High Resolution Seismic Reflection Survey near SPR Surface Collapse Feature at Weeks Island, Louisiana

by

Richard D. Miller
Jianghai Xia
Joe M. Anderson
David R. Laflen
Jeffrey M. Erickson
Patricia M. Acker
Mary C. Brohammer

of the
Kansas Geological Survey

and

Don W. Steeples
Ross A. Black

of the
Department of Geology
University of Kansas

NOTE: This report contains a general discussion of field parameters, examples of field data, all the processed data, results, and conclusions from the surface seismic reflection profile conducted by the University of Kansas. Time limitations did not allow for inclusion of publication quality figures.

Summary

Shallow, high resolution seismic reflection techniques effectively delineated the horizontal extent of the subsurface expression of a 40 ft wide and 30 ft deep sinkhole above DOE's Weeks Island, Louisiana, Strategic Petroleum Reserve storage cavities. The two-level underground cavities, presently holding 73 million barrels of crude oil, are a former room and pillar salt mine. The top of the salt dome is approximately 180 ft below the ground surface at the sinkhole and is responsible for the more than 125 ft of topographic uplift that produced Weeks Island. Four nominal 180 shotpoint, 24-fold P-wave CDP lines were acquired with 8 ft station spacing. The reflections have an average dominant frequency of approximately 80 Hz and an apparent NMO velocity ranging from 1350 to 2100 ft/sec. The field recording parameters and quality control were based on the reflection interpreted during walkaway tests to be from a reflector about 150 ft deep. This coherent reflection event interpretable on all four lines is dramatically altered directly north of the surface expression of the sinkhole on the east/west line. **The disturbed area of the reflector interpreted to potentially be related to dissolution and subsidence might extend further north than the sinkhole. The subsurface expression of the current sinkhole is very steep and probably best described as a chimney.**

Introduction

This seismic reflection survey was designed both to detect and delineate any geologic or hydrologic features associated with the small sinkhole discovered on May 18, 1992, above DOE's Weeks Island, Louisiana, Strategic Petroleum Reserve storage cavities and identify any other areas potentially at risk of subsidence over the storage cavities. The two-level underground cavities, presently holding 73 million barrels of crude oil, are a former room and pillar salt mine. The old mineworks range in depth from about 500 ft to more than 700 ft below the ground surface. The top of the salt dome is approximately 180 ft below the ground surface at the sinkhole and is responsible for the more than 125 ft of topographic uplift that produced Weeks Island. The water table at the sinkhole is about 90 ft below the ground sur-

face. The absence of a cap rock (at least in a classic sense) leaves the salt boundaries of this dome in direct contact with overlying unconsolidated and saturated marine sediments. At the time of this survey the sinkhole was approximately 35-40 ft in diameter and slightly more than 30 ft deep. The collapse feature had surface expression about 50 ft south of Morton Road.

A high-resolution seismic survey was originally proposed to consist of five lines, each approximately 1500 ft in length: four P-wave (compressional wave) lines and one S-wave (shear wave) line (Figure 1). The lines were laid out to maximize the potential of imaging the subsurface expression of the present sinkhole and to identify other areas potentially susceptible to subsidence. The proposed primary target was the top of the salt dome. Secondary was the water table, followed by structural or stratigraphic signatures within the salt dome. From previous work (Black and Voigt, 1982) a very irregular salt/sediment contact is a strong likelihood at this site. If the surface is very irregular, recording a coherent reflection from the top of the salt dome could represent both an acquisition and processing challenge (Kinsland and Rutter, 1994). Dissolution features associated with evaporite beds have produced easily interpreted signatures on shallow seismic reflection sections (Miller et al., 1993; Steeples and Miller, 1987; Steeples et al., 1986). Irregularities in the surface of the salt associated with either dissolution or joints are of particular interest.

The seismic reflection survey reported here was conducted between March 2 and 4, 1994. It was based on proven shallow high resolution seismic reflection techniques (Steeples and Miller, 1990). The project consisted of several walkaway noise tests and four nominal 180 shotpoint, 24-fold P-wave CDP lines (Figure 1). The surface conditions varied from heavily wooded (hand cleared 5 ft wide path) to manicured lawn to asphalt roads. Some secondary clearing was necessary along wooded paths previously cleared for elevation surveying. The asphalt and gravel roads were obstacles that not only resulted in minor reductions in fold but also provided a source for traffic noise. No shots were recorded while vehicles were close enough to active recording stations to produce more than 0.2 mV peak-to-peak of background noise. Underground utilities including petroleum pipelines, propane pipeline, high voltage powerlines, fiber optic lines, standard telephone lines, and water lines inhibited continuous coverage across several sections of the four lines. The ground surface was damp, with several significant topographic and cultural obstacles including ditches, relatively steep terraces, partially buried founda-

tions from previous surface structures, and about 55 ft of relative elevation change on lines 1, 2, and 3. The field recording parameters and quality control were based on the reflection interpreted during walkaway tests on the north end of line 1 to be from reflectors about 150 ft deep.

Data Acquisition

Data for this study were acquired on a 48-channel EG&G Geometrics 2401x seismograph. The seismograph amplifies, filters (analog), digitizes the analog signal into a 15-bit word, and stores the digital information in a demultiplexed format. Analog filters have an 18 dB/octave rolloff from the selected -3 dB points. The 1/2 ms sampling interval resulted in a record length of 500 msec and a 1000 Hz Nyquist frequency. A 500 Hz high-cut filter with a 24 dB/octave rolloff acted as an anti-alias filter and to reduce wind noise. This floating point seismograph possesses a dynamic range that was more than adequate to record high-quality reflection information in the presence of source-generated and cultural noise at this site.

The walkaway noise tests were conducted on the northeast end of line 1. The source (8-gauge auger gun) (Healey et al., 1991) and receivers (3 Mark Products L28E 40 Hz) were selected based on field conditions and previous experience. On-site testing concentrated on source/receiver geometries and recording parameters. Test data were recorded with analog low-cut filters out, 50 Hz, 100 Hz, and 200 Hz and source-to-receiver offsets ranging from 8 to 376 ft with adjacent stations separated by 8 ft (Figure 2). The analog filters effectively attenuate ground roll while increasing the dominant frequency of the reflection wavelets. A strong reflection with a zero offset time of about 140 to 150 msec can be interpreted on all the walkaway files. The calculated NMO velocity is about 2100 ft/sec which correlates to a depth of around 150 ft (Figure 3). This depth (based on borehole information from a location unknown to the authors of this report) is about 15% to 20% shallower than expected for the top of the salt and almost double the measured depth to the water table. The data quality was sufficient to allow selection of optimum parameters and geometries for acquisition of data at this site targeting reflectors between 50 and 250 ft of depth.

Direct waves, refractions, ground roll, reflections, and air-coupled waves can all be identified on the walkaway data (Figure 4). The direct wave possesses a very uniform 1700 ft/sec velocity from the source out to about 300 ft of offset. The refraction is interpretable from about 304 ft to the end of the spread (376 ft), with an apparent linear velocity of about 11,000 ft/sec (this is an unreversed velocity and

considering the local dip and topography is probably 20% to 30% higher than the true velocity). Two-layer refraction analysis places this first significant acoustic interface at a depth of about 130 to 140 ft. Ground roll velocities range from 800 to 1300 ft/sec. The previously identified 150 msec reflection possesses the greatest resolving power and potential depth control at near-source offsets (i.e. <200 ft). The prominent reflection may be from the same interface as the refracted waves.

Based on the walkaway data and the dynamic range of the recording instrument, the source-receiver geometry was split-spread with a source-to-nearest-receiver spacing of 12 ft and a furthest offset of 196 ft. The recording parameters included an analog low-cut filter of 50 Hz and a sampling interval of 0.5 msec. Identification of various unique arrivals on the walkaway data allowed for confident selection of parameters and geometries used for the CDP portion of the survey.

The production portion of the survey took just over 2 days and included 673 shotpoints along three northwest/southeast lines and one southwest/northeast tie line. A 3-D test was also performed that consisted of 45 shotpoints and was located near the sinkhole along lines 2 and 4. The 8-gauge auger gun allowed detonation of a 400 grain black powder load 2 to 3 ft below the ground surface in a water saturated, tightly stemmed 2" hole. The rough wooded terrain, rubble and fill material, shallow tree roots, as well as the narrow paths made the auger gun an ideal source for the conditions and the required data quality. The three geophones were placed in a 3 ft in-line array to help attenuate source-generated air-coupled wave. The source was detonated and receivers were planted into competent material beneath the organic surface layer. The seismograph was configured to focus on reflections within the upper 250 msec with average velocities from 1200 to 6000 ft/sec. The pre-digital conversion spectrum was shaped with 50 Hz analog low-cut filters in an attempt to enhance the higher frequency components of the recorded energy. This emphasis on pushing the high side of the spectra was necessary if any chance was given to separating the water table reflection from the top of the salt and any layers that might produce a coherent reflection from within the salt.

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). The main distinctions relate to the conservative use and application of correlation statics, precision re-

quired during velocity and spectral analysis, and extra care during muting operations. A very low percentage allowable NMO stretch (<20%) was extremely critical in avoiding wide-angle reflections, maximizing resolution potential, and avoiding distortion in the stacked wavelets (Miller 1992). Many processing techniques that have not routinely been effective on shallow data sets (including f-k migration, deconvolution, and f-k filtering) were tested to evaluate their potential on this data set.

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 (Yilmaz, 1987) that are violated by most shallow data sets, this data set being no exception. 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 (Black et al., 1994). Migration for this data set was effective in reducing the apparent distortion associated with the subsurface expression of the subsidence and the non-uniform reflecting surface. Processing/processes used on data for this report has/have been carefully executed with no *a priori* assumptions and with care not to create anything through processing, but to simply enhance and correct what can be interpreted on unstacked data.

The experimental 3-D reflection array was collected at the intersection of line 2 and line 4. This data set possesses 1-fold redundancy and was processed using parameters established through analysis of 2-D data from line 2 and line 4. The data have been filtered, scaled, muted (based on source offset), elevation corrected, deconvolved, sorted (binned), NMO corrected, and displayed. The software used was a special set of algorithms developed in association with *Eavesdropper* for the PC.

Results

Unequivocal identification of reflection energy on field files is essential for accurate interpretation of CDP stacked sections. Raw field files acquired during the production portion of the survey from each line have reflection events identifiable between 70 and 150 msec (Figure 5). The reflections have a dominant frequency of approximately 80 Hz and an apparent NMO velocity ranging from 1350 to 2100 ft/sec. These would result in an approximate depth to the reflector of between 80 and 150 ft (relative to the ground surface). The signal-to-noise ratio on the raw field

5

files is very good and allows confident identification of reflections on 90% of the raw field files.

Analysis of processed field files improves confidence in interpretations of CDP stacked sections. Digital filtering, first arrival muting, appropriate trace balancing, bad-trace editing, and conservative application of correlation statics were key processes in improving the pre-stack appearance of coherent events interpretable on raw field files (Figure 5). The coherent event identifiable on filtered and scaled files possesses an arrival pattern consistent with the classic hyperbolic move-out of a reflection. These interpreted reflection arrivals allow significant confidence in interpreting the CDP stacked section. It is still prudent to practice care and a conservative approach to interpretations of coherent energy on stacked data.

The shallowest significant acoustic impedance contrast suggested from analysis of first arrival information on field files was a layer that varied in depth from approximately 150 ft in the northern part of the survey area to less than 70 ft in the south below the ground surface. Based on direct wave and refraction analysis, the near-surface material across the entire survey area ranges in velocity from 1200 to 2000 ft/sec. The first refracting horizon possesses an unreversed phase velocity of between 7,200 and 12,000 ft/sec. Based on refraction analysis performed on most files with an interpretable first-arrival crossover and the lack of any indication of reflection information shallower than the previously identified prominent reflection arrival (Figure 5), data processing beyond brute stack focused on enhancing events deeper than 100 msec.

A strong coherent event can be interpreted across all the nominal 24-fold CDP stacked sections (Figures 6 through 9). The drop in fold near the ends of the lines inhibits high confidence in interpreting the stacked section within 20 CDPs of the line ends. Data were processed relative to multiple sloping datums (as many as four on some lines). Following completion of the processing flows tailored for each line, the stacked sections were adjusted to a flat datum. There is but a single, confidently correlatable event above 200 msec. The irregular reflector, as interpreted on the stacked data, is very suggestive of either a highly variable (dissolved/faulted and folded) surface or significant velocity variation in the near surface. From analysis of field files very little variation in velocity of direct refracted and reflected waves is observed within the length of a spread. However, across the expanse of an entire line the near-surface velocity may change by as much as 30%. The single strong

6

reflection event ties extremely well line-to-line prior to correction to a single flat datum.

Conversion from time seismic section to depth cross section requires an average velocity representative of actual material. In the absence of sonic logs and/or check shot surveys, depth determination using stacking velocities and multiple sloping datums represents the most accurate method of estimating depth. The conventional use of a flat datum incorporates a single horizontally consistent velocity. At this site, velocity analysis clearly suggests the stacking velocity varies by as much as 25% across each of the lines. Hence, depth determination based on sections corrected to a flat datum will inherently possess more error than depth determination based on multiple sloping datums. Stacked sections were corrected to a flat datum of 48 ft above sea level using an approximated velocity of 2150 ft/sec. This process produced time sections that in theory should remove some of the effects of the variable surface layer (topographic correction). Depth error at this site, associated with this approximate layer-stripping velocity, could be 10 ft greater on flat-datum sections than depth estimates using the multiple sloping datum sections.

The reflection event is very coherent and well defined on the northern end of line 1 but data acquired south of Morton Road have a decrease in signal-to-noise ratio and the reflection wavelet bandwidth (Figure 6). The dominant frequency north of Morton Road is about 80 to 100 Hz with a drop to about 50 Hz to the south. The near-surface velocity ranges from 1700 ft/sec on the north to less than 1250 ft/sec on the south, while the stacking velocity ranges from 2000 ft/sec on the north to 1900 ft/sec in the center and back to over 2100 ft/sec on the south. These changes in velocity are not coincident with the change in reflection bandwidth and are not a surprise based on the variability of the surface material and elevation across the line.

Several places along the line show indications of a disturbed reflecting surface (Figure 6). Line 1 ties very nicely with line 4 at CDP 192. An apparent disturbance at about CDP 120 is coincident with a 10 to 12 ft deep ditch on the surface. The presence of the ditch on the surface could have resulted in a static shift that was not completely removed during processing, or the ditch might somehow be the effect of this subsurface disturbance. More processing will be necessary to resolve which is the cause and which is the effect. Between CDP 190 and the southern end of the line the data quality drops drastically. The reflection event is confidently interpretable out to about CDP 300, but beyond that point the very periodic nature of the lower 200 msec

7

of the time section and the lack of a strong reflection wavelet makes any interpretation speculative. The northern half of line 1 clearly suggests an irregular reflecting surface with a very subtle dip across the line.

General wavelet characteristics, irregularity in the reflecting surface, and apparent change in the bandwidth and signal-to-noise ratio on the southern end of line 2 are quite consistent with observations on line 1 (Figure 7). The topographic change of the ground surface at the start of line 2 inhibited the acquisition of high fold data between CDP 0 and about CDP 40. The surface of the reflection on the north end of the line is very irregular and similar to the character in the northern end of line 1. The dominant frequency is about 80 to 100 Hz on the north and 50 to 70 Hz on the south end of the line. The near-surface velocity changes from 1700 ft/sec on the north to 1200 ft/sec on the south with the stacking velocity ranging from 2000 ft/sec on the north to 2300 ft/sec on the south. As on line 1, these changes in velocity do not seem to correlate with the drop in bandwidth and resolution. The surface of the reflector on the south seems to be much smoother, changing much less rapidly than on the north.

Line 2 passes within about 50 ft of the eastern edge of the sinkhole. The portion of line adjacent to the sinkhole does not detect any significant change associated with the subsidence. An apparent depression in the prominent reflector seems to be imaged north of the intersection of lines 2 and 4 (Figure 7). A subsurface disturbance, possibly related to the sink, seems to extend from about the southern road ditch to about CDP 125. CDP 125 is in about the middle of the wooded area between Morton Road and Snyder Road. If this depression in the reflector is related to active subsidence, then Morton Road could experience future subsidence. Based on the general appearance of the stacked section from line 2, the only possible subsurface expression of the sinkhole interpretable on the seismic data is between CDP 125 and CDP 185.

The stacked section from line 3 has several localized features that are suggestive of significant offset or rapid changes in the surface of the reflection (Figure 8). The most striking apparent offset in the reflector is at CDP 125. This feature has no surface expression and no apparent change in shallow acoustic properties associated with it. The general appearance of the reflection between the north end of the line and about CDP 185 is a little more distinct, but in general very similar to the north end of the other two north/south lines. The dominant frequency is about 80 to 100 Hz on the north and 50 to 70 Hz on the south. The near-surface velocity ranges

8

from 1600 ft/sec on the north to 2000 ft/sec in the middle to less than 1200 ft/sec on the south. The stacking velocities for the line were between 2000 ft/sec on the north and 2300 ft/sec on the south. Again, as with lines 1 and 2, the changes in both the stacking and near-surface velocities do not correlate to the interpreted decrease in resolution and bandwidth and are, therefore, most likely related to changes in the reflecting surface.

The distinct offsets at CDP 60 and CDP 125, as well as the change in wavelet characteristics at CDP 185, represent the most significant features interpreted on line 3. The time tie between lines 3 and 4 are excellent. The offsets are a narrow, very well defined zone with no apparent energy scatter (Figure 8). These offset features may relate to features previously suggested, from remote sensing methods, to be present on Weeks Island (Figure 10) (Martinez et al., 1976).

The uniformity in the near-surface material and the lack of significant elevation variation across line 4 was probably key to the quality of this stacked section (Figure 9). With the dominant stacked reflection frequency at about 80 Hz and an approximate average velocity of 1500 ft/sec, the vertical resolution based on 1/4 wavelength criteria of Widess (1973) is approximately 5 ft and the radius of the first Fresnel zone is about 25 ft. The most striking feature on this line is the depression between CDP 180 and CDP 210. This area is directly adjacent to the sinkhole. Based on the stacking velocities, the depth to the reflecting interface at the edge of the disturbed zone is about 75 ft beneath the ground surface. If the diameter of this subsurface depression is less than the radius of the first Fresnel zone, the depression could extend vertically much more than the 15 ft suggested from direct calculations and not be resolved with these data.

The depth to the reflector changes slightly across line 4. As a result of the lower stacking velocity on the east end of the line, the calculated depth to the reflector is relatively consistent between 75 and 80 ft between CDP 10 and CDP 180. The stacking velocity increases from about CDP 250 to the west end of the line. This increased stacking velocity corresponds to an increase in depth from the ground surface to the reflector on the west (CDP 260 = 94 ft; CDP 250 = 110 ft). The intersection of Advanced Products Road and Morton Road resulted in a significant drop in fold and is credited with producing the slight offset between CDP 275 and CDP 280. The only other noteworthy features on line 4 are the changes in reflection wave character observable at CDPs 110, 240, and 310. These are near or over a large area of rubble fill, a culvert and surface drainage channel, and an area with the

remains of a structure. These changes in wavelet characteristics are similar to those observed on all three north/south lines. Based on the stack of line 4, the anomaly observed in the 120 msec reflection between CDP 180 and CDP 210 is directly related to the surface subsidence near station 100 (CDP 200).

Conclusions

The horizontal extent of the affected subsurface was only roughly delineated, but the subsurface subsidence associated with the sinkhole was effectively detected. Dissolution and the resulting subsidence that produced the Weeks Island sinkhole has a distinctive subsurface expression. The coherent reflection event interpretable on all four lines is dramatically altered on line 4 directly north of the surface expression of the sinkhole. Line 2 possesses a depression in the reflection consistent in depth with line 4 but not as dramatically different from the reflection signal produced from the surrounding area. It is possible that line 2 has imaged either a subsurface subsidence without surface expression yet or an irregular surface that resulted from the uplift of the island. From the seismic section along line 4 the subsurface expression of the sinkhole is very steep and probably best described as a chimney.

The 2-D data did not allow a conclusive determination of southern or northern extent. The north/south line (line 2) did not suggest any subsurface expression south of the intersection of lines 2 and 4, but some distinct topographic change can be interpreted on the surface of the reflector on line 2 north of the intersection of lines 2 and 4. Incorporation of the single fold 3-D data should greatly enhance the interpretation of the areal extent and relative change in the surface of the prominent reflector.

Recommendations

The data presented and interpreted here needs ground truth (i.e., a check shot velocity survey). These data have undergone CDP processing without the incorporation of any other geologic or geophysical data. The velocity, and therefore depths, are based on curve matching techniques which could possess as much as 20% error (Hughes, 1985). With the extreme variation in velocity across this site and with the need for a high level of depth accuracy, stacking velocities need to be replaced with true average velocities for depth calculations.

The area defined by the seismic survey as susceptible to subsidence needs to be confirmed with exploratory drilling. A drill hole placed at approximately station 85 on line 2 would determine if the disturbed reflecting surface identified on line 2 and speculated to be related to the sinkhole was truly an extension of the subsidence feature identified on line 4 or the artifacts of either uplift or previous dissolution. If drilling encounters a void, a second drill hole should be attempted near station 60 to determine northern extent. If no void is encountered, then the disturbed surface is related to previous periods of uplift or dissolution and should probably not be considered an immediate threat.

The 3-D test survey clearly shows the utility of the method in this area. A more extensive survey, possibly including multi-fold data, would be an effective method to improve the accuracy of the interpretation of this feature as well as delineate other potential subsidence features. The 2-D data from this survey could be used to help locate potential candidates for future multi-fold 3-D surveys. The 3-D data acquired as a test on this survey could undergo more extensive processing. The velocity variation observed across the area included with this 3-D survey suggests conventional 3-D velocity analysis and possibly migration would help to improve the accuracy of the interpreted expression of the subsurface subsidence.

References

Black, R.A., D.W. Steeples, and R.D. Miller, 1994, Migration of shallow seismic reflection data: *Geophysics*, v. 59, p. 402-410.

Black, W.E. and Voigt, J.O., 1982, The use of seismic refraction and mine-to-surface shooting to delineate salt dome configuration and map fracture zones [Exp. Abs.]: Soc. Expl. Geophys., p. 465-466.

Healey, J., J. Anderson, R.D. Miller, D. Keiswetter, D.W. Steeples, and B. Bennett, 1991, Improved shallow seismic-reflection source: Building a better Buffalo [Exp. Abs.]: Soc. Explor. Geophys. v. 1, p. 588-591.

Hughes, D.R., 1985, Velocity without tears: *The Leading Edge*, v. 4, n. 2, p. 50-52.

Kinsland, G.L. and Rutter, III, A.W., 1994, Shallow seismic survey on Weeks Island, Louisiana, ... an attempt to define "top of salt": submitted to Golf Coast Association of Geological Societies.

Martinez, J.D., et al., 1976, An investigation of the utility of gulf coast salt domes for the storage or disposal of radioactive wastes: Office of Waste Isolation, Union Carbide Corporation–Nuclear Division, U.S. Energy Research and Develop-

ment Administration. Report ORNL-Sub-4112-25 prepared by the Institute for Environmental Studies, Louisiana State University.

Martinez, J.D., et al., 1977, An investigation of the utility of gulf coast salt domes for the storage or disposal of radioactive wastes: Office of Waste Isolation, Union Carbide Corporation–Nuclear Division, U.S. Energy Research and Development Administration. Report Y/OWI/SUB-4112/37 prepared by the Institute for Environmental Studies, Louisiana State University.

Miller, R.D., D.W. Steeples, L. Schulte and J. Davenport, 1993, Shallow seismic-reflection feasibility study of the salt dissolution well field at North American Salt Company's Hutchinson, Kansas, facility: *Mining Engineering*, October, p. 1291-1296.

Steeples, D.W., R.W. Knapp, and C.D. McElwee, 1986, Seismic reflection investigations of sinkholes beneath Interstate Highway 70 in Kansas: *Geophysics*, v. 51, p. 295-301.

Steeples, D.W., and R.D. Miller, 1987, Direct detection of shallow subsurface voids using high-resolution reflection techniques; *in* Sinkholes: Their geology, engineering, and environmental impact, 2nd edition., ed. Barry Beck and W.L. Wilson: A.A. Balkema, Boston, p. 179-183.

Steeples, D.W., and R.D. Miller, 1990, Seismic-reflection methods applied to engineering, environmental, and ground-water problems: Soc. Explor. Geophys. Investigations in Geophysics, Investigations in Geophysics no. 5, Stan Ward, ed., *Volume 1: Review and Tutorial*, p. 1-30.

Widess, M.D., 1973, How thin is a thin bed?: *Geophysics*, v. 38, p. 1176-1180.

Yilmaz, O., 1987, Seismic data processing; S. M. Doherty, Ed.; *in* Series: Investigations in Geophysics, no. 2, Edwin B. Neitzel, Series Ed.: Soc. of Explor. Geophys., Tulsa, Oklahoma.

TABLE 1

Processing flow

Primary Processing
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)
elevation correction to multiple, floating datums
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)
correlation statics (2 msec max shift, 7 pilot traces, 100 msec window)
digital filtering (bandpass 25-50 250-375)
secondary editing (manual review and removal of bad or noisy traces)
CDP stack
amplitude normalization (whole trace with 40 msec delay)
correct to flat datum (48 ft above sea level)
display

Secondary Processing
f-k filtering
f-k migration
deconvolution (spiking and second zero crossing)

Table 1. Processing flow for CDP stacked data. Parameters were determined by analysis for each prior step as well as through iterative analysis of particular operations.

FIGURE CAPTIONS

Figure 1   Site map indication the relative location of Weeks Island and the survey orientation. The four seismic lines are annotated with both survey distance measurements as well as CDP numbers. The shaded area represents the foot print of the 3-D test survey. The walkaway tests were conducted on the northeast end of line 1.

Figure 2   Walkaway noise tests conducted along the northeastern end of line 1. The four files have been acquired with the same set of geophones and source location with analog low-cut filters out, 100 Hz, 50 Hz, and 200 Hz (respectively). The prominent 145 msec reflection possess text book curvature a dominant frequency on the 100 Hz low cut filtered data of over 150 Hz. The resolution potential on this field file is less than 3 ft.

Figure 3   A 2100 ft/sec reflection hyperbola was simulated by computer and display over the walkaway noise test using the 100 Hz analog filter. The theoretical curve is a perfect match suggesting a reflector depth of 150 ft.

Figure 4   Walkaway file collected with 50 Hz analog low-cut filter, scaled, and with all coherent arrivals interpreted. The analysis seems to suggest the prominent reflection and refraction are from the same interface.

Figure 5   Normalized and filtered field file from along line 4. The reflection from about 130 msec traces a symmetric hyperbola in this split-spread source receiver geometry with near offset of 12 ft and far offset of 196 ft.

Figure 6   24-fold CDP stacked section of line 1. These data have been corrected to a flat datum of 48 ft. The northeast end of the section possesses the highest quality reflection event.

Figure 7   24-fold CDP stacked section of line 2. These data have been corrected to a flat datum of 48 ft. The surface depression is located directly adjacent to CDP 200. The most significant disturbance on the surface of the reflection is centered around about CDP 160.

Figure 8   24-fold CDP stacked section of line 3. These data have been corrected to a flat datum of 48 ft. Several dramatic offset features are interpreted on the stacked section which do not correlate to any apparent surface or near-surface anomaly.

Figure 9   24-fold CDP stacked section of line 4. These data have been corrected to a flat datum of 48 ft above sea level. The most obvious feature of all the data acquired and processed in association with this contract is the expression of the subsidence directly north of the sinkhole.
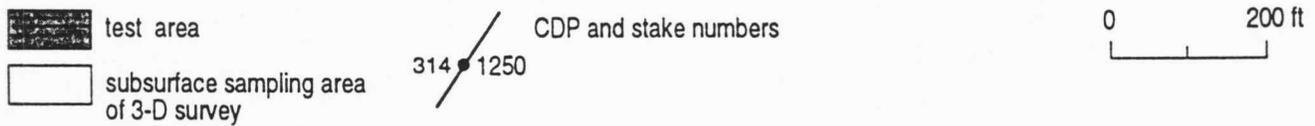
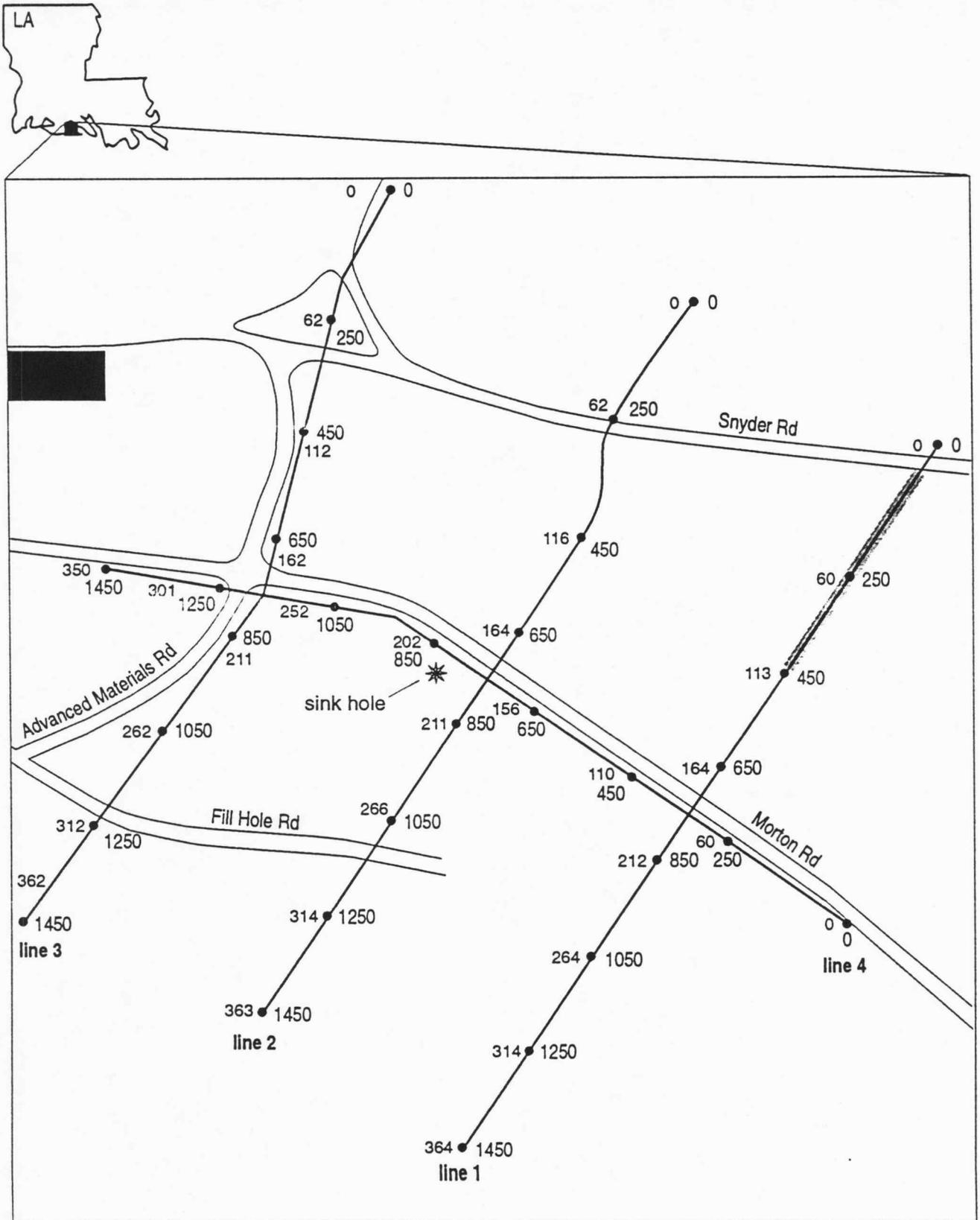Figure 10 Lineament and fault map from Martinez, 1976.
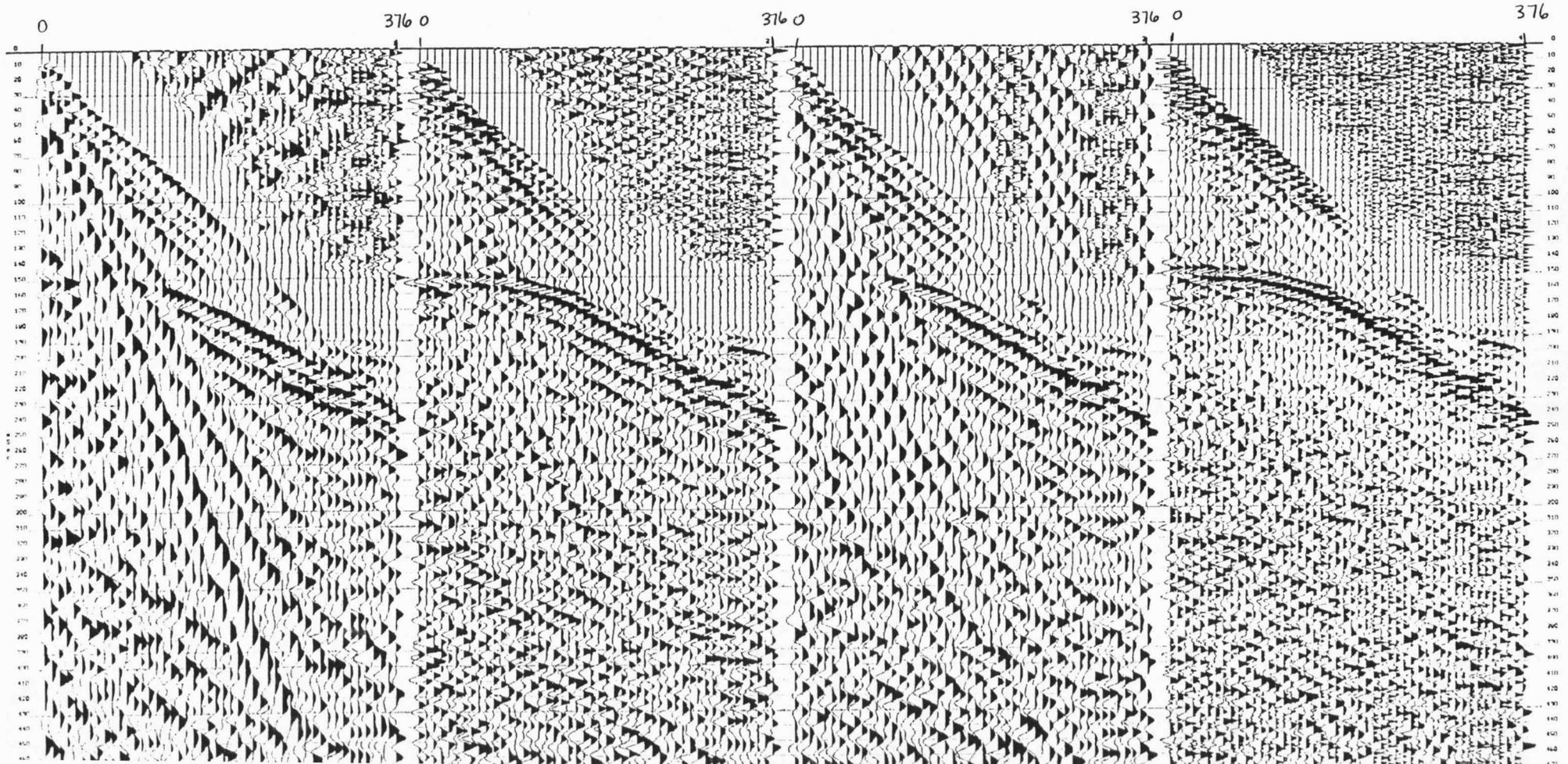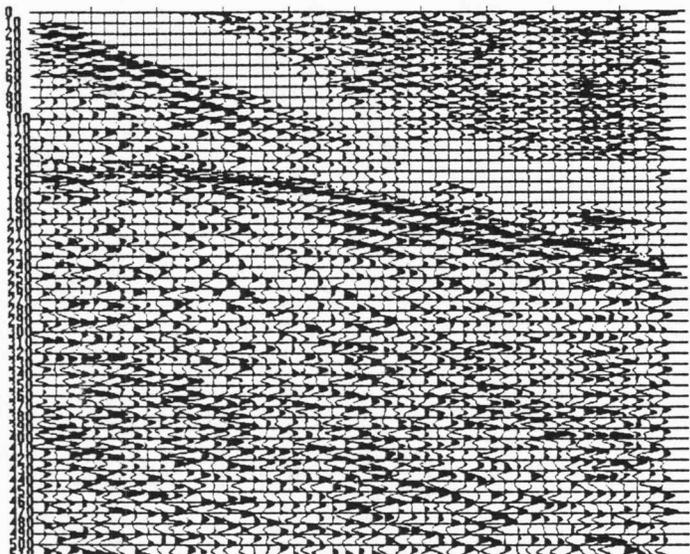
Figure 1. Site map.

Figure 2

Figure 2

Analog Low-cut Filter Out
Source-to-Receiver
offset (ft)

Analog Low-cut Filter 100Hz
Source-to-Receiver
offset (ft)

Analog Low-cut Filter 50Hz
Source-to-Receiver
offset (ft)
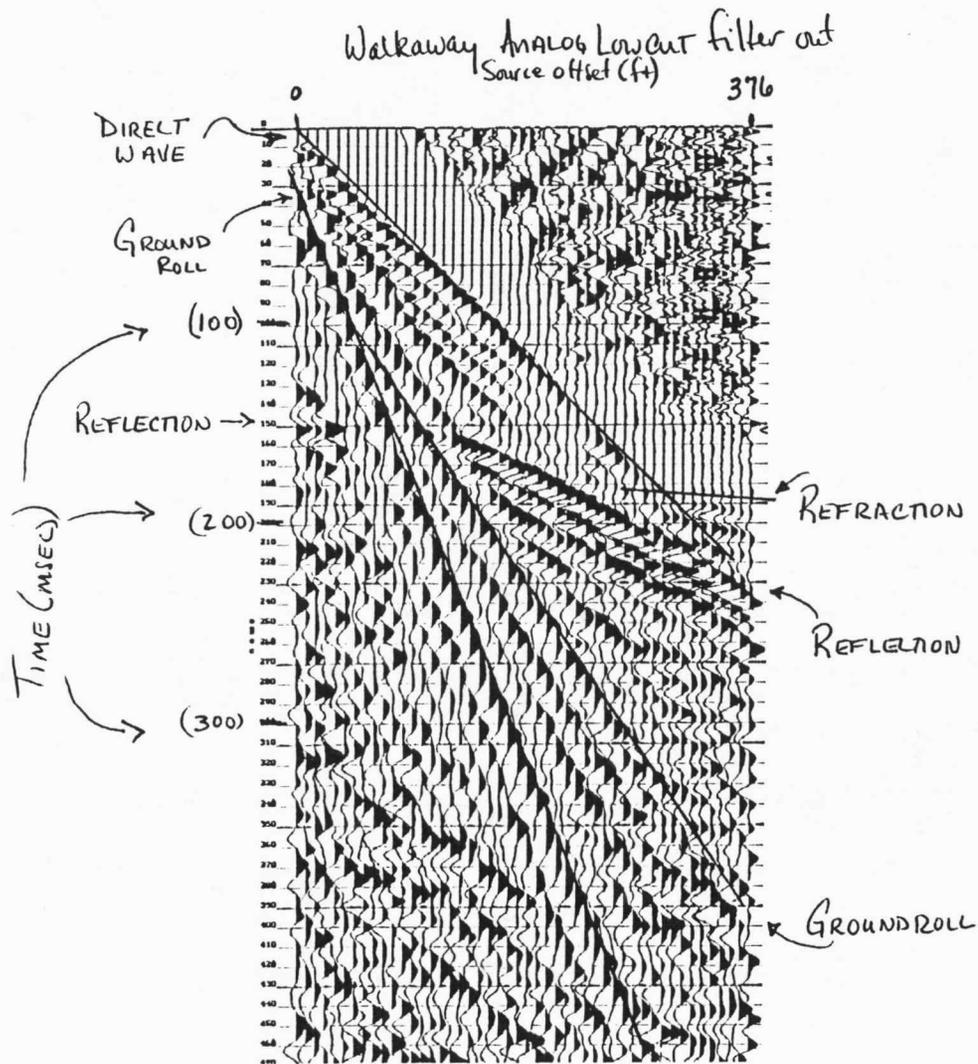
Analog Low-cut Filter 200Hz
Source-to-Receiver
offset (ft)

0   376 0   376 0   376 0   376

$\text{Velocity (NMO)} = 2,100$

$\text{Depth (ft)} \approx 150$

Figure 3

Walkaway Analog Lowcut filter out
Source offset (ft)

Figure 4

WAVE TYPE	VELOCITY (ft/sec)	
DIRECT WAVE	1700	(LINEAR)
REFRACTION	11,000	(LINEAR)
REFLECTION	2,000	(HYPERBOLIC)
GROUND ROLL	800	(LINEAR)

DEPTH TO REFLECTION ≅ 140 ft

* DEPTH TO REFRACTING LAYER ≅ 130 ft

* REFRACTION DEPTH BASED ON UNREVERSED PROFILE

Figure 5

Line 1

SW

source-to-receiver offset (ft)

NE

350 340 330 320 310 300 290 280 270 260 250 240 230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30

Figure 6.

Line 2

source-to-receiver offset (ft)

350 340 330 320 310 300 290 280 270 260 250 240 230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40

0   80 ft

Figure 7.

Line 3
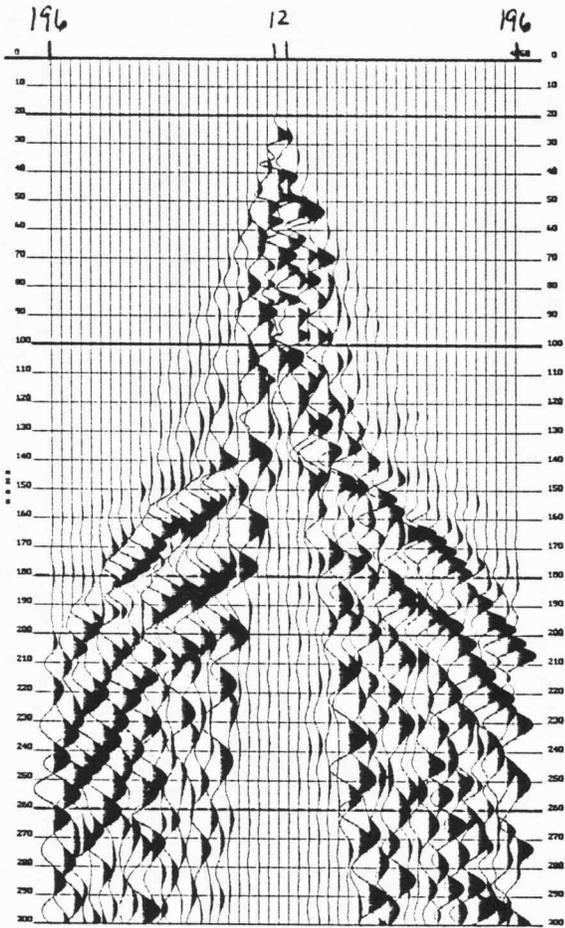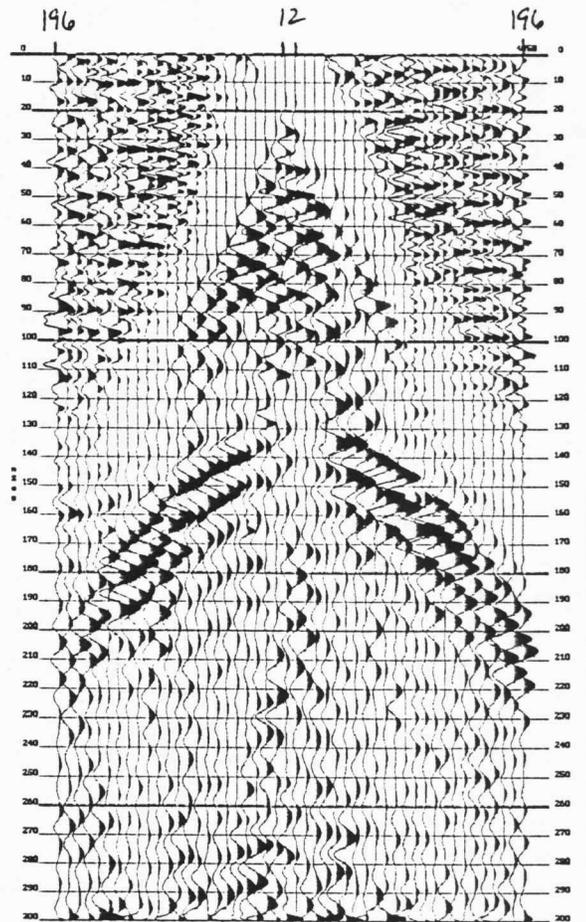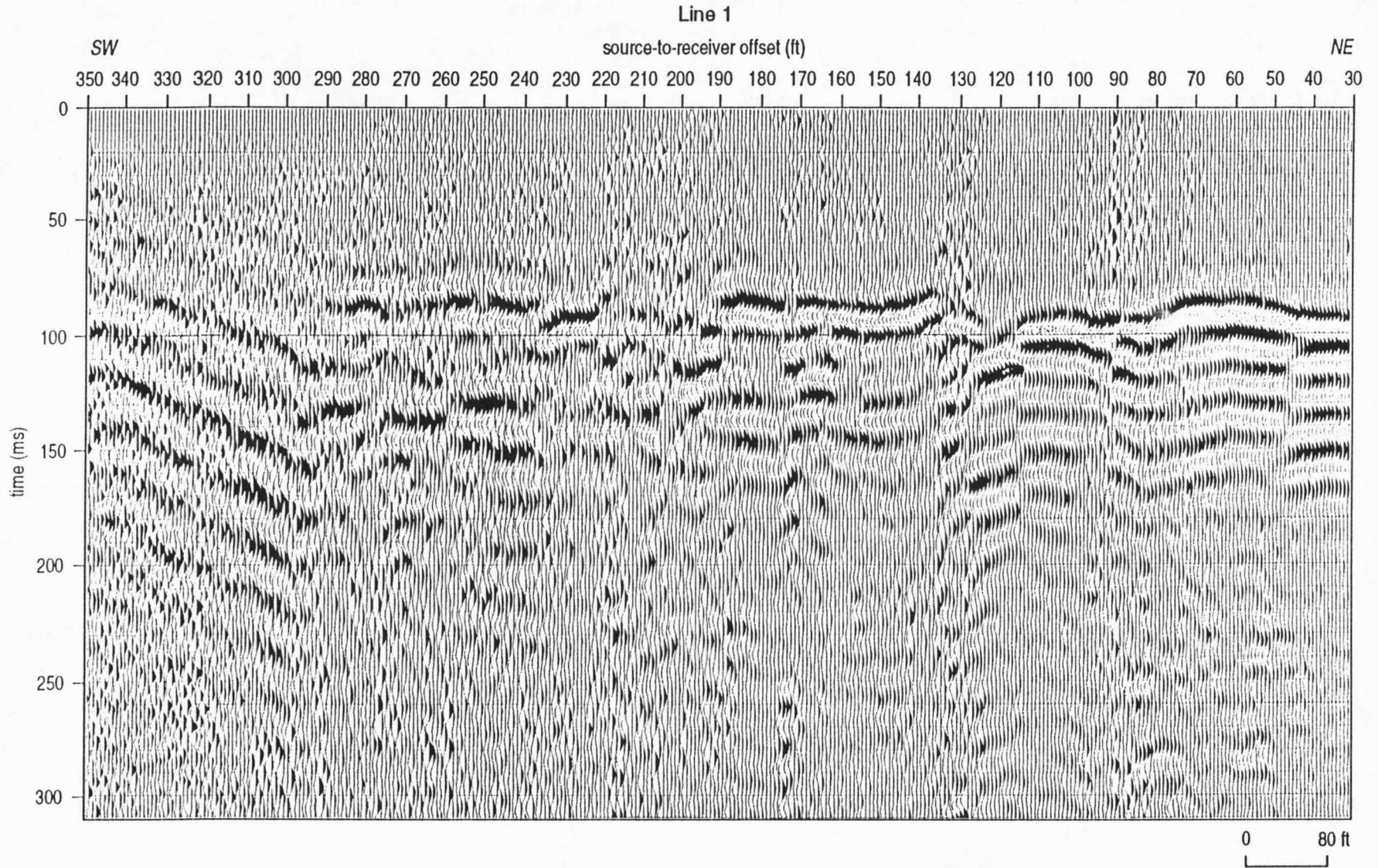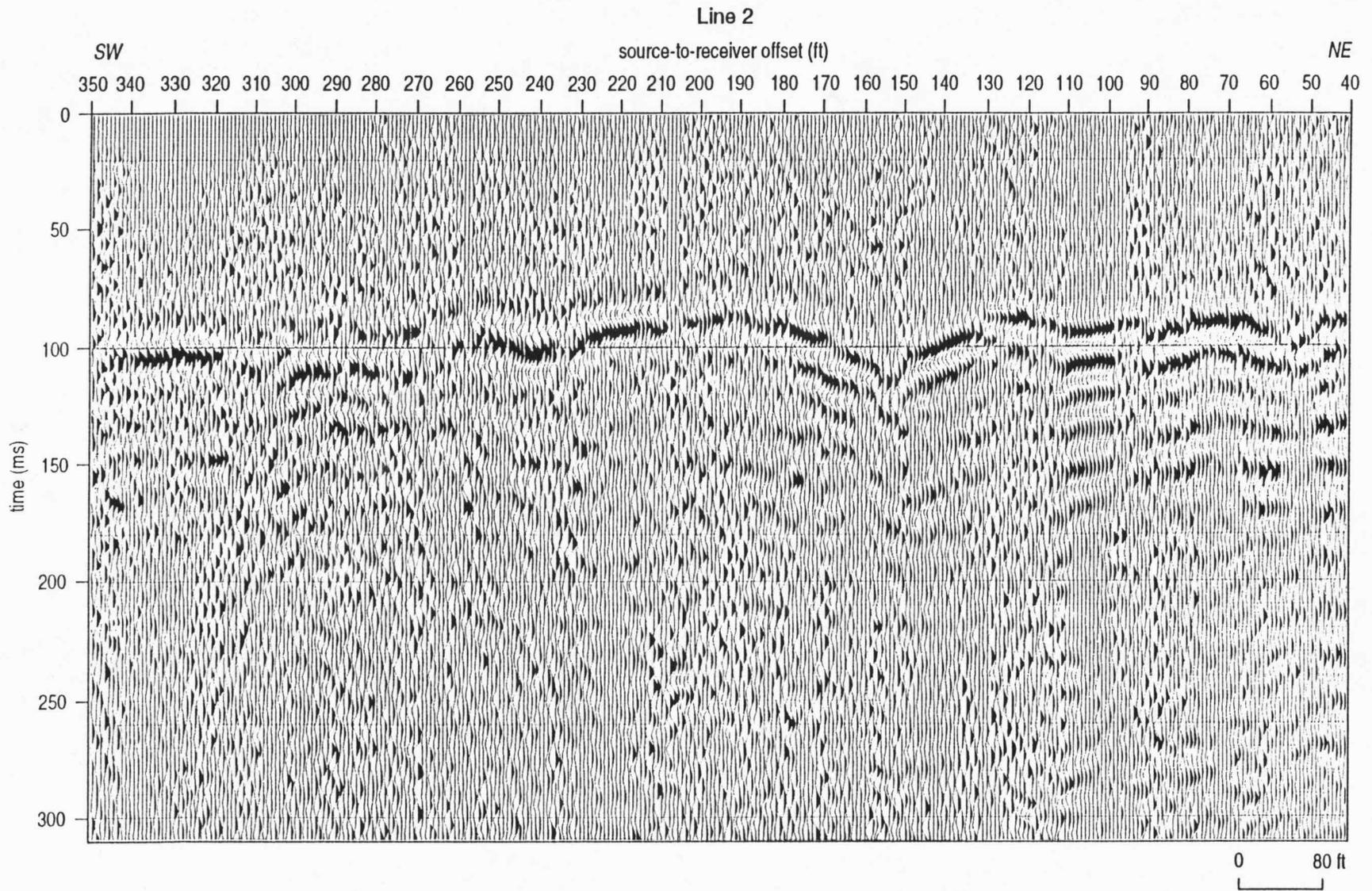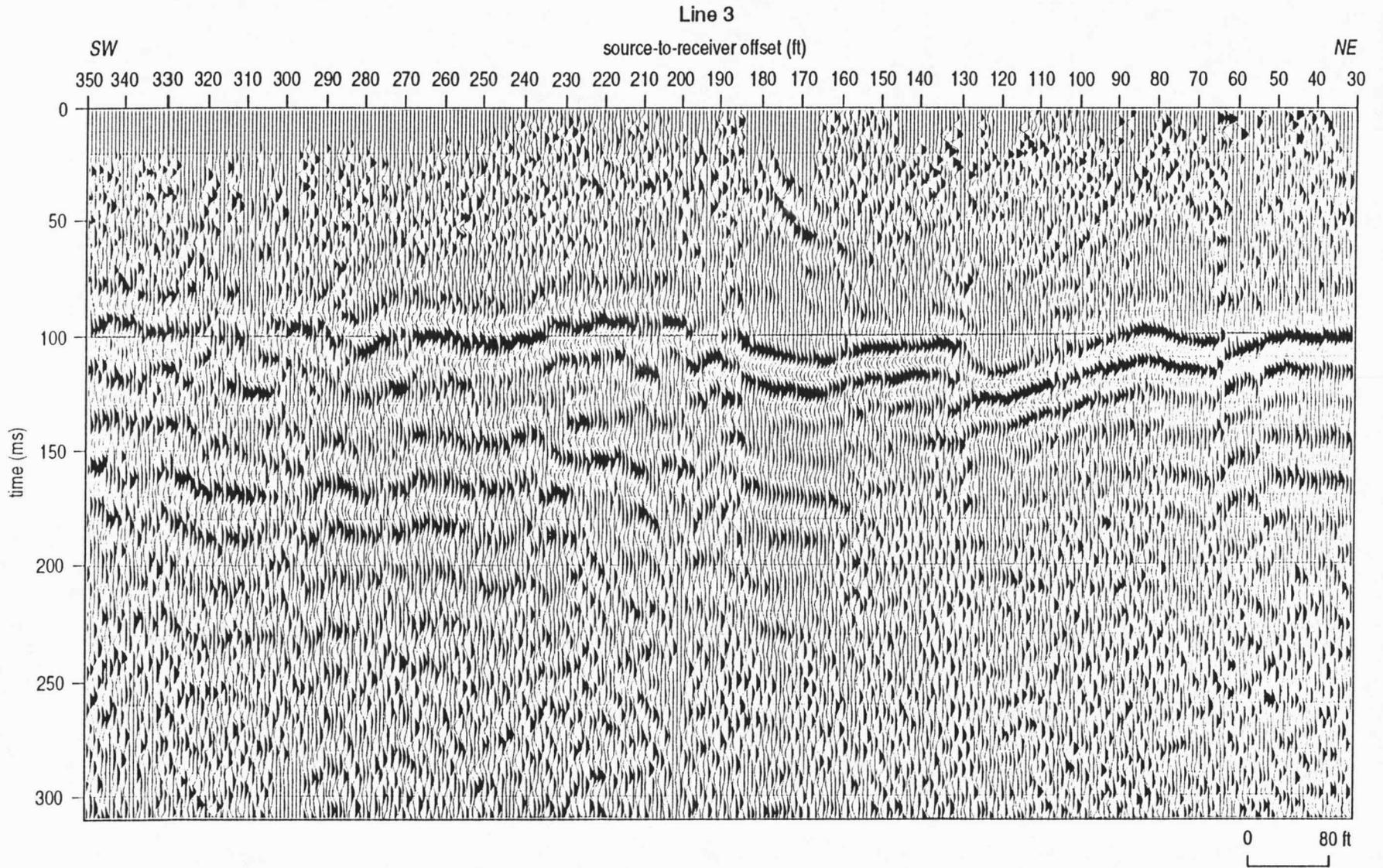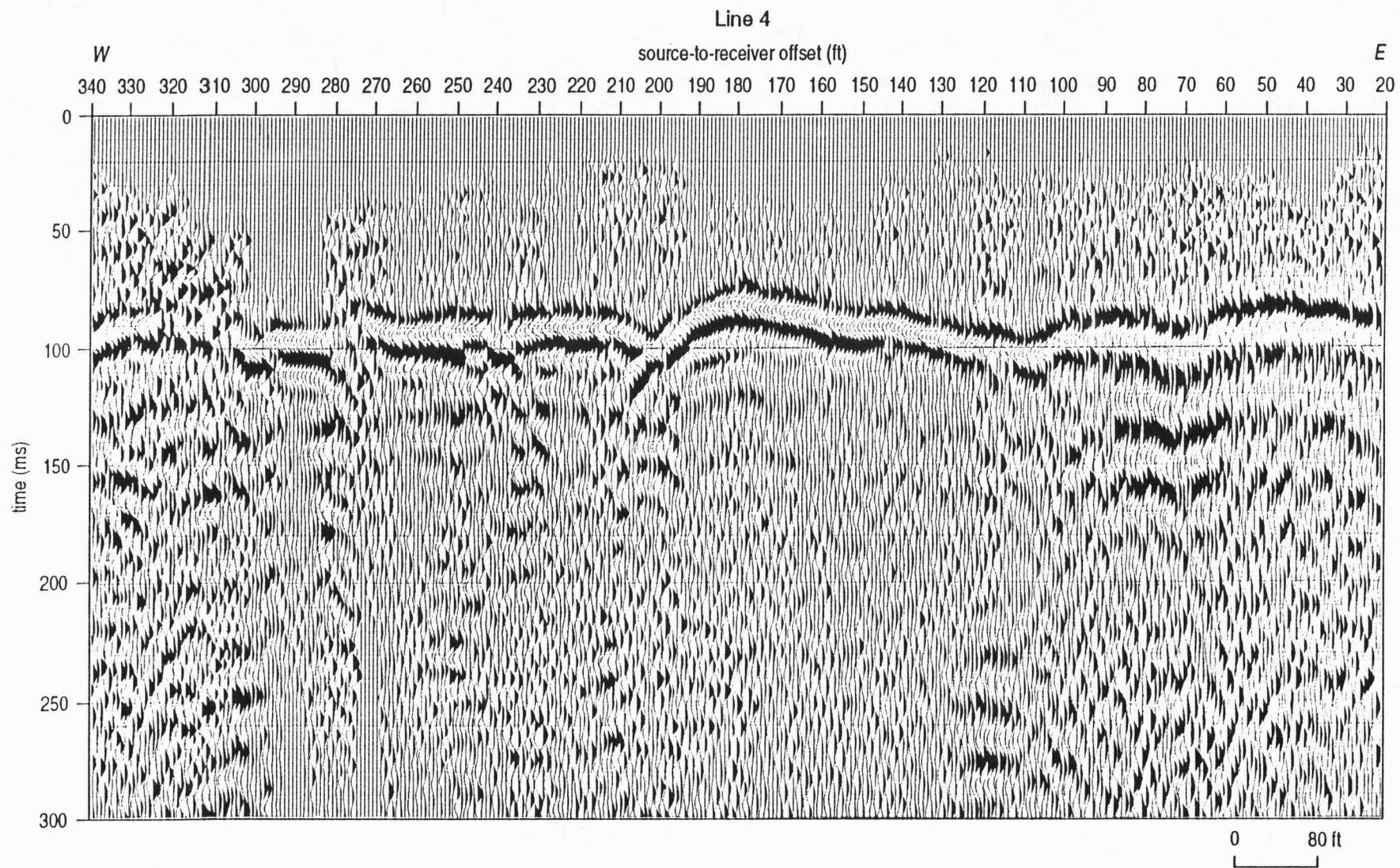
Figure 8.

Figure 9.
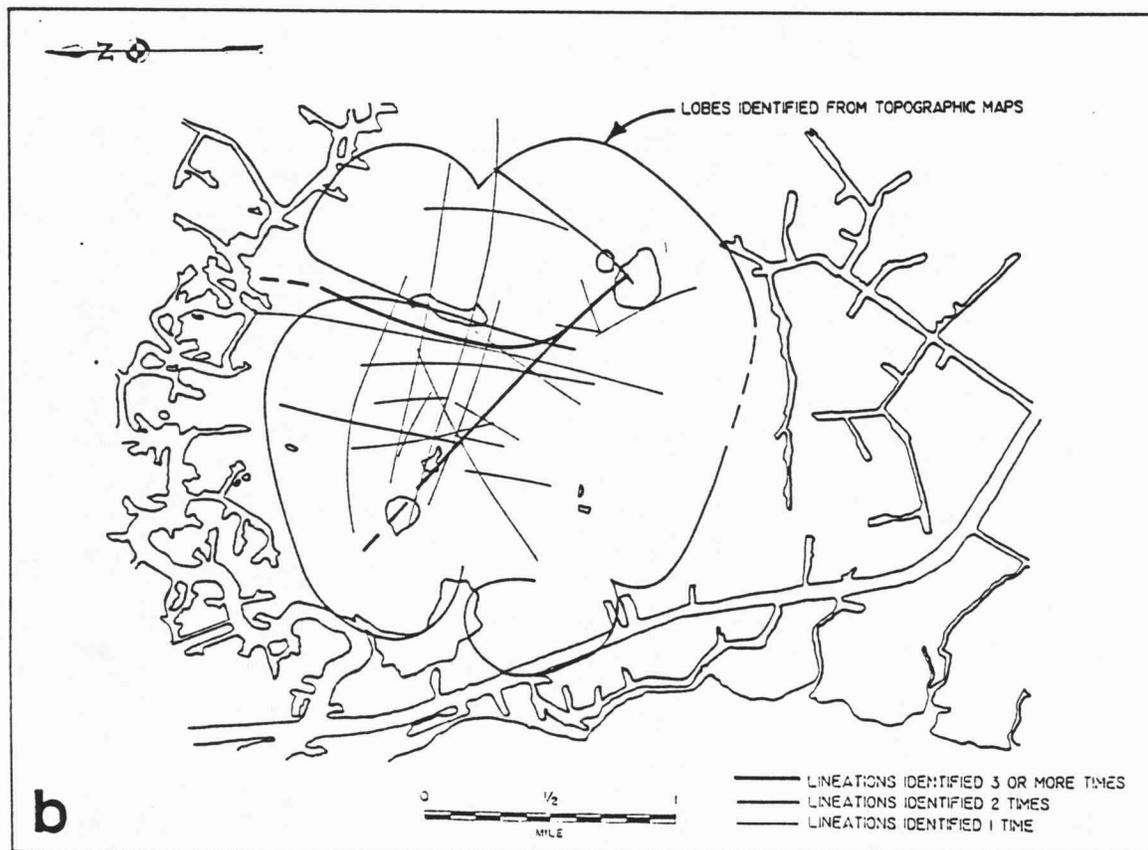
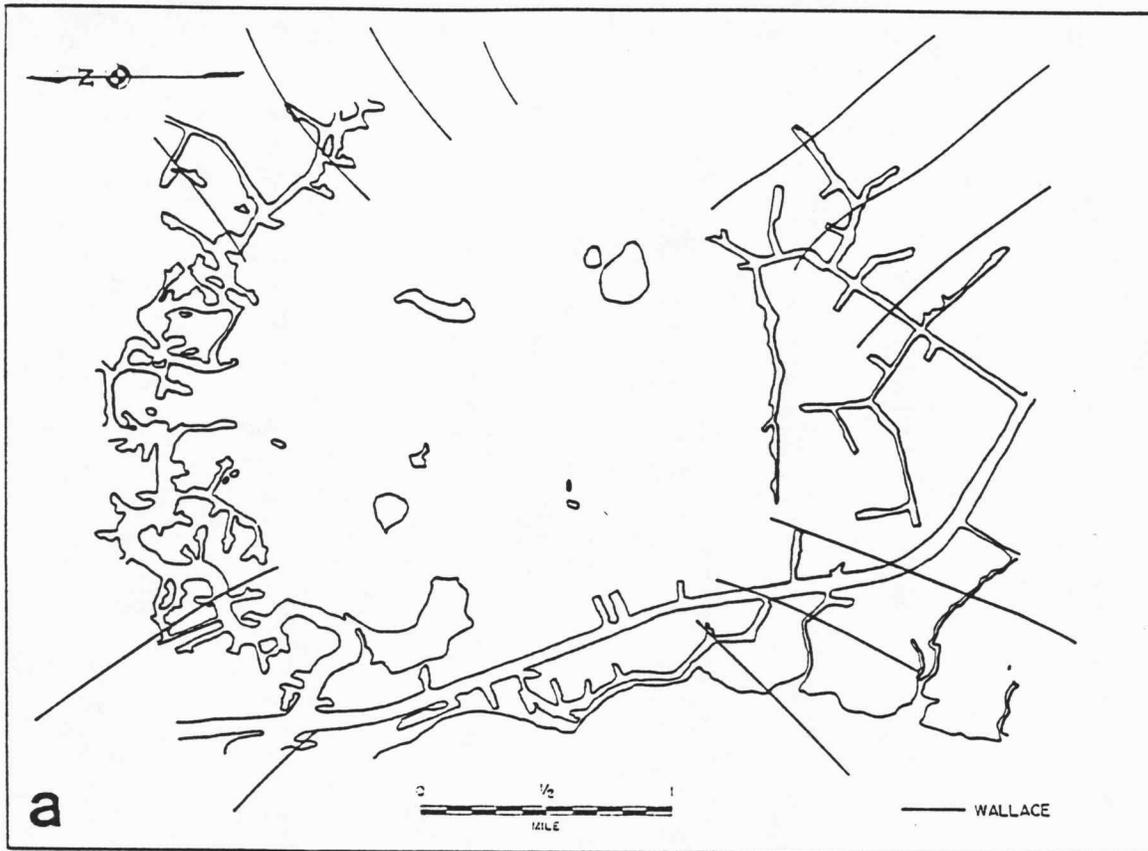Figure 10   Maps of Weeks Island Salt Dome.   From Martinez et al.,
             a. Faults (from Wallace, 1966).   1976
             b. Lineations and Lobes (from this study).