger Bolson deposits is on the order of 50-60 feet. The precise age of these gravel formations is not well known but they include volcanic ash beds dated at 2.02 m.y.b.p. (Izett and Witcox, 1982). Deposition of the Younger Bolson deposits is believed to have ceased about 300-400,000 years ago (Gile and others, 1981).

The Older Bolson deposits are fine-grained, semi-consolidated late Tertiary sandstone and silty clays that include the older basin deposits of Albritton and Smith (1965) and are equivalent to the Fort Hancock formation of Strain (1966). The angular unconformity separating the Older Bolson deposits from the underlying Cretaceous formations is not exposed in the study area, thus making it difficult to estimate the depth to bedrock here. However, a deep test borehole (LLWA-10) recovered multicolored limestone cuttings at a depth of about 390 feet that resemble the Cretaceous Mesa Bluff formation which is exposed in nearby outcrops along the Campo Grande fault. Also a distinctive sand unit within the Older Bolson deposits was penetrated in several of the shallow test wells at a depth of about 100-120 feet. The precise age of the Older Bolson deposits is not known but fossil fauna evidence suggests a late Pliocene age.

The ages of the most recent displacements along the major faults which crosses the study area are not well known. The Campo Grande fault appears to have cut the pediment surface developed on the Younger Bolson deposits (Camp Rice formation) indicating movement since about 300,000 years ago but it is not clear if it displaces the modern caliche and/or the surficial, windblown sand and alluvium. Also it is known that these surficial overburden materials and the Younger Bolson gravels obscure normal faults in the underlying Older Bolson deposits, as depicted by the generalized diagram along a transect just south of Campo Grande Mountain (Figure 4). The major east-west normal fault along the Diablo Plateau rim, approximately 4 miles north of the study area, is known to displace the Cretaceous bedrocks from the eastern border of the Hueco Bolson. However, displacement of the Tertiary and Quaternary bolson deposits has not been demonstrated.

SEISMIC LINE LOCATIONS

Figure 5 shows the location of the seismic reflection profile lines (UT-1, 2, 3, and 4) on an enlarged scale version of the computer generated base map of Figure 2. Note that in order to minimize the seismic field survey cost the profile lines were positioned as closely as possible along existing roads and previously brushed-out trails and fencelines. Line UT-3 was designed to provide a long regional-type profile across the entire study area. It has been subdivided into UT-3A and UT-3B. It was oriented nearly perpendicular to the Campo Grande fault trend as shown in Figure 2. Lines UT-1, 2, 4 and the northeast end of UT-3A formed a wide-spaced grid pattern over a region whose surface presently drains into Alamo Arroyo (Figure 5).

DATA ACQUISITION

All seismic field data were acquired by the Dawson Geophysical Company of Midland, Texas. The VIBROSEIS vibrator-type sound source system was used to generate the seismic signal energy in the survey. A 48-geophone (LRS-100) split-spread receiving array with a Geosource MDS-15 digital data acquisition system was used to record the field data. The vibrator point and geophone station interval were both 27.5 feet yielding 24-fold data multiplicity with maximum spread offset of 660 feet. A MERTZ-12 vibrator truck swept linearly between 27-150 hz over 14 seconds, once at each station location. In general, the vibrator point (truck) was located immediately adjacent to each station location along the line. The data record length was 2000 milliseconds with a 1 millisecond sample interval. The receiver group at each station was a linear array of 12 geophones, 2 feet apart except for line UT-1. Here the geophones were tightly grouped (podded) at each station. A summary of the field acquisition parameters is listed in Table 1.

In addition to acquiring the seismic reflection data as described above, reversed refraction data was also acquired at a 48-station interval along each profile line by end-firing down a 48-geophone array in each direction away from the vibrator station. Two sweeps were made and summed for these refraction observations. No results from these observations are

TABLE 1

HUDSPETH COUNTY

HIGH RESOLUTION CDP SEISMIC STUDY
FIELD ACQUISITION PARAMETERS

Seismic Contractor:	Dawson Geophysical Company Midland, Texas
Source:	Mertz 12 Vibrator
Vibrator point spacing:	27.5 feet
Sweeps per station:	1
Sweep band:	27-150 Hz Linear
Sweep length:	14 seconds
Group interval:	27.5 feet
Number of groups:	48
Geophone receivers:	LR 1000 28 Hz 12 per group, podded (UT-1) 12 per group, linear array (UT-2, UT-3, UT-4)
Split spread:	660'-27.5'-0-27.5'-660'
Recording instrument:	Geosource MDS-15 (60-channels)
Output format:	SEG-B
Sample rate:	1 millisecond
Record length:	2000 millisecond
Filter low:	Out
Filter high:	250 Hz

included in this report.

DATA PROCESSING

Both the University of Texas Institute for Geophysics (UTIG) and Dawson Geophysical participated in the data processing and analysis. Dawson was responsible for the primary processing tasks while UTIG performed the advanced processing and analysis functions.

Conventional seismic data processing methods were first used to demultiplex, correlate and sort the VIBROSEIS shot (vibrator point) gathers into CDP bin gathers spaced 27.5 feet apart along each line. Datum statics and weathering layer refraction-type statics (DAWSTAT) were also calculated for each shot-receiver station pair. Next, velocity analysis of selected CDP gathers with subsequent normal moveout and stacking of all gathers and post-stack filtering was done. Table 2 lists the steps used in the processing sequence.

A display of a typical raw CDP gather acquired along line UT-1 is shown to the left in Figure 6. Note the extremely large amplitude air blast noise which traverses the gather at about 1150 ft/sec velocity. This high noise was largely due to the podded configuration of the 12 geophone group at a single point and close proximity of the vibrator truck to the line. This air blast problem was quickly recognized in the field and on subsequent lines the 12 geophones were spaced 2 feet apart parallel to the line direction. This arrangement served as a spatial filter which markedly reduced the surface airblast wave traveling down the receiving array (Figure 6, right). It was also noted that moving the vibration truck about 30 feet off line from the geophone station markedly reduced the airblast effect (Figure 7). Unfortunately, due to logistical considerations, this offline shot point (vibrator) arrangement was not implemented for the

TABLE 2

HUDSPETH COUNTY

HIGH RESOLUTION CDP SEISMIC STUDY
DATA PROCESSING SEQUENCE

1. Demultiplex/Reformat to SEG-Y
2. Correlate
3. Shot Edit
4. Sort/Common Depth Point Gathers
5. Airblast Attenuation (on UT-1 by UTIG)
   Apply: Surface wave reducing velocity moveout
   Align airblast arrivals
   F-K Velocity Filter
   Remove Airblast Align Statics
   Remove Reducing Velocity Moveout
6. Velocity Analysis
7. Mutes Applied
8. Normal Moveout
9. Automatic Datum Statics
10. Refraction Statics (Dawstat)
11. Stack (24-fold)
12. Band Pass Filter 27-150 Hz

entire survey. In any event, the airblast/noise was ultimately found to be too large to be attenuated with conventional CDP stacking procedures. Accordingly, an offset traveltime mute was designed to completely eliminate all data within the airblast envelope in each CDP gather. This airblast mute schedule is shown in Figure 8. Also shown is a typical percentage stretch-type mute that was designed to eliminate any refracted arrivals from the stack. This "inside-outside" mute schedule was applied before stacking in the processing of the CDP sections for lines UT-1, 2, 3A, 3B, and 4 shown in Figures 9, 10, 11, 12, and 13, respectively.

While application of the "inside-outside" mute schedule allowed satisfactory stacking of the CDP data, clearly a large amount of potential data was not utilized in the final stack, particularly for shallow reflections recorded on the near offset stations. This markedly reduced the trace multiplicity and thus signal-to-noise ratio. Accordingly, we utilized an F-K velocity filtering procedure which selectively reduced the low velocity airblast noise but retained all other data. Figure 14 shows a typical gather from line UT-1 before F-K processing. The procedure consisted of first applying a linear reducing velocity static of 1150 ft/sec to each gather (Figure 15), aligning the airblast arrival wave train using an automatic residual static computation process (Figure 16), and then applying an F-K velocity filter to attenuate the aligned airblast (Figure 17). The aligning and reducing velocity statics were then removed (Figure 18) and the conventional processing described above was continued for the velocity analysis through normal moveout and stack sequence. Figure 19 shows the marked reduction of the airblast after F-K velocity filtering.

Note that this F-K velocity filtering technique appears to have reduced the airblast noise to levels as low as those experienced when the vibrator truck was located 30 feet off the seismic line (Figure 20). To further demonstrate the utility of the F-K velocity filtering procedure we completely reprocessed the line UT-1 using the procedure. A comparison of the stacked sections is shown in Figure 21. Note that the F-K processed line (top of Figure 21) shows considerably more continuity for reflections within the first 150 milliseconds. In fact, a reflector is seen at about 50 milliseconds that is not even apparent on the conventional processed line. Also, the reflector sequence seen between 300 and 400 milliseconds on the left of the line is more clearly depicted after F-K filtering.

GEOLOGIC INTERPRETATION

The CDP stacked sections have been further enhanced to aid in their geologic interpretation by applying a coherency filter after stacking. This filter has the effect of emphasizing the lateral continuity of reflection events on adjacent traces. The results of applying this filter is shown in the section at the top of Figures 22, 23, 24, 25, and 26 for Lines UT-1, 2, 3A, 3B, and 4, respectively. The geologic interpretation of the respective profile lines is shown at the bottom of each figure.

1) The Cretaceous Bedrock is unambiguously shown on each line at about 300 milliseconds (two-way traveltime) or about 840 feet depth. It is characteristically an undulating interface separating the southwestward dipping Cretaceous formation from the overlying sediment layers (Line UT-3A, SP 200-450, Figure 24). The bedrock surface appears to deepen gradually to the southwest to form a deep basin near SP 650 (Line UT-3B, Figure 25). Near SP 760 in the vicinity of the Campo Grande fault, the bedrock abruptly rises to form a buried ridge just northeast of the fault. The ridge is about 100 milliseconds below the surface or at about 100 feet depth. This may be only a local feature, we do not know the northwest-

southeast extent of the ridge. An outcrop of the Cretaceous formation is located about 1/4 mile to the southeast of this ridge. The Cretaceous bedrock cannot be seen southwest of the Campo Grande fault at SP 900, Line UT-3B (Figure 25).

2) A strong reflection from a basal Older Bolson deposit layer is also seen across the entire survey area. It is found at about 200 milliseconds, or about 450 feet depth. Significantly, this reflection can be traced to the southwest of the buried Cretaceous bedrock ridge, suggesting the ridge did not serve as a barrier to the sediment dispersal.

3) The most shallow continuous reflector seen across the study area is found at about 70-80 milliseconds (two-way traveltime) below the surface. The depth of this reflector is difficult to estimate from the seismic data since no direct velocity measurement can be made for these near-surface reflectors. However, if an average velocity of 1500-1800 ft/second is assumed for the overlying sediments, the reflector would lie at a depth of about 50-60 feet. This would suggest that the reflector marks the base of the Younger Bolson gravel deposits observed at 50-55 feet in the test well boreholes (LLWA, 7, 10, 11, 12, 13). This is not an unreasonable correlation. Alternatively, the reflector could be the sand unit within the Older Bolson deposit, penetrated at a depth of 100-200 feet in the test wells. However, this correlation would require the velocity of the overlying sediments to be 3000-3600 ft/second. This seems rather high since our normal moveout stacking velocity data indicate velocities this high are not encountered until the 150-180 millisecond traveltime interval. Accordingly, we prefer the former interpretation that the most shallow reflector observed at about 80 milliseconds is the base of the Younger Bolson gravel deposits.

4) Fault locations can also be inferred from the seismic reflection

profiles. The Campo Grande Fault is most clearly delineated at the southwest end (SP 900) of Line UT-3B (Figure 25) where it offsets the Cretaceous bedrock and basal Older Bolson reflectors by a large but unknown amount. These reflectors cannot even be seen on the downthrown side of the fault! However, about 50 milliseconds of offset of the basal Older Bolson deposit reflector can be inferred. If the surficial sediment velocity is about 1500-1800 ft/sec, the displacement would be about 45 feet.

Additional smaller offset faults can also be inferred in the primary study area grid survey (Figure 5). These faults as seen on Figures 22, 23, 24, and 25 do not unambiguously cut the Younger Bolson deposit but they do appear to offset the basal Older Bolson deposit layer and the Cretaceous bedrock. There is no obvious surface expression of these inferred buried faults.

5) The ancient sediment dispersal pattern in the Hueco bolson can be inferred from the long, regional Line UT-3 profile (Figures 24 and 25). In general, the gradual thickening of the Younger and Older Bolson deposits to the northeast at the northeast end of line UT-3A suggest that the sediment source was generally to the northeast toward the Diablo Plateau. However, in the vicinity of the buried Cretaceous bedrock ridge (SP 760, Line UT-3B), the onlapping reflector sequences clearly indicate sediment source to the southwest. For the basal Older Bolson deposits, the ridge itself appears to have provided sediment which flowed into the adjacent small basin to the northeast (SP 650). However, the southwest source for the sediment represented by the onlapping reflector sequence at the top of the Older Bolson deposits (SP 500-600, Lines UT-3A and 3B) is more difficult to explain. Moreover, the onlapping sequence appears thickened to the southwest and can be traced across the top of the buried ridge. This clearly

suggests a source from ancient higher terrain located along the present Rio Grande river valley axis or beyond. Isochron maps were constructed for the top of the Cretaceous Bedrock, the top of the basal Older Bolson deposits and the base of the Younger Bolson deposits and are shown in Figures 27, 28, and 29, respectively.

CONCLUSIONS

The VIBROSEIS seismic reflection data that we have acquired and processed for this study have provided the following information:

1) CDP-processed seismic reflection profiles can be used to measure continuous reflections from the Cretaceous bedrock surface, the top of the basal Older Bolson deposits layer, and the base of the Younger Bolson deposits over the entire study area.

2) The location of faults in the bedrock and overlying sediments can be inferred from offset reflector sequences.

3) The Cretaceous age well cuttings from the deep aquifer found at 390 feet in test well LLWA 10 appears to correlate with the top of the basal Older Bolson deposit layer made up of Cretaceous rock fragments, not the Cretaceous bedrock.

4) The VIBROSEIS technique can be utilized to obtain reflection image from reflectors as shallow as 50-60 feet and as deep as 1000 feet. Material velocity can be estimated with an error of 10%. The maximum frequency of the observed reflection event was about 80 Hz with the dominant reflection energy in the 40-60 Hz range. The resolution for mapping continuous reflection events is on the order of 10 milliseconds.

5) The cost for acquisition, processing, and interpretation was approximately $6000 per line mile. This is comparable to conventional oil exploration seismic work.

RECOMMENDATIONS

Although this study showed that shallow seismic reflection data useful for engineering studies can be obtained by adapting conventional VIBROSEIS techniques, certain improvements should be considered for future work.

1) The vibrator truck should be offset from the seismic line. This will clearly reduce airblast noise. A linear geophone group array should also be employed.

2) The vibrator mass should be enclosed to further reduce airblast noise.

Regarding further analysis and processing of the present data set, the following work should be done:

1) The seismic refraction data collected at 48 station intervals should be processed and analyzed to better estimate the depths to the subsurface reflectors.

2) Selected portions of each CDP line should be reprocessed using the F-K velocity filtering to improve the reflection image in regions of critical importance, such as near potential faults and to recover the shallow reflection above 100 milliseconds.

Knowledge of offsets for these shallow reflections will be important to determine the age of the most recent fault displacement. This will be particularly valuable for locating faults covered by modern alluvium. Future seismic work in the Fort Hancock study area might include a borehole seismic survey using one of the existing deep test wells or, preferably, a deep well could be drilled and logged. This survey would provide extremely valuable seismic velocity information which could be used to calibrate the present data set. Also future CDP survey work should include a detailed grid survey in the area of specific waste disposal siting and future reconnaissance surveys in the vicinity of the Cretaceous bedrock ridge to determine the northwest-southeast extent of this barrier which interrupts the basal Older Bolson layer.

ACKNOWLEDGEMENTS

We thank Hal Pardue of Dawson Geophysical Company. His knowledge and broad expertise in seismic data processing was invaluable. Kathy Moser was also of great help in preparing this report. This work was supported by a contract with the Texas Low-level Radioactive Waste Disposal Authority (IAC (86-87)-0994.

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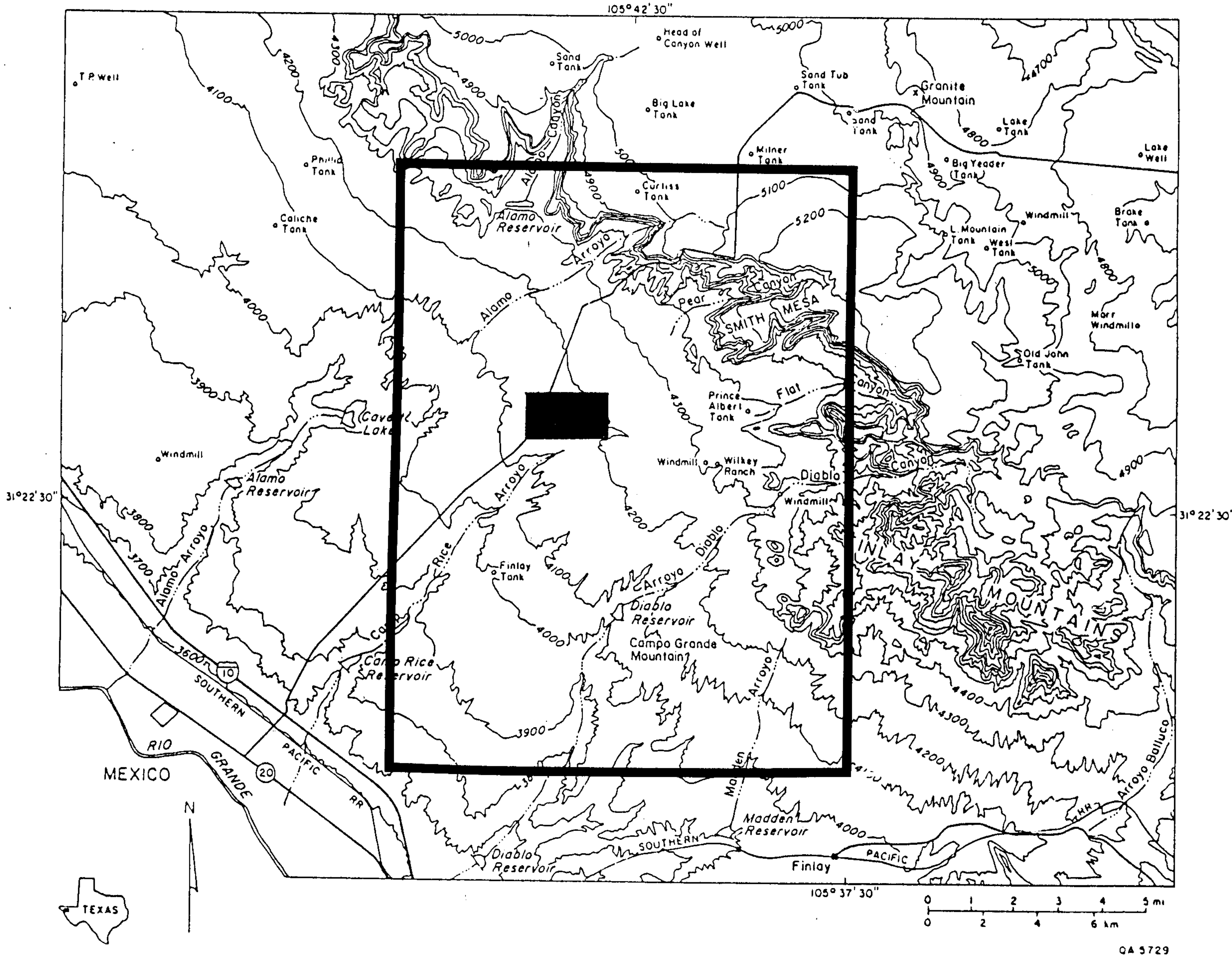

Figure 1. Topographic sketch map of Fort Hancock, Hudspeth County, Texas area. Open rectangle outlines general study area and the limits of the computer-generated data base map shown in Figure 2. Black rectangle shows location of primary study area. Modified after Kreitler, et al. (1986).

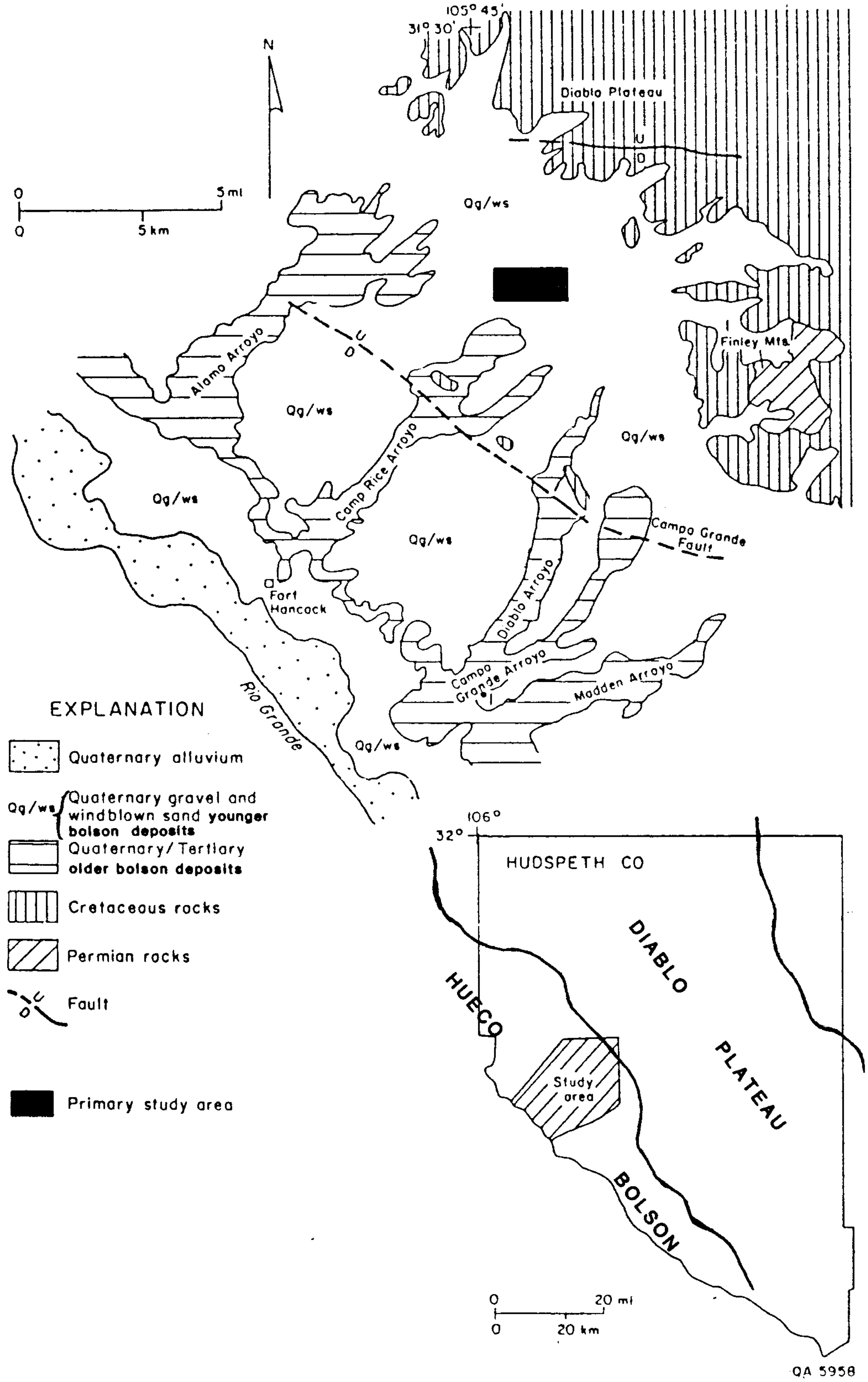

Figure 3. Geologic sketch map showing regional setting of the Fort Hancock study area. Modified after Kreitler, et al. (1986).

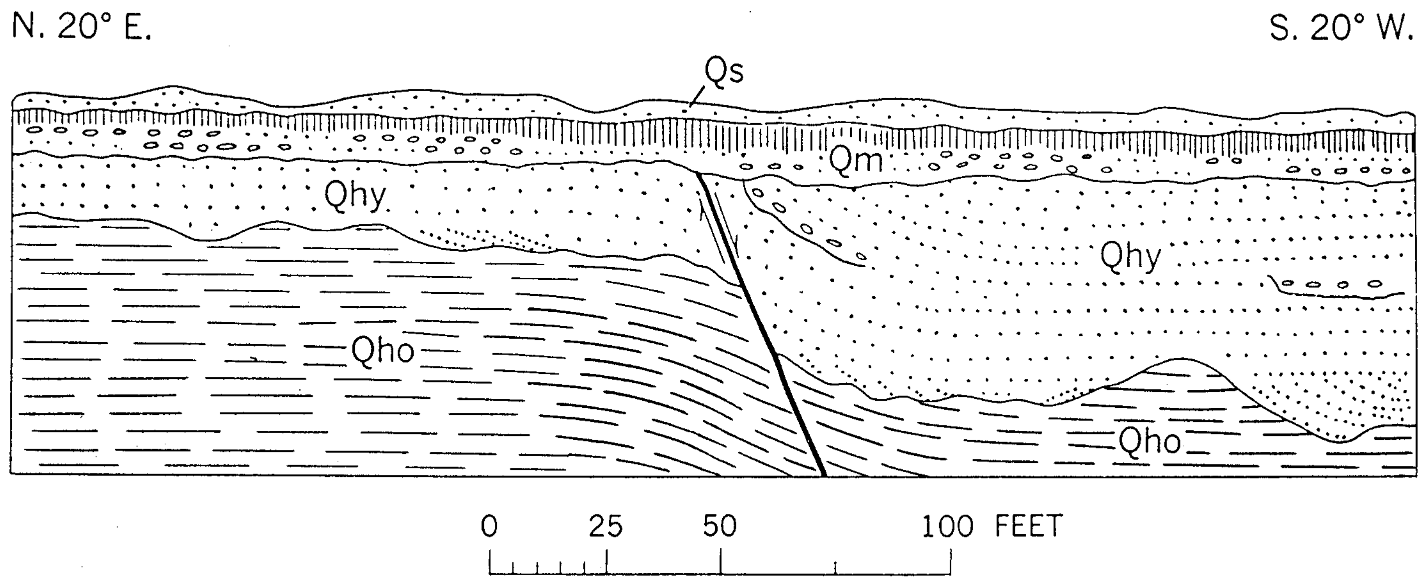

Figure 4. Structural diagram of normal fault in alluvial deposits, 600 yards southwest of Campo Grande Mountain. Shown are sand and gravel of the younger basin deposits (Qhy) displaced downward against clayey beds of the older basin deposits (Qho). The fault is truncated by an erosional surface at the base of the Madden Gravel (Qm); caliche at top of gravel shown by vertical lines. Qs is windblown sand. Modified after Albritton and Smith (1965).

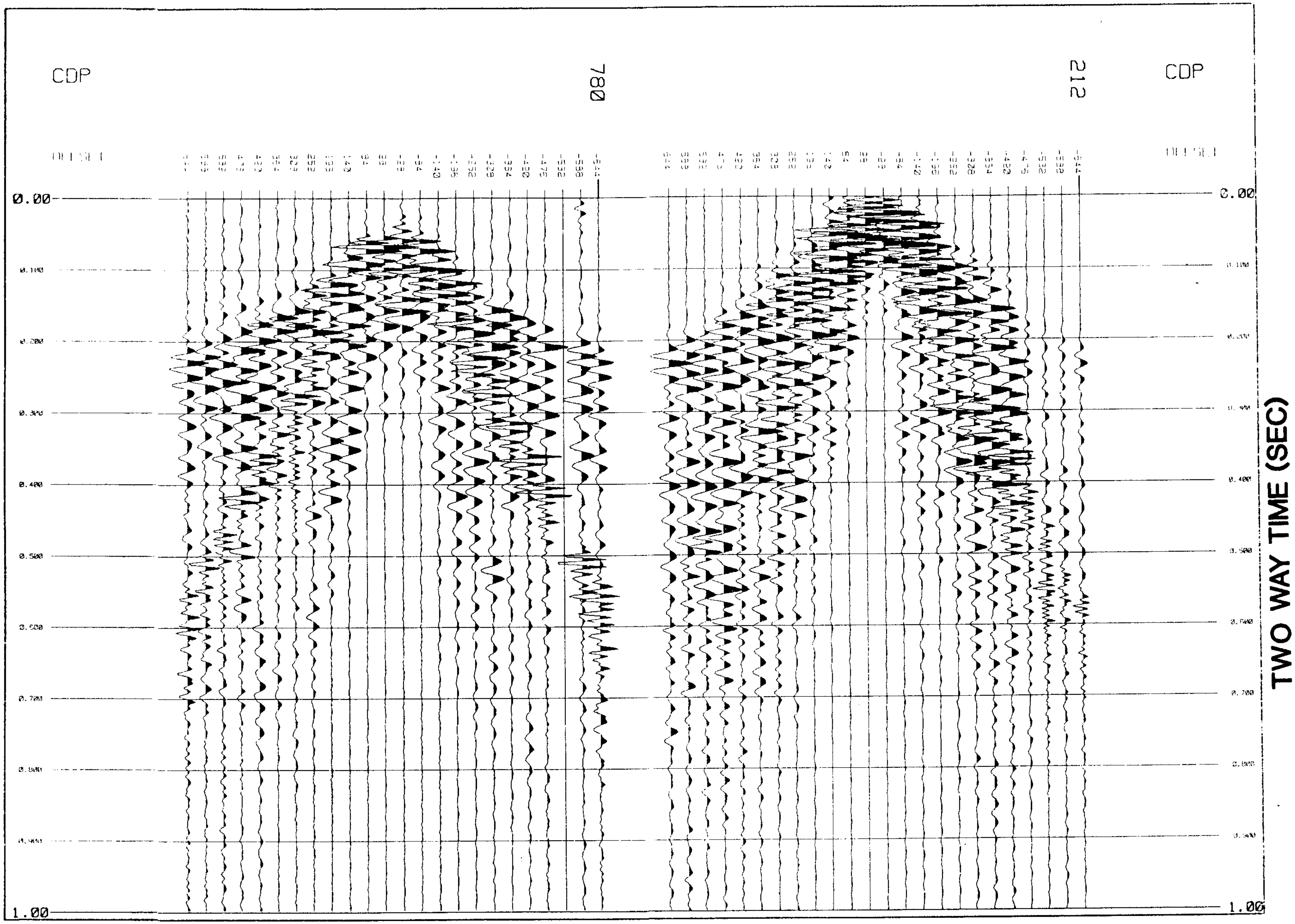

Figure 6. Comparison of airblast noise level using a podded, 12 geophones, single-point receiver group (left) for a CDP gather along Line UT-1 with a linear array of 12 geophones spaced 2 feet apart (right) for a CDP gather along Line UT-2. Note the marked reduction of airblast amplitude for the 12 geophone linear array receiver group. Low pass filter 120 Hz.

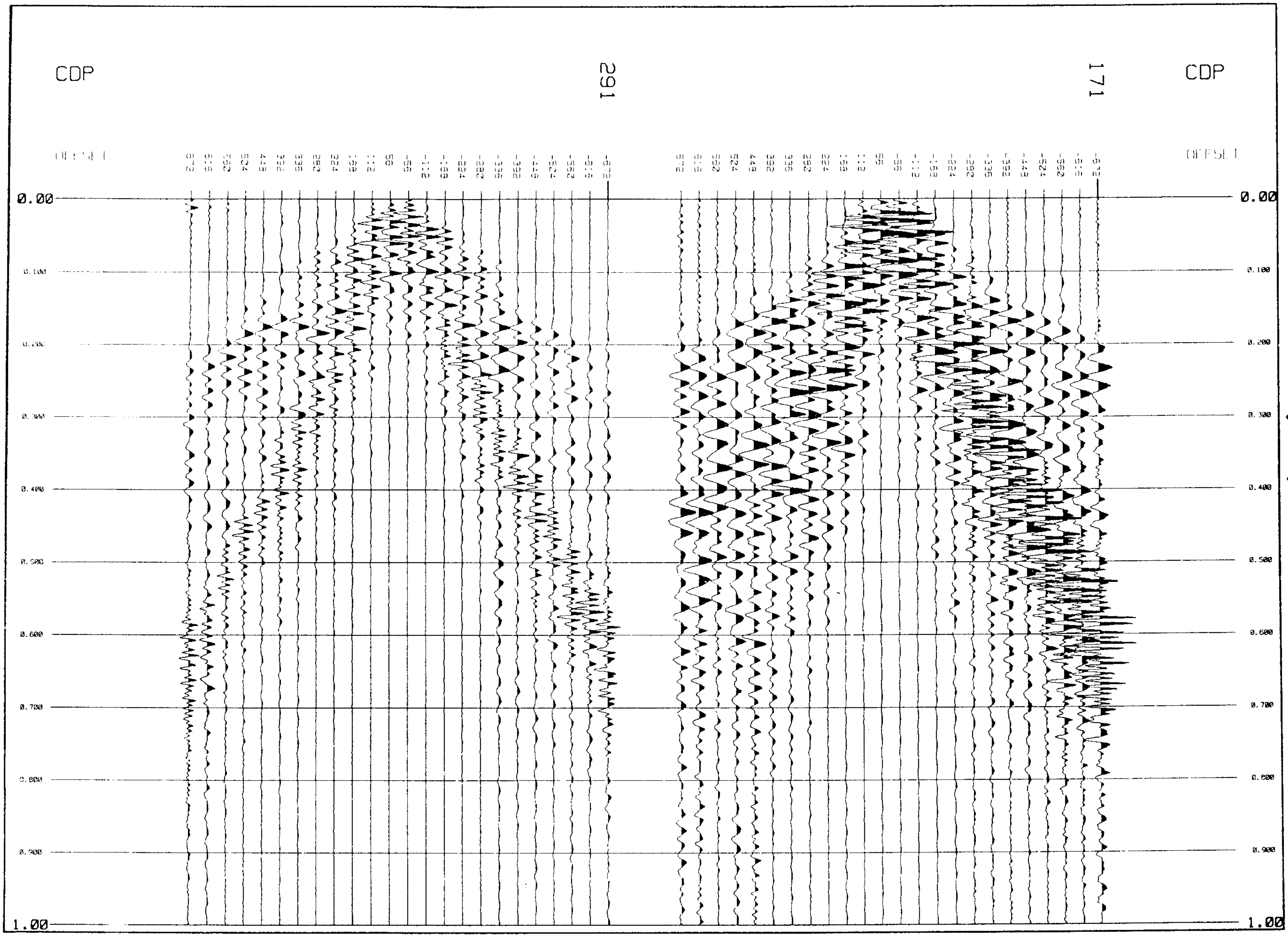

Figure 7. Comparison of airblast noise level for CDP gathers along line UT-2 with the vibrator truck positioned on the line (right) and offset from the line about 30 feet (left). Low pass filter 120 Hz.

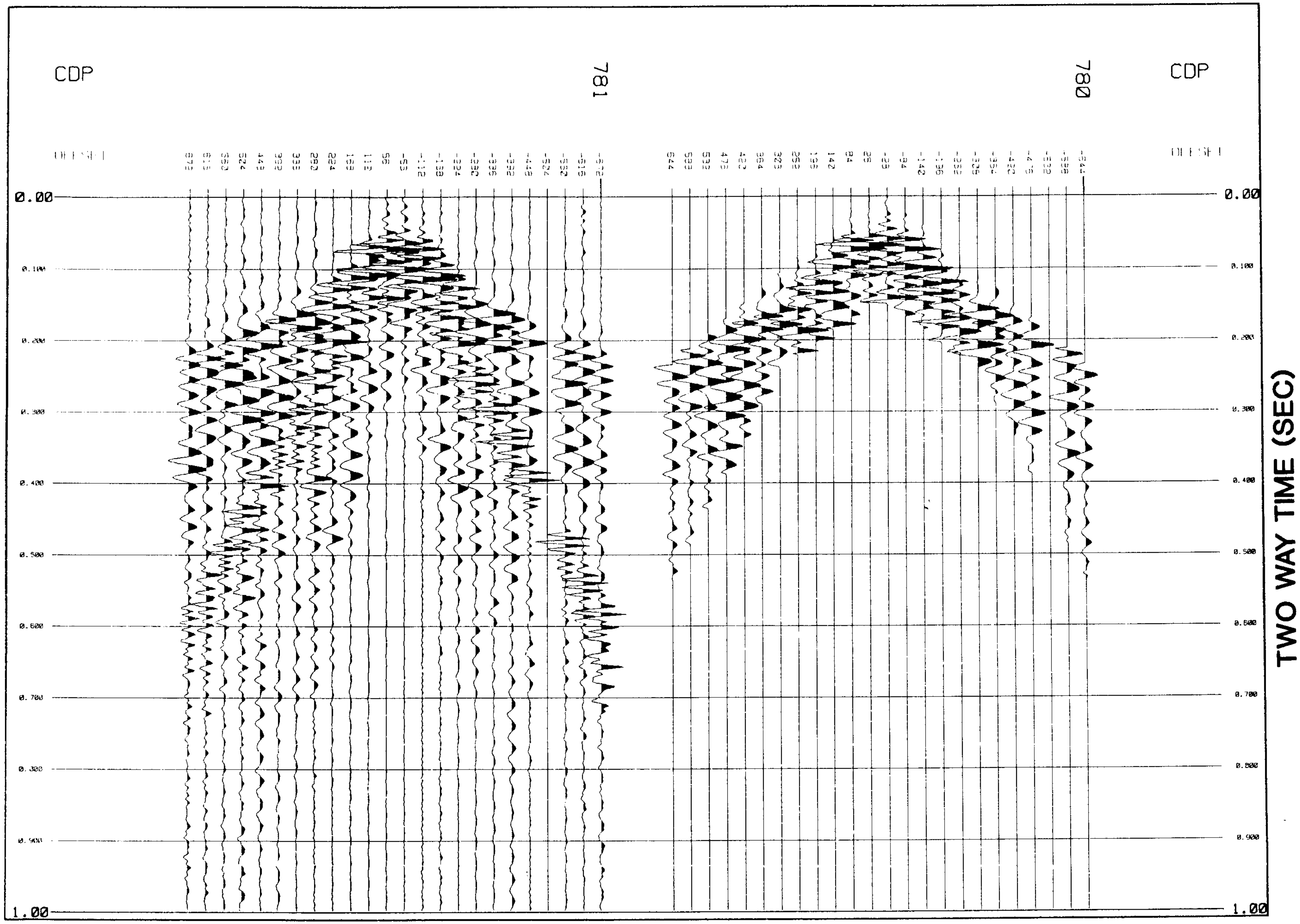

Figure 8. Typical CDP gathers showing the "inside-outside" mute schedule used to eliminate the airblast noise and refracted arrivals. Low pass filter 120 Hz. Gather on left is before application, gather on right is after application.

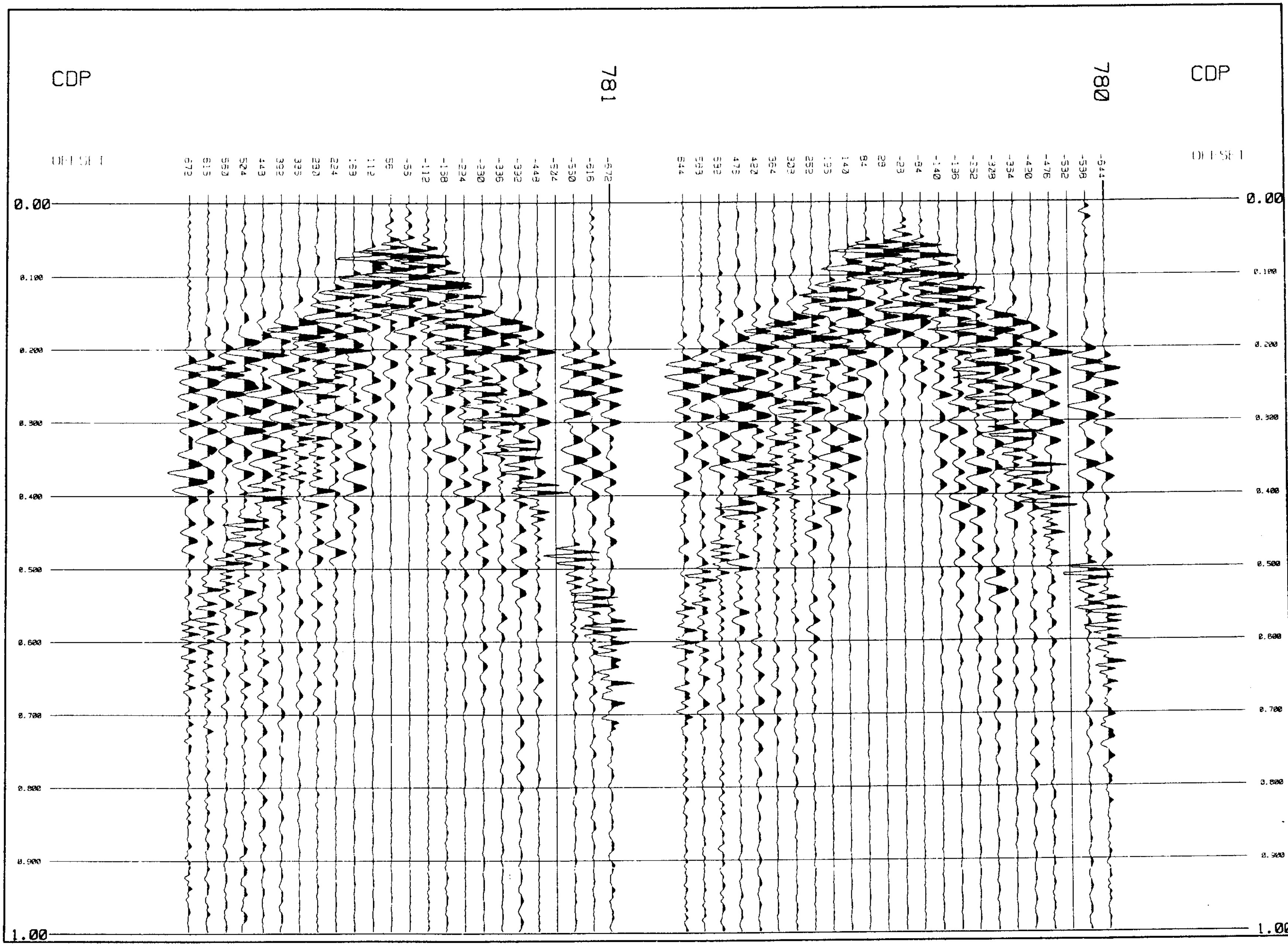

Figure 14. Typical raw CDP gathers. Line UT-1 using podded, 12-geophone single-point, receiver group. Low pass filter 120 Hz.

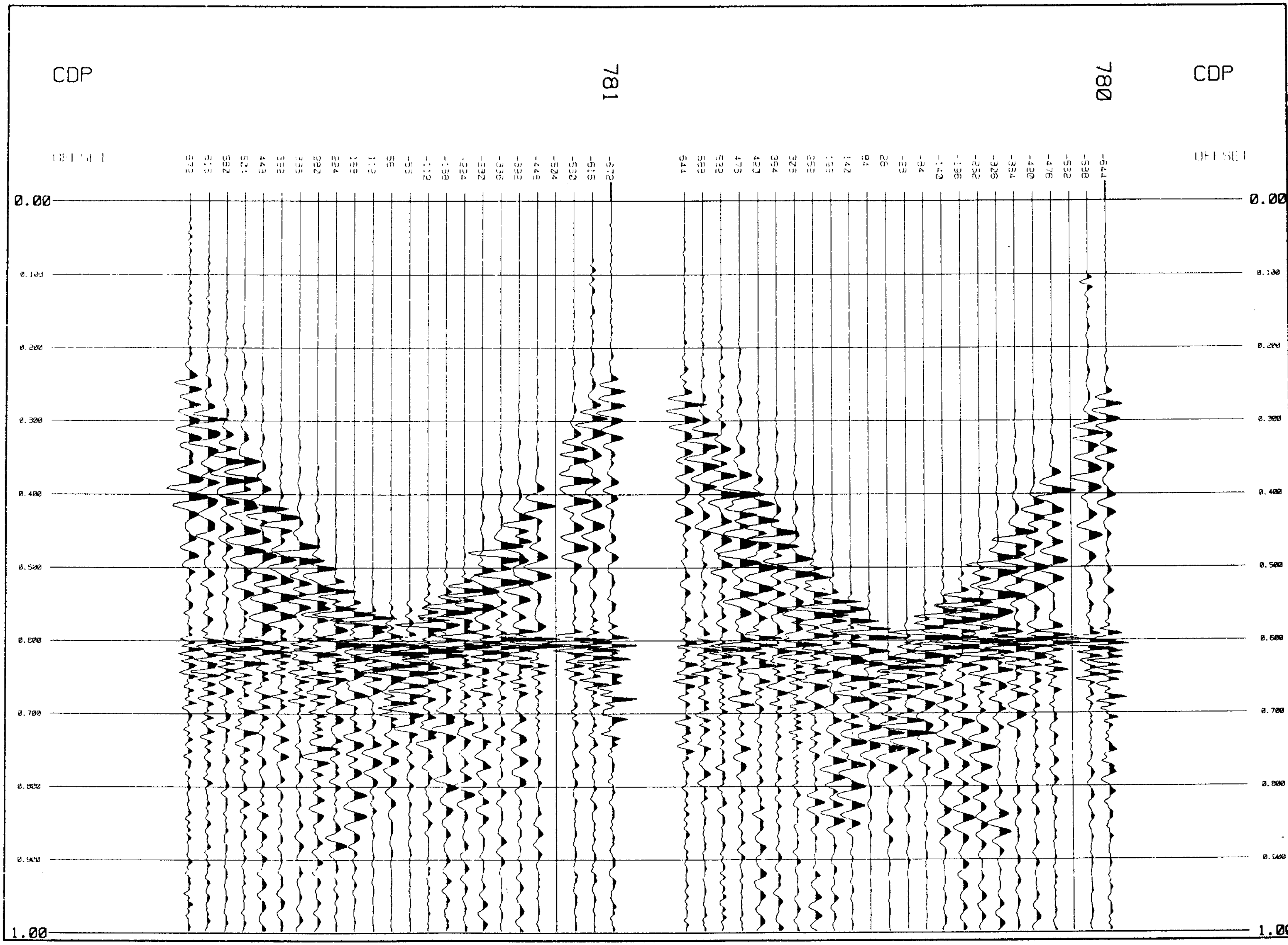

Figure 15. Raw CDP gathers of Figure 14 after application of 1150 ft/sec airblast linear reducing velocity static.

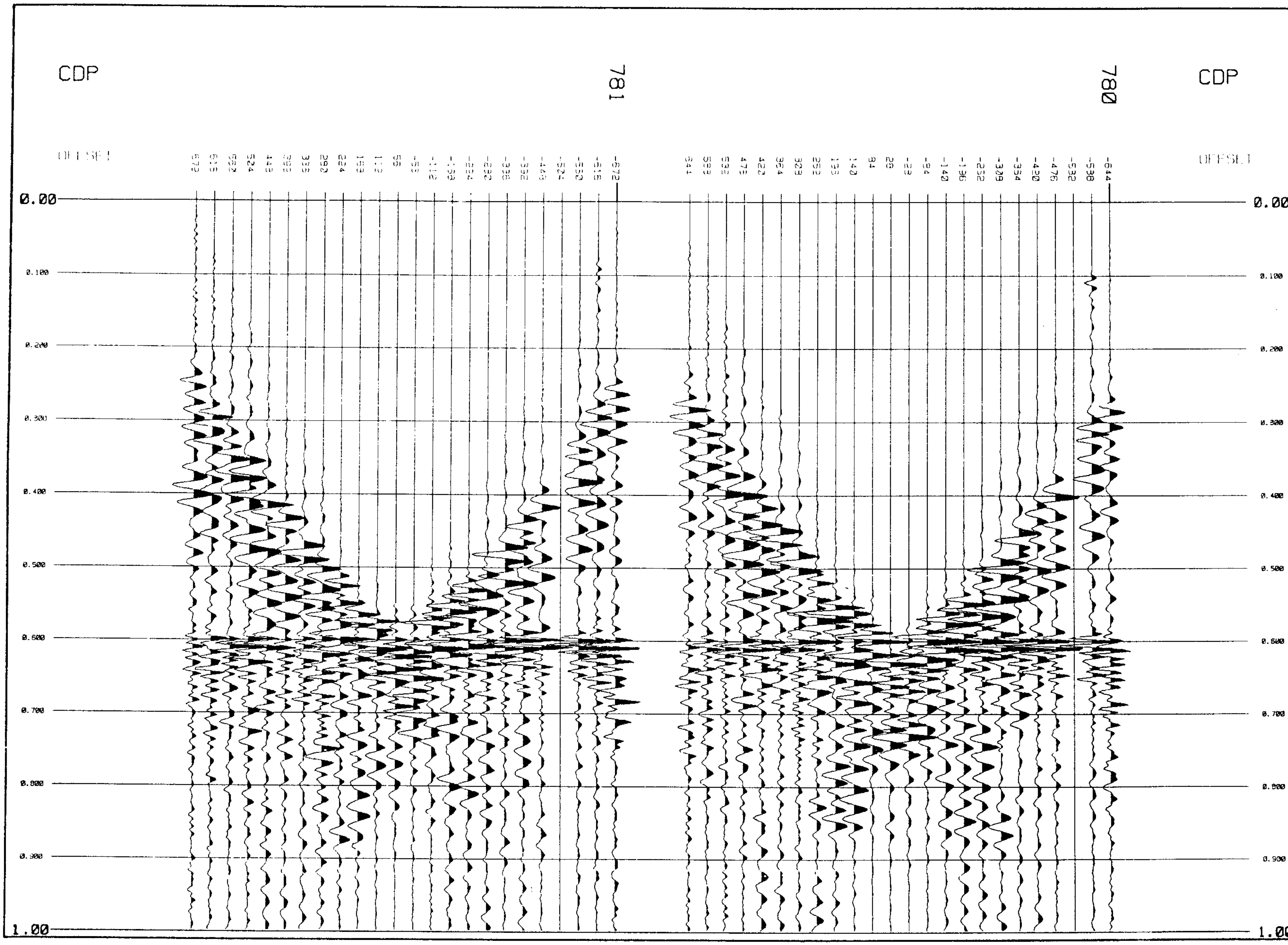

Figure 16. CDP gathers of Figure 15 after application of automatic residual static correction to align airblast wavetrain arrival.

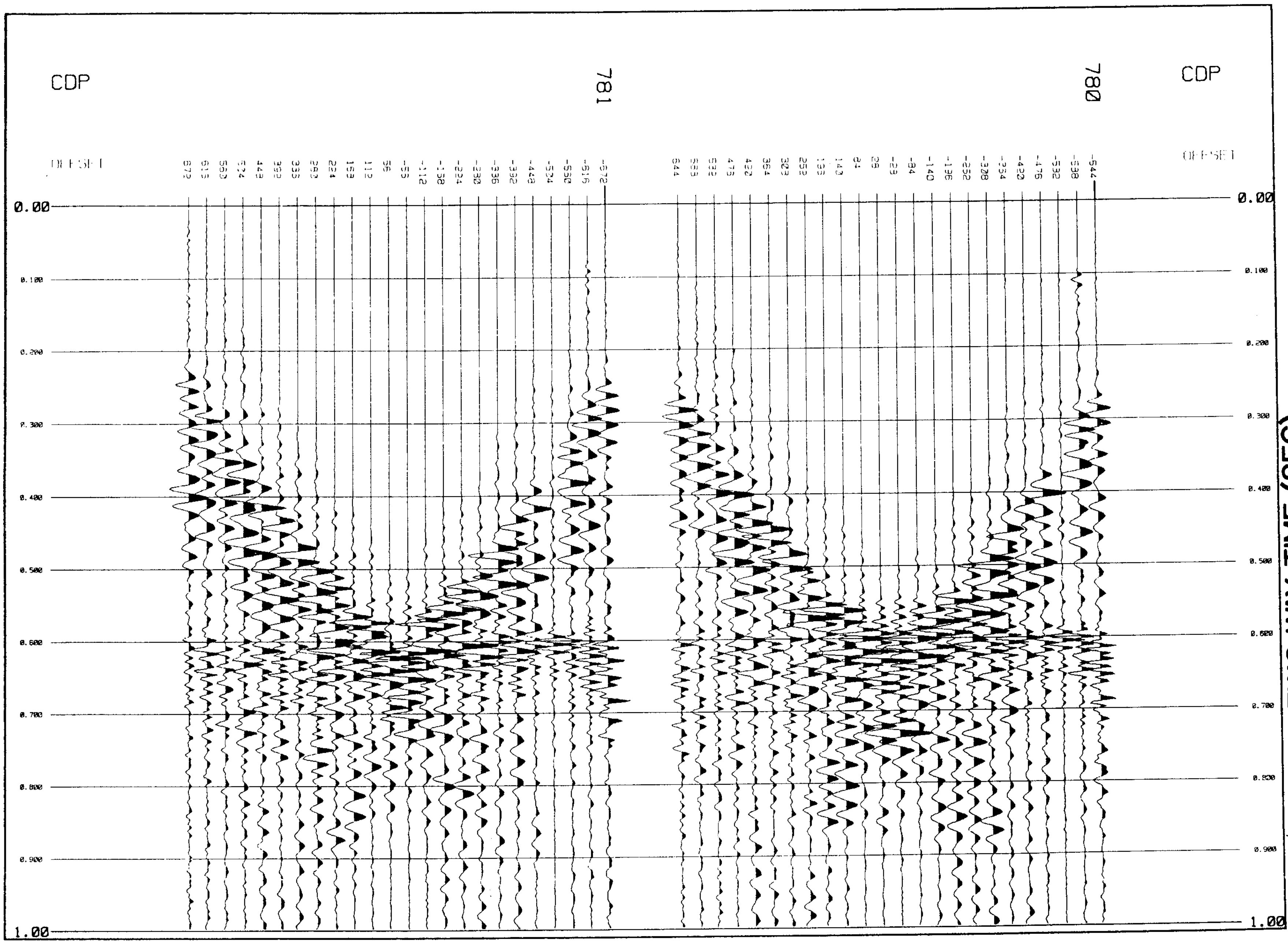

Figure 17. CDP gathers in Figure 16 after application of F-K velocity filter to attenuate horizontal airblast arrivals.

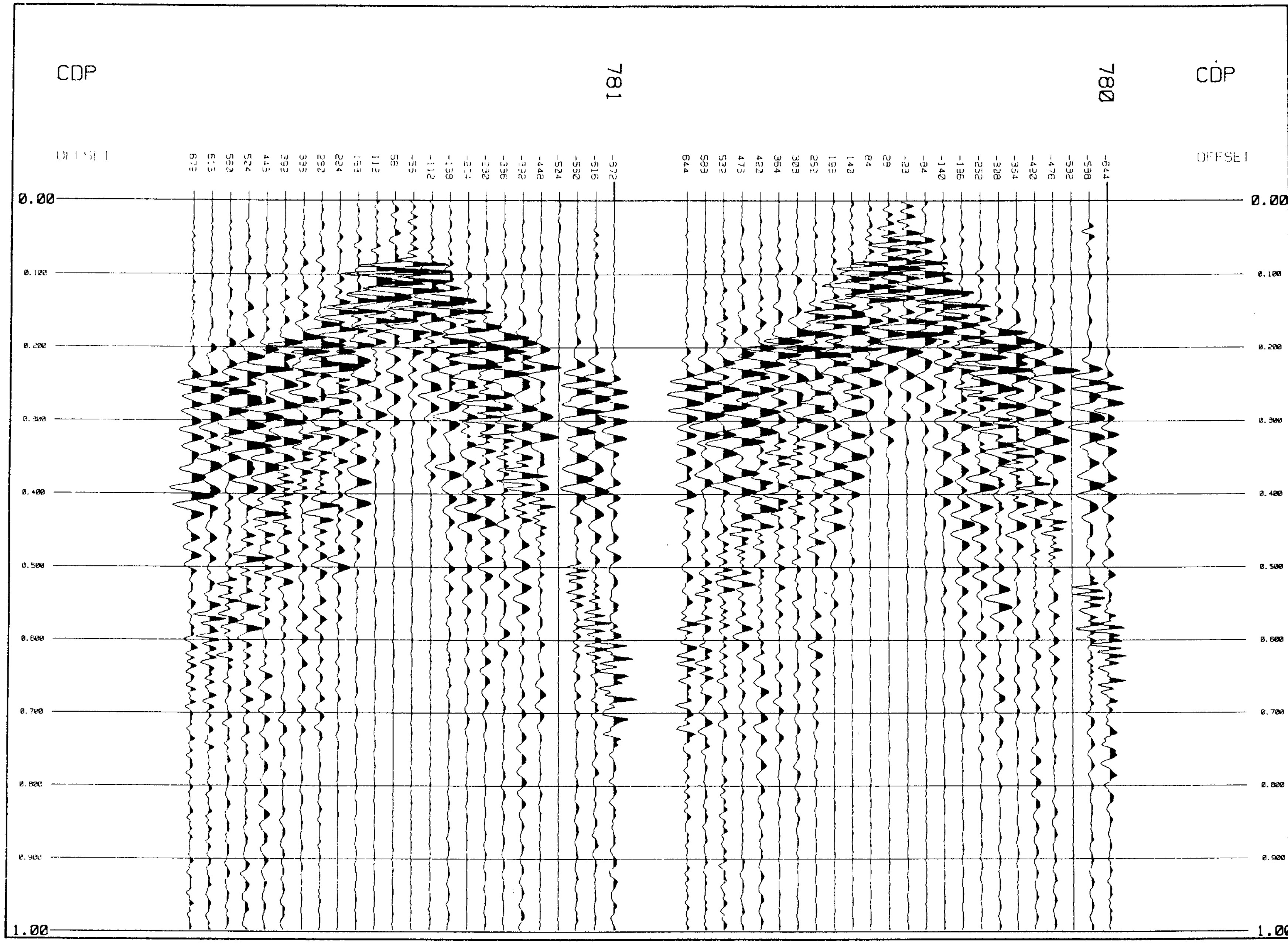

Figure 18. CDP gathers in Figure 17 after removing the airblast wavetrain aligning and linear reducing velocity statics.

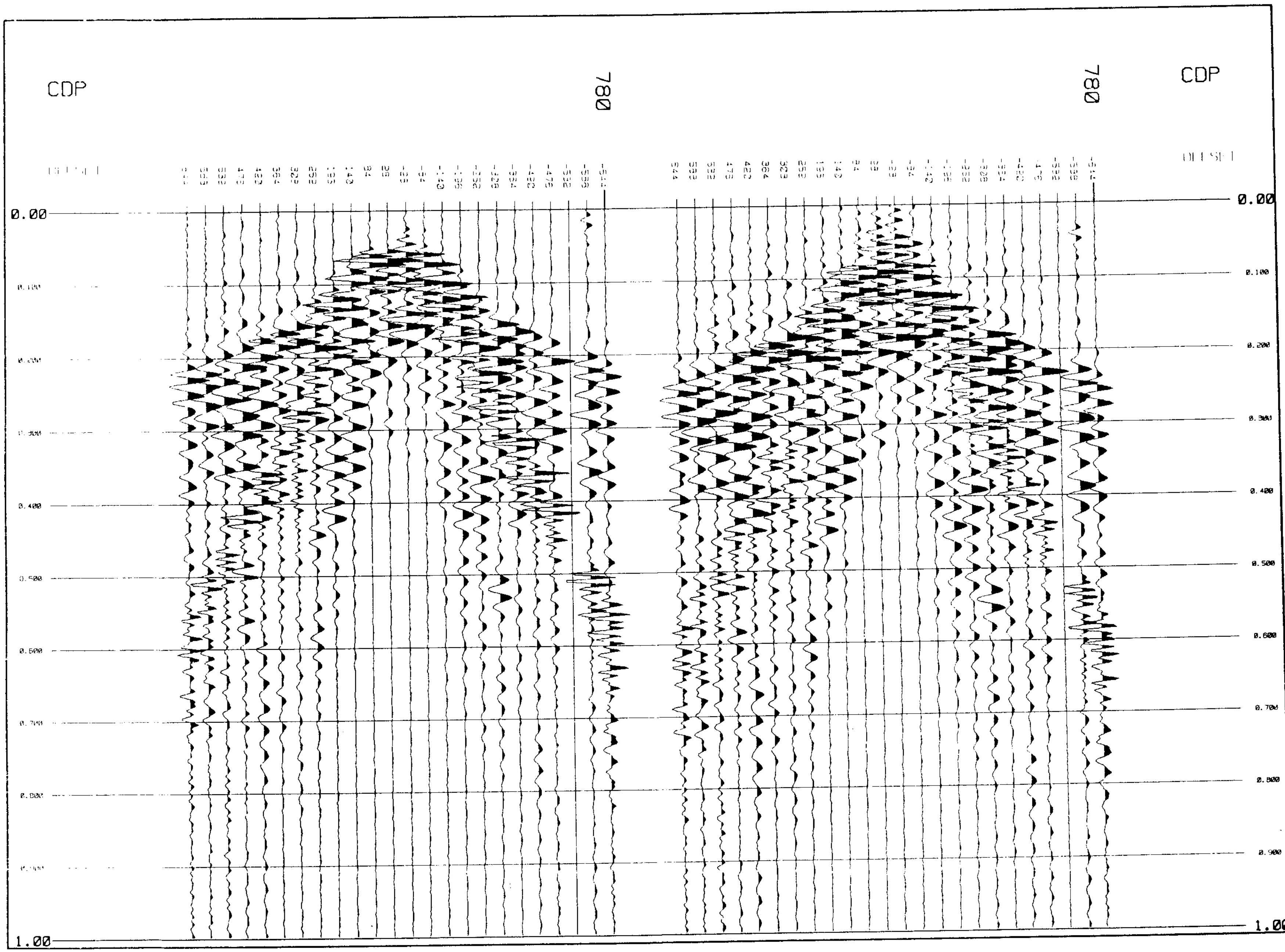

Figure 19. Comparison of raw CDP gather in Figure 14 (left) with same CDP gather F-K velocity filtering shown in Figure 18 (right).

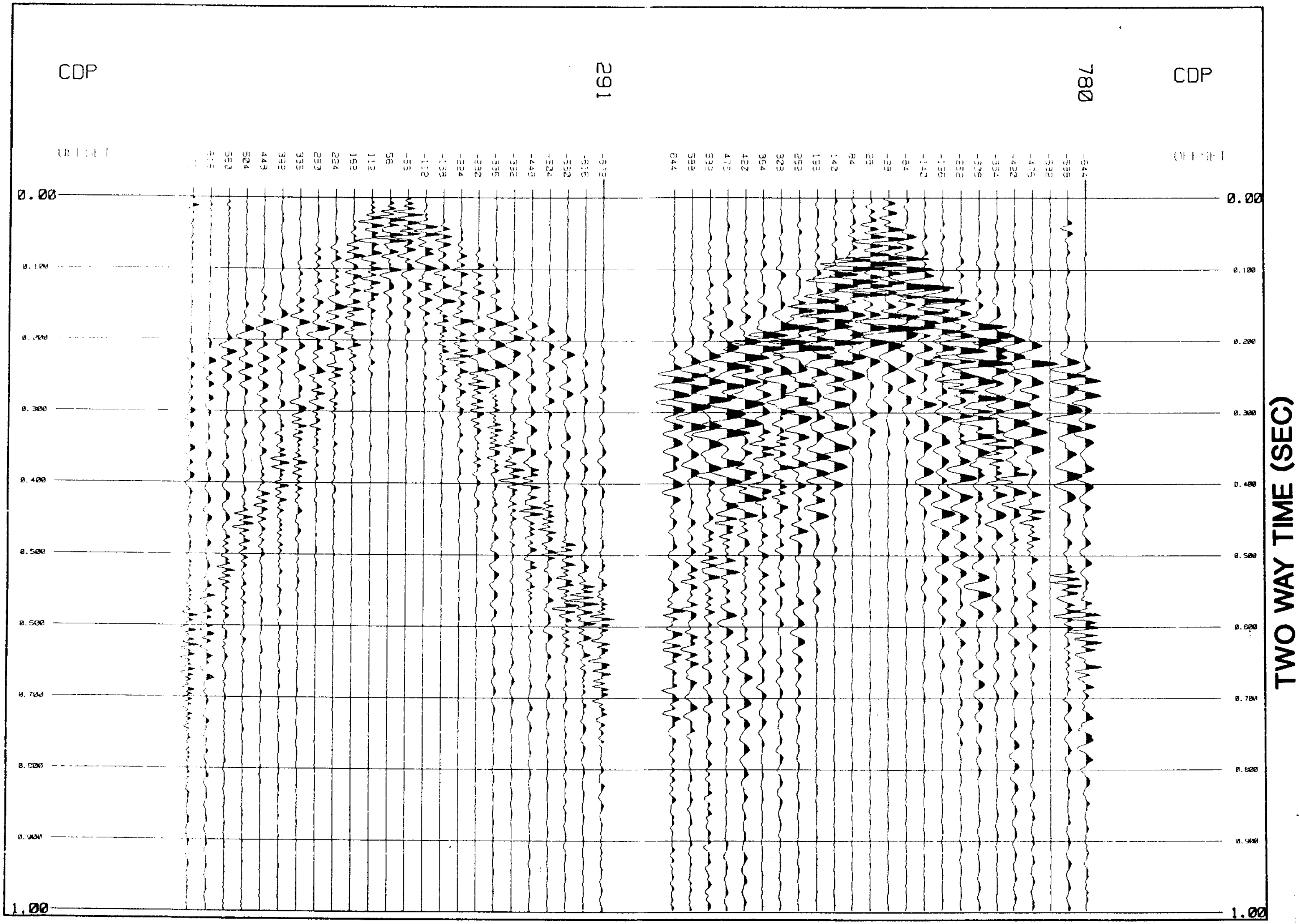

Figure 20. Comparison of an F-K velocity filtered gather from Line UT-1 (Figure 18) (right) with a CDP gather acquired using a 12-geophone linear array receiver group with the vibrator truck positioned 30 feet off the seismic line (left). Note the similar amplitude levels of the airblast noise.