Shallow Seismic Reflection Feasibility Study at the Drop Test Facility, Paducah Gaseous Diffusion Plant, Paducah, Kentucky

by

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INTRODUCTION

This study was designed to determine the feasibility of shallow seismic reflection to map discontinuous sands and gravels at the Paducah Gaseous Diffusion Plant (PGDP), a DOE-contracted uranium enrichment facility in western Kentucky (Figure 1). The Drop Test Area (DTA) at the PGDP was used between 1964 and 1979 for testing uranium hexafluoride shipping cylinders. Prior to structural testing the cylinders went through thermal conditioning. This conditioning required the cylinders be immersed in a concrete pool containing dry ice and trichloroethelene (TCE), a dense, nonaqueous phase liquid (DNAPL). Once chilled the cylinders were dropped onto a cement pad from various heights. An unknown amount of TCE leaked during this process and DNAPLs have since migrated from the test site, and remediation tactics are being considered. Remediation of DNAPLs is particularly difficult because many traditional approaches could exacerbate the problem rather than remediate it. Geophysical characterization could identify stratigraphic features which might constrain contaminant migration and directly detect changes in the location or concentration of DNAPL as the surfactant test proceeds.

Quaternary sand and gravel layers overlie the Mississippian bedrock in this portion of the Mississippi Embayment (Olive, 1980). Critical to site characterization at DTA is determination of a non-invasive method to map drill confirmed, discontinuous sand and gravel deposits at 18-25 ft deep (Figure 2). These deposits probably represent channel and bar features resulting from drops in the Wisconsinan slack-water lake level (Clausen et al., 1992). Delineating the base of a 40 ft thick sandy clay that underlays these discontinuous sands and gravels is of secondary interest. This sandy-clay layer represents the boundary between the unconfined and confined (Regional Gravel Aquifer) aquifer systems in this area.

Shallow seismic reflection was one of several non-invasive geophysical methods tested at this site. Previous geophysical testing at the site have included a 120 MHz GSSI (HRGI, 1993) and 25 and 50 MHz pulse EKKO IV (Carpenter et al., in review) ground penetrating radar (GPR), EM-31 and EM-34 electromagnetic induction instruments (CH2M Hill, 1991), and Schlumberger resistivity soundings (HRGI, 1993). These methods were unsuccessful in identifying (with sufficient resolution) the critical sand and/or gravel units within the clayey silt layers at the site. Only the low frequency GPR surveys were able to correlate (with resolution on the order of 2 to 4 ft) interpreted results with the target sands and gravels identified in nearby borings at 18-25 ft.

The shallow seismic reflection study was designed in two parts, testing and evaluation, to be followed by production. The testing phase included 24 channels of downhole hydrophones spaced at 2 ft and 96 channels of surface deployed geophones spaced at 1 ft. This configuration of receivers remained constant, recording all 120 channels for each shot station occupied and source evaluated. Three non-invasive sources were tested at a 2 ft station spacing. These three sources included OYO's miniature vibrator, Kansas Geological Survey's SIST/KISS, and ACE Hardware's 16 lb sledge hammer. The test area was parallel to the north/south ditch directly west of DTA (Figure 1). The testing phase of the shallow seismic reflection study is the focus of this report.

DATA ACQUISITION

The data were acquired on a 120-channel OYO DAS-1 seismograph. The DAS-1 is a fixed-gain, 24-bit seismograph. Recording conditions were as consistent as possible for each of the three sources to allow for future comparisons. A gas engine powered 120-volt AC supply was necessary to operate the external hard drive when recording the 4 seconds of vibrator data and 8 seconds with SIST. The sampling interval was 250 msec for the vibrator and 500 msec for SIST and the sledge hammer. The final record length was 250 msec.

The field geometry was designed to allow optimum recording of reflections from interfaces between about 15 and 60 ft. The receiver stations were separated by 1 ft and located at the base of the north/south drainage ditch bank along the western edge of the drop test area (Figure 1). The source stations were located on the eastern bank of the ditch and separated by 2 ft. This vertical and horizontal source offset resulted in a source elevation approximately 2 ft greater than the equivalent receiver. The receivers were single Mark Products L-40A 100 Hz geophones with 5 in spikes. The improved planting conditions closer to the base of the saturated ditch should have decreased attenuation of the higher frequencies commonly associated with dry near-surface conditions.

Each of the three sources traversed the fixed spread of geophones. The source and recording conditions were tailored for each source. The recorded 16 lb sledge hammer data are the summation of 5 individual impacts at each shot station. These data were vertically stacked following a careful seating of the impact plate. A 120 V power supply provided the conditioned signal necessary to operate the electric OYO vibrator. A linear, 4 second pilot sweep ranging from 150 to 500 Hz was delivered to the vibrator. At each shot station the vibrator base plate was firmly placed into depressions left by the hammer and plate. Each shot record represents the vertical stack of 4 individual 4 second sweeps. The SIST followed the vibrator and was seated prior to each impact sequence. Each 8 second SIST record includes between 250 and 500 impacts. The impact rate was linear from about 1 to over 70 Hz. Each source and location was optimized for conditions and geologic target.

Walkaway tests were performed for each source to help identify the optimum offset, record length, sweep length and frequency, and stack count. The extremely shallow target depth and abundance of high amplitude linear arrivals made confident identification of reflection on single impact data sets difficult. The difficulty correlating on-site forced all geometries to be determined using the sledge hammer source. The sweep frequency band and length were determined from frequency content and bandwidth on single impact records. QA/QC was only possible on sledge hammer files as well as all analysis of walkaway data, which was undertaken on sledge hammer records.

DATA PROCESSING

Data processing was done on an Intel 80486-based microcomputer using *Eavesdropper,* a set of commercially available algorithms. The processing flow was similar to those used in petroleum exploration (Table 1). This processing flow concentrated on precision during velocity and spectral analysis, careful yet liberal muting operations, and conservative application of correlation statics.

For most basic shallow, high-resolution seismic reflection data the processing steps/operations are a simple scaling down of established petroleum based processing techniques and methods. However, processes such as deconvolution have basic assumptions that are violated by most shallow data sets. Migration is another operation that, due to non-conventional scaling (vertical and/or horizontal), many times may appear to be necessary when in actuality geometric distortion may be simple scale exaggeration. Processing/processes used on data for this report has/have been carefully executed with no assumptions and with care not to create anything after an operation that was not present before.

The OYO miniature vibrator and SIST data were recorded uncorrelated/time shifted allowing analysis of various correlation and time shift processes post-acquisition. The vibrator data were correlated with the source mounted accelerometer. Both the pilot and accelerometer traces were tested to determine which provided the best correlation. The SIST data required a simple time shift for each unique impact recorded as a spike on the aux channel. This time shift process is the time equivalent to correlation in the frequency domain. The correlated data for both the vibrator and SIST were 250 msec long with one-quarter and one-half msec sampling interval, respectively.

TABLE 1
Processing flow

<u>Primary Processing</u>
format from SEG2 to KGSEGY
preliminary editing (automatic bad trace edit with 10 msec noise window)
trace balancing (150 msec window)
first arrival muting (direct wave and refraction)
surgical muting (removal of groundroll based on trace-by-trace arrival)
assign geometries (input source and receiver locations)
sort into CDPs (re-order traces in common midpoints)
velocity analysis (whole data set analysis on 100 ft/sec increments)
spectral analysis (frequency vs amplitude plots)
NMO correction (station dependent ranging from 1350 to 2,500 ft/sec)
digital filtering (bandpass 60-120 350-500)
secondary editing (manual review and removal of bad or noisy traces)
CDP stack
amplitude normalization (whole trace with 40 msec delay)
display

<u>Secondary Processing</u>
f-k filtering

PROCESSING FLOW FOR CDP STACKED DATA. Parameters were determined by analysis for each prior step as well as through iterative analysis of particular operations.

RESULTS

Field file analysis represents the most reliable method of confident identifying, distinguishing, and classifying coherent events on CDP stacked sections. Primary reflections are difficult if not impossible to identify on either raw or filtered and scaled field files from any of the three sources. The extremely shallow reflectors (based on approximate average velocity from first arrival analysis) should arrive between 15 and 25 msec. That time window is saturated with groundroll, direct wave, air coupled wave, and refractions. The very cyclic nature of the refraction after digital filtering is indicative of a narrow band source wavelet. The high frequency energy necessary to resolve such a shallow, thin set of reflectors is not being transmitted through the near-surface. The air coupled wave is a significant problem on all three sources. The near-offset traces for the data recorded with the hammer and SIST were over driven. This is probably related to improper selection of pre-A/D gain. The lack of confidently identifiable reflection arrivals inhibits defense of any interpretation of the CDP stacked data.

The sledge hammer CDP stacked section was not of sufficient quality to confidently interpret the presence or absence of intermittent sands and gravels between 15 and 30 ft at this location. The survey geometry was designed to allow acquisition of source-to-receiver offsets appropriate for both the shallow (18-25 ft) and deep (60 ft) targets. Neither was confidently imaged. Field files possess strong refraction, air wave, and ground roll components with but a single questionable arrival that could be reflected (Figure 3). The refraction arrival is very narrow band and therefore of a cyclic nature. Production and propagation of a broad band, high frequency source wavelet was not accomplished with the sledge hammer. The sledge hammer (as with most accelerated weight drop sources) produces a proportionately large amount of ground roll and direct/refracted wave. This characteristic seems to be accentuated by a hard near-surface. Digital filtering has very little effect on the quality of the CDP stacked sections (Figure 4). Subtle indications of coherent events between 40 and 60 msec could be reflections but they lack confirmation on field files. The "ringy" direct and refracted wave in conjunction with the large air wave component and always-present ground roll inhibited the effectiveness of the sledge hammer at this site.

The OYO miniature vibrator represented the most promising of the non-invasive sources tested at this site. The non-impacting, low energy, high frequency nature of this source acoustically matches well with the near-surface and target at this site and should have produced records with the highest ratio of reflection signal-to-noise (everything else). Selected field files from across the line possess no arrivals that can be confidently identified as reflection (Figure 5). The three files have been digitally filtered (a) followed by an fk-filter (b). The frequency filter was designed to attenuate as much of the high frequency and power line noise possible. The f-k filter was intended to remove steeply sloping events, potentially revealing any gently sloping reflection arrivals. Neither operation facilitated confident identification of near-vertically reflected energy. The CDP stacked section both with f-k filter and with only digital possess subtle features easily interpreted as representative of subsurface geology (Figure 6). Only a very limited degree of confidence can be placed in an interpretation without field file confirmation.

The SIST source was a proto-type at best. It was tested on the off chance something encouraging might be observed in this relatively unique method of imparting seismic energy into the ground. Each correlated trace possessed between 75 and 250 impacts (depending on the quality of the linear sweep). Field files both digitally and f-k filtered possess strong remnants of the correlation process (time shift) (Figure 7). In several places on both files prior to f-k filtering spurious air wave arrivals can be interpreted. The same stacked refractions are interpreted on the SIST CDP stack as the sledge hammer (Figure 8). The narrow band appearance is present but not as obvious as the sledge hammer. The f-k filter did a relatively good job in reducing the amount of correlation noise on stacked section but did little to enhance coherent arrivals that could be interpreted as reflections.

CONCLUSIONS

With the equipment available during this test, shallow seismic reflection does not appear to possess the imaging, much less the resolution potential, necessary to properly characterize this site for future remediation. The vibrator produced higher frequency data, but the field files, even after filtering do not seem to possess any high confidence reflection arrivals. The sledge hammer and the SIST have similar frequency components but nether have reflection events that can be correlated between field files and CDP stacked data. Ignoring the lack of field file confirmation, several events on the vibrator data and at least one on the sledge hammer data possess characteristics consistent with expectations of reflection from this area. Without field file confirmation, events on CDP stacked data are not sufficient to justify the production portion of this project.

ACKNOWLEDGMENTS

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FIGURE CAPTIONS

Figure 1. Site map of the Drop Test Area at the Paducah Gaseous Diffusion Facility. The line location and extent is dependent of analysis of existing drill data.

Figure 2. The three boring significant to this survey possess similar geologic intervals with varying thicknesses. At around 20 ft the packet of sand, sandy-clay, clayey sand, sandy clay w/silt, etc. seem to be concentrated in at least two of the three holes.

Figure 3. Scaled and digitally filtered field files with the sledge hammer as source. The three files (a) are scaled and from different places along the fixed 96-channel spread. Digital filtering (b) with a lower corner frequency of 120 Hz has little if any effect on the data quality.

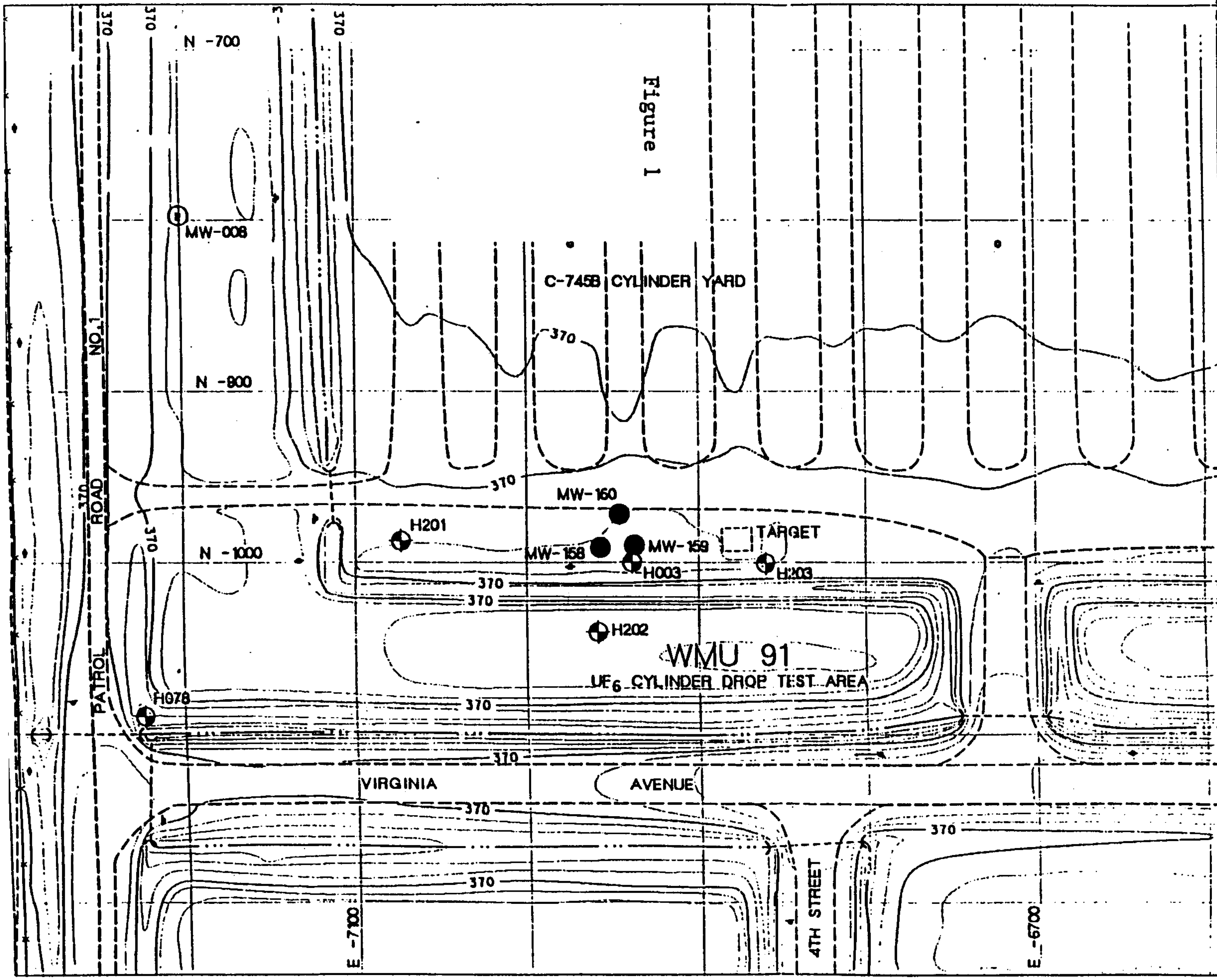
Figure 4. Nominal 24-fold CDP stacked along the 96 station fixed spread. Without first arrival muting (a) the refraction arrival is the strongest and most coherent event interpretable on the section. After application of a liberal first arrival mute to complement both the surgical air wave mute and the bad trace edit, the strong refraction arrival is reduced over a large portion of the line. Some subtle indication of coherent arrivals that did not mimic the refraction can be interpreted between 40 and 60 msec. This would be the appropriate time for a 60 ft deep reflector at this site.

Figure 5. Digitally filtered and f-k filtered field files with the OYO miniature vibrator as source. The three files (a) from different places along the 96-channel fixed spread are scaled and digitally filtered. F-k filtering (b) of the files to remove the strong air coupled and refracted arrival was effective, but did little to enhance reflection signal, if present.

Figure 6. Nominal 24-fold CDP stacked section using the vibrator along the 96 station fixed spread. Without f-k filtering (a) the refraction arrival is very prominent. The dominant frequency is around 150 Hz (the lowest sweep frequency). The shallow high amplitude event is almost totally removed on the stacked section after the f-k filtering (b). Subtle coherent events with significant geometry are interpretable between 10 and 30 msec in the middle portion of the f-k filtered stacked section. Some indications of an event at 30 msec is also interpretable. All these interpretations are made without field file confirmation and are therefore suspect.

Figure 7. Digitally filtered and f-k filtered field files with SIST/KISS as source. The two files (a) from different places along the 96-channel fixed spread are scaled and digitally filtered. F-k filtering (b) of the files to remove the strong air coupled and refracted arrival was effective, but did little to enhance reflection signal, if present. The repetitive air coupled wave is a result of the correlation process and was also the target of the f-k filter. The ground roll is quite pronounced before and after f-k filtering.

Figure 8. Nominal 24-fold CDP stacked section using the SIST/KISS along the 96 station fixed spread. Without f-k filtering (a) the refraction arrival is evident. With the exception of the correlation noise, the general appearance of this data and the sledge hammer data are similar. The stacked refraction event and the correlation noise are almost totally removed on the stacked section after the f-k filtering (b). It is not possible to interpret any coherent event on the before or after f-k filter stacked section that could be interpreted as reflection.



GROUNDWATER ANALYSES			
PARAMETERS	MW-158 (RGA-BOTTOM) (MAXIMUM)	MW-159 (RGA-TOP) (MAXIMUM)	MW-160 (SCS) (MAXIMUM)
1,1,1-TRICHLOROETHANE			5J
1,2-DICHLOROETHENE	4J		3J
CARBON TETRACHLORIDE			18J
CHLOROFORM			2J
PCE			3J
TCE	8	120	160,000J
TOTAL			
ALUMINUM			37,400J
ARSENIC	3.5J		
BARIUM	225		327J
BERYLLIUM			4.2J
CHROMIUM	113		110J
COBALT	8.4J	8.3J	35J
IRON			184,000J
LEAD		4.7	68.8
MANGANESE	1,320	1,800	1,410J
NICKEL	88		28.3J
VANADIUM		8.5J	285J
Tc-99		(4.8)J	33J
U-234			2.5J
U-238			2.3J
DISSOLVED			
ANTIMONY	28.3J		
ARSENIC	13.8		
BARIUM	220		
COBALT	8.5J		
LEAD			4.3
MANGANESE	1,380	1,300	388
NICKEL	10.8J		10.8J
Tc-99	(3.4)J	(5.8)J	(3.1)J

NOTES: CHEMICAL DATA REPORTED IN µg/L RADIOLOGICAL DATA REPORTED IN pCi/L

J INDICATES ESTIMATED VALUE.

( ) INDICATES ERROR VALUE EXCEEDS HALF OF REPORTED VALUE.

ONLY VALUES FOR DETECTED ANALYTES OF INTEREST ARE PRESENTED. SEE VOLUME 4 FOR COMPLETE DATA SET.

MW-008 WAS NOT SAMPLED.

LEGEND

- MONITORING WELL
- EXISTING PGDP MONITORING WELL
- SOIL BORING

TRUE NORTH 20° PLANT NORTH

0 30 60 90
SCALE 1"= 60'

~~Figure 4-6~~

SAMPLING RESULTS AT WMU 91: UF_6 CYLINDER DROP TEST AREA

PADUCAH GASEOUS DIFFUSION PLANT
PADUCAH, KY.
PHASE II SITE INVESTIGATION

eb-1992 0888w033.dgn

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SUBJECT AND LOCATION ______ W.O. ______
PAGE ______ OF ______
DESIGN BY ______ CHK'D ______ APP. ______

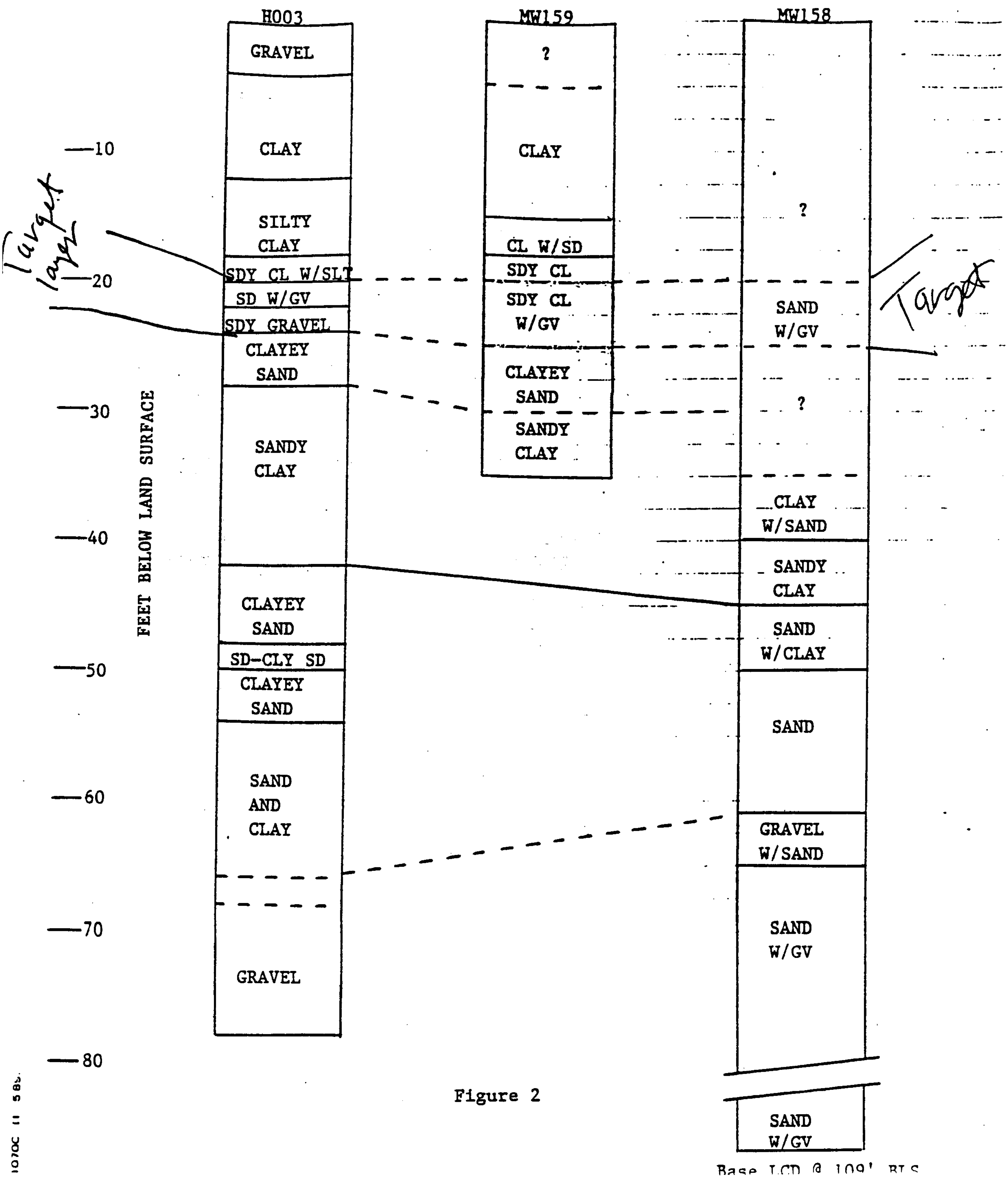


Figure 2

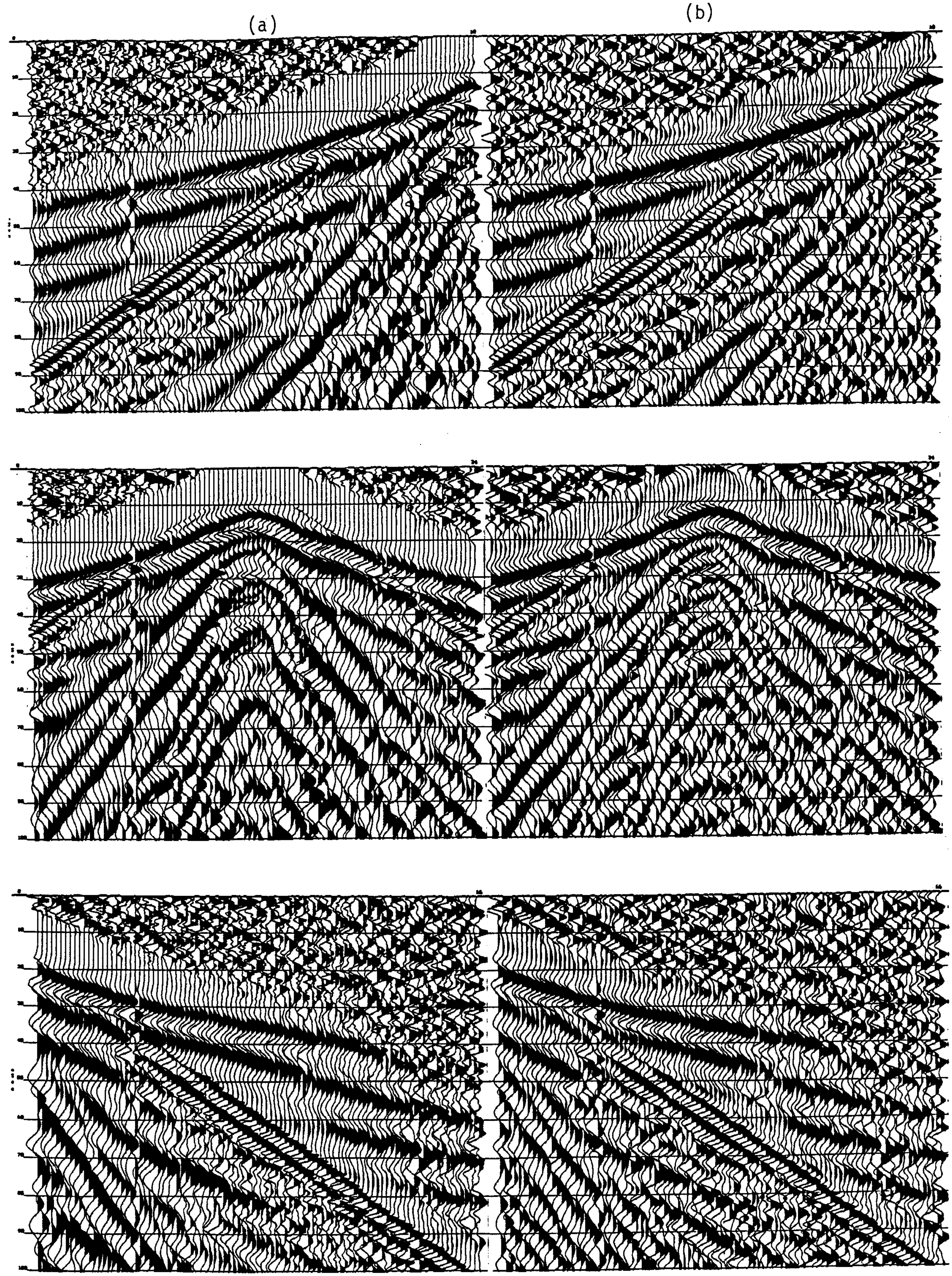


Figure 3

Figure 4

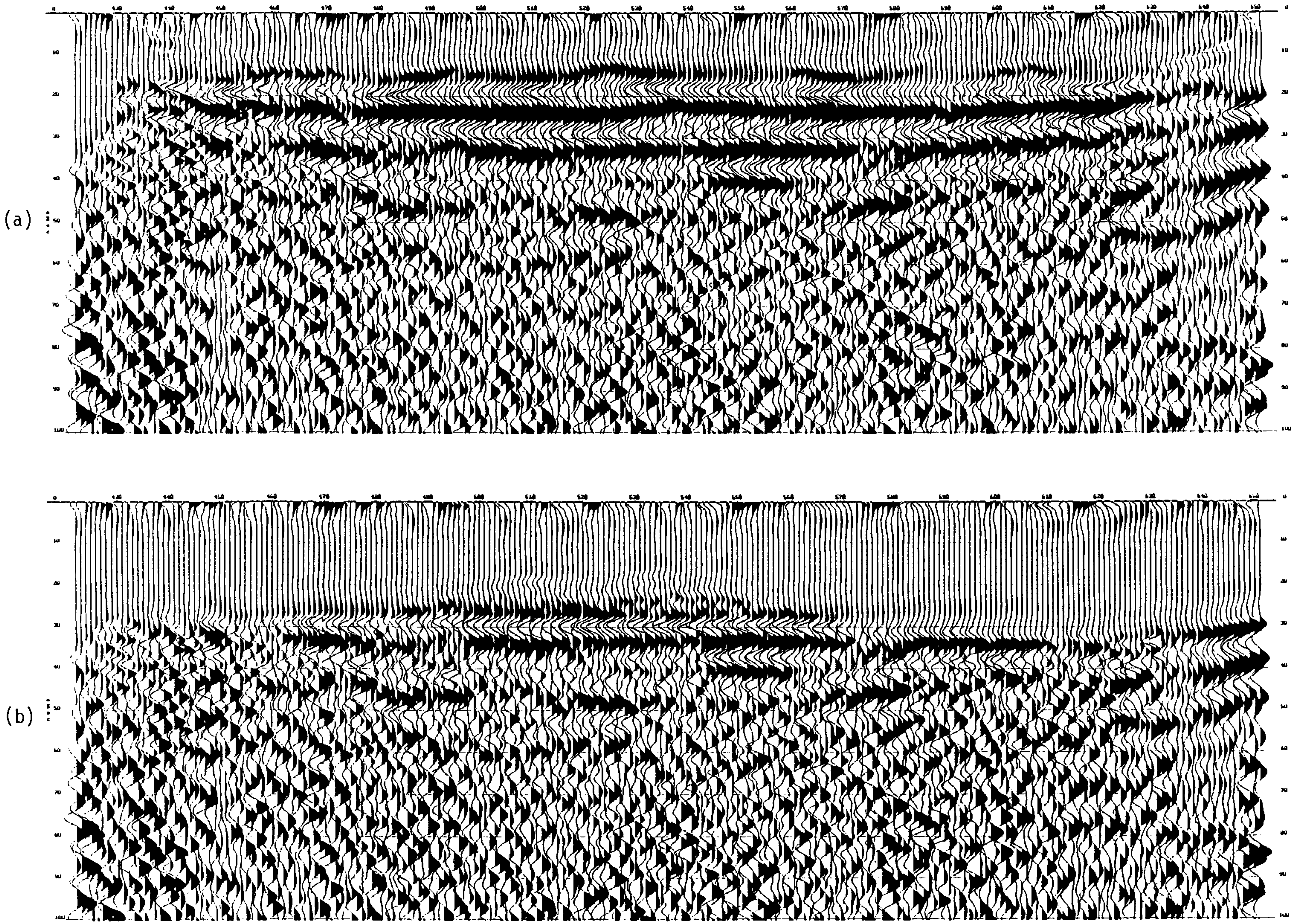


Figure 5

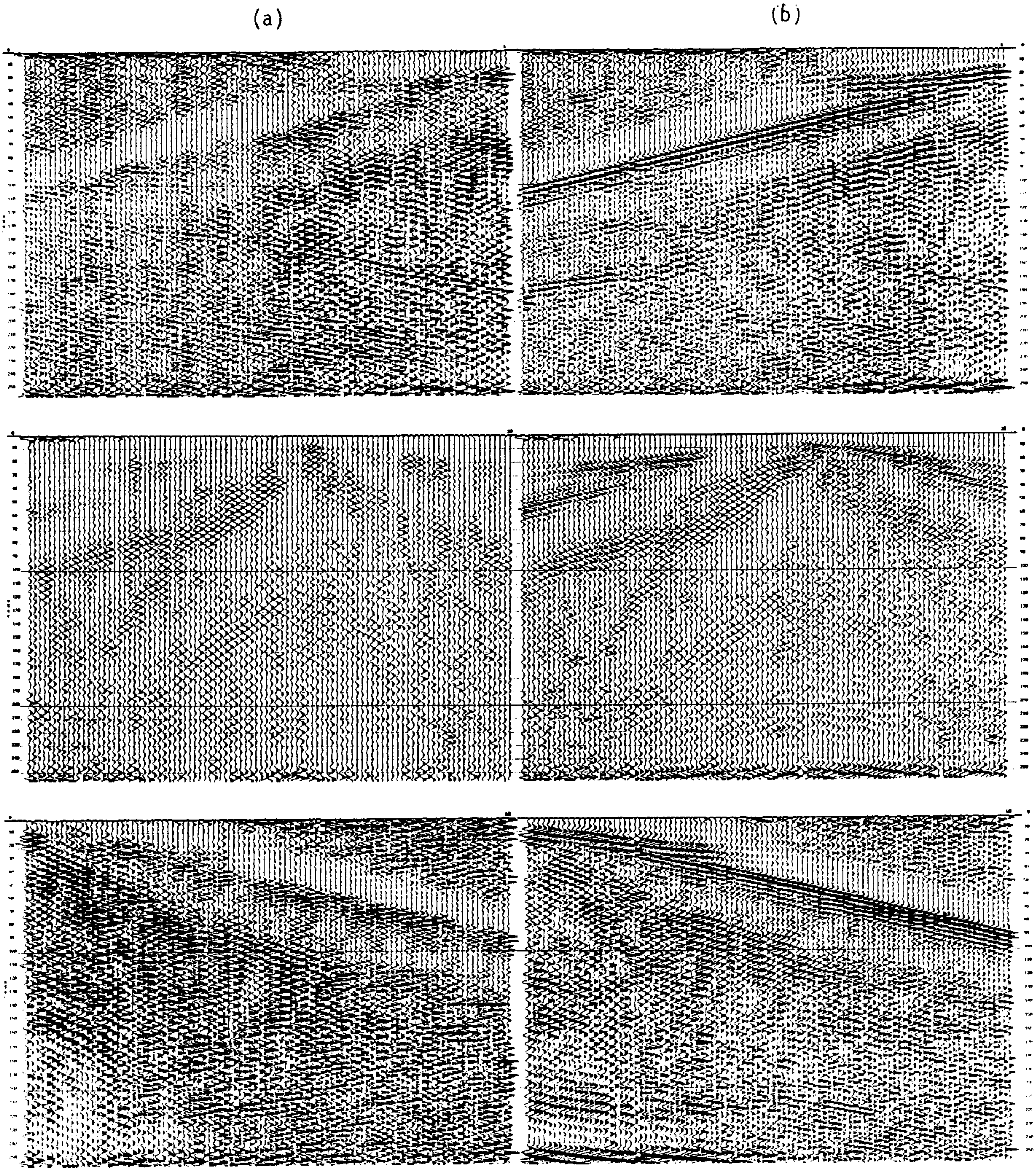
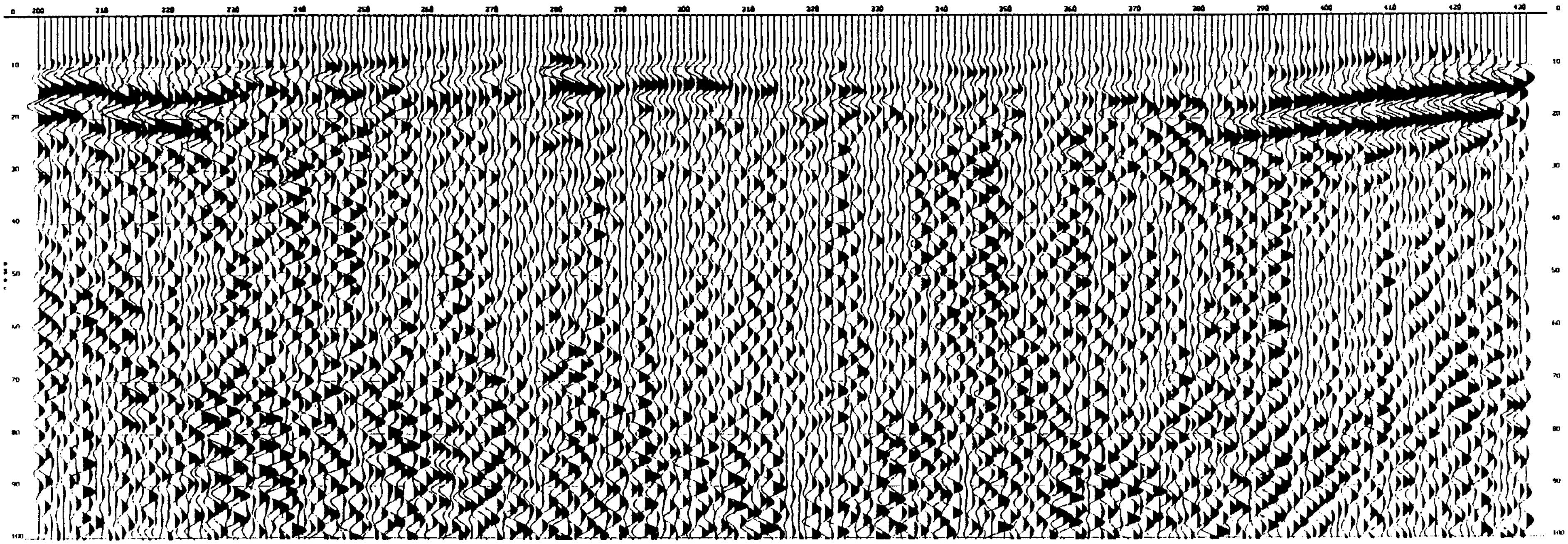


Figure 6

(a)



(b)

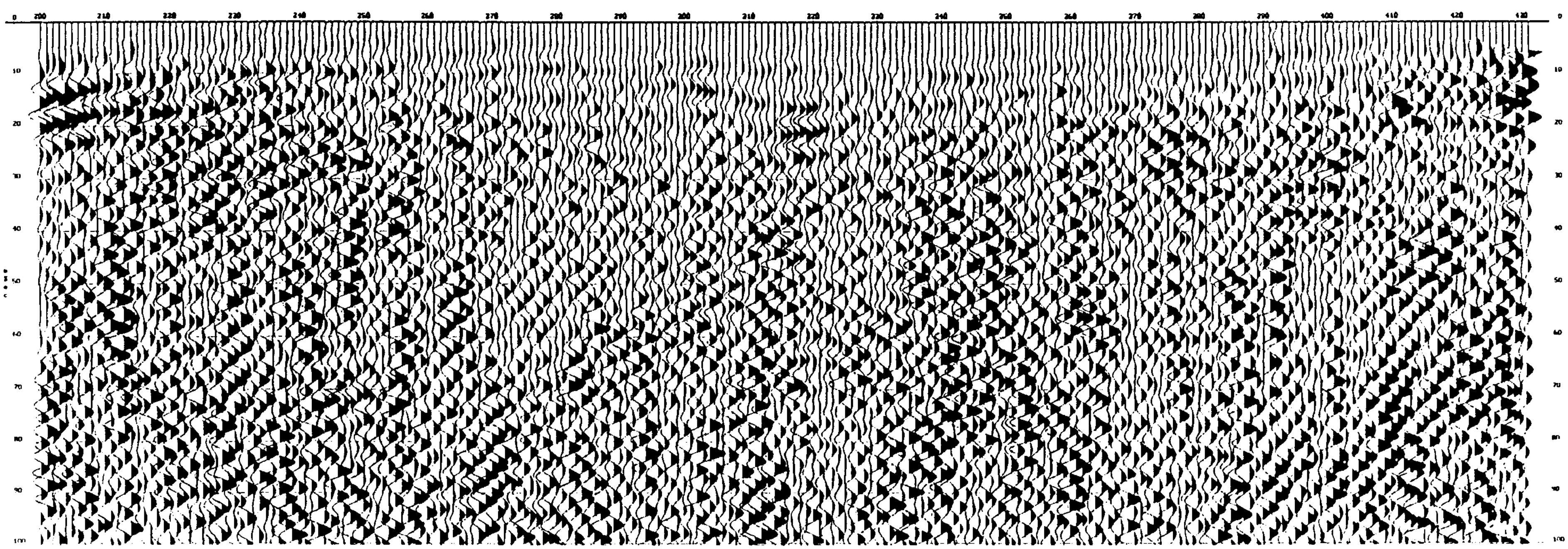


Figure 7

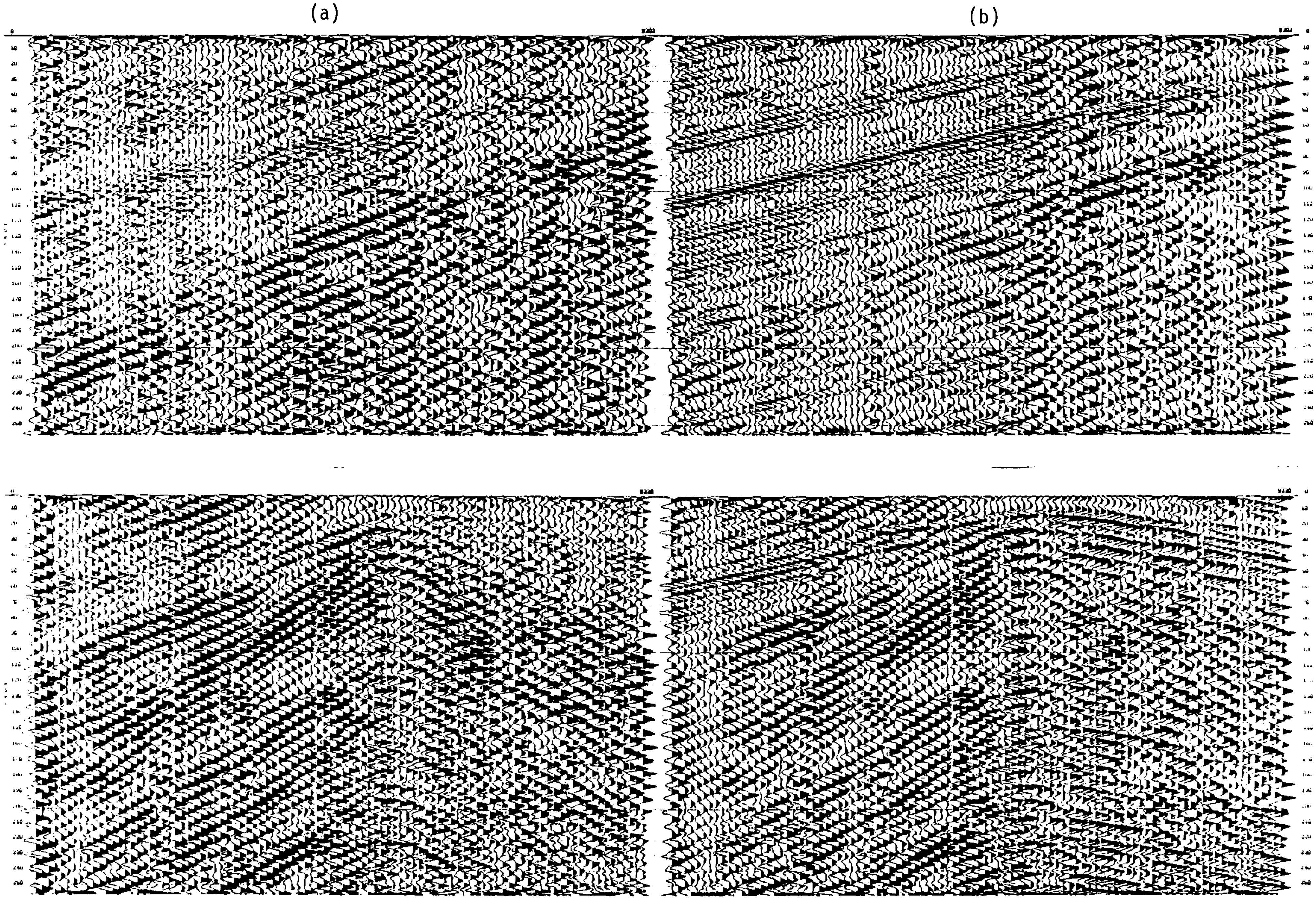
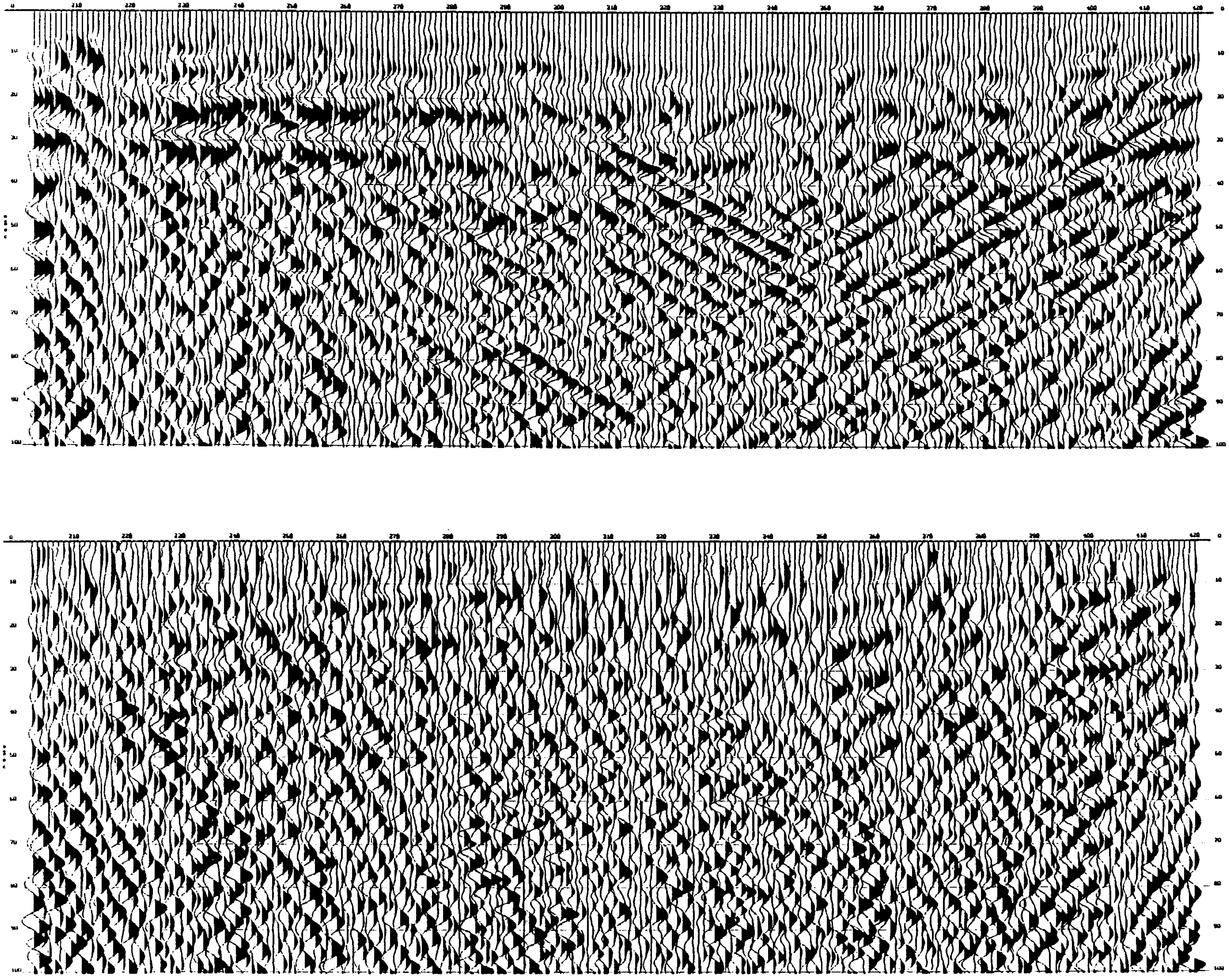


Figure 8

(a)



(b)