# Enclosure 2 to E-54844

# Seismic and Resistivity Surveys Exhibit A and Exhibit B, 2001
(Public)

# ATTACHMENT 5-4
# SEISMIC AND RESISTIVITY SURVEYS

| | |
|---|---|
| Exhibit A | Shallow Seismic Survey, Proposed Radioactive Waste Site, Andrews County; Texas, 2001 |
| Exhibit B | Geophysical Survey Results, WCS Andrews Site, Andrews County, Texas; 2001 |

# EXHIBIT 5-4 A
# SHALLOW SEISMIC SURVEY,
# PROPOSED RADIOACTIVE WASTE SITE,
# ANDREW COUNTY, TEXAS 2001

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# FINAL REPORT

## SHALLOW SEISMIC SURVEY
**Proposed Radioactive Waste Site**
Andrews County, Texas

November 1, 2001

Prepared for

**Waste Control Specialists**
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# SHALLOW SEISMIC SURVEY
Proposed Radioactive Waste Site
Andrews County, Texas

November 1, 2001

## SUMMARY

A shallow seismic survey was carried out in late July and early August, 2001 for Waste Control Specialists in the 11(e)2 area, Andrews County, Texas. The survey consisted of four seismic lines totaling slightly more than two line miles in length. The purposes of the survey were to trace and map the top of the Triassic redbeds under a variable thickness of Tertiary fluviatile beds, and to determine whether the top of the redbeds and the upper few hundred feet of the redbeds appear to be faulted. One seismic line, northwest of the proposed cell area, crossed a shallow valley and playa in order to investigate the origin of the depression and playa.

The lines were recorded using Geological Associates' method combining both refraction and reflection recording systems. The refraction data usually yield information regarding the top 100 feet or so, and the reflection system commonly yields CDP stacked data from about 20 feet to about 300-400 feet deep.

The refraction data indicate that there may be numerous indurated beds, possibly not rippable, in the lower half of the Tertiary. The Tertiary appears to thicken from the southwest to the northeast in the cell area, with a mean thickness of about 50 feet. The refraction results show no distinct, continuous zone of refractions from the top of the Triassic redbeds, which is unusual; this suggests that the top of the Triassic here is deeply and variably weathered.

The reflection data are interpreted as showing that most of the cell area is underlain, at the top of the redbeds, by a gentle buried hill. The hill appears to be bounded on the south by a buried stream channel, possibly draining eastward. The reflection data are interpreted as showing no evidence of faulting at the top of the Triassic redbeds. Deeper seismic events believed to be reflections suggest that the redbeds are not faulted at a depth of about 350-400 feet; thus the seismic results are interpreted to suggest that the cell area is unfaulted at depths less than about 400 feet.

The isolated seismic line northwest of the cell area appears to indicate that the playa is underlain by buried paleo-stream beds, and is not a collapse feature.

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SHALLOW SEISMIC SURVEY
Proposed Radioactive Waste Site
Andrews County, Texas

INTRODUCTION - During late July and early August, 2001, a shallow seismic survey was carried out by Geological Associates for Waste Control Specialists in the 11(e)2 area, Andrews County, Texas. The survey consisted of four seismic lines, designated as Lines S-1, S-2, S-3 and S-4, totaling just over two miles in length (see Figure 1).

The purposes of the study were to trace and map the top of the Triassic redbeds under the overlying Tertiary strata, at a depth of about 20 to about 70 feet, and to determine whether the top of the redbeds and the strata in the upper part of the redbeds appear to be faulted or otherwise disturbed in the area. Line SL-4, located northwest of the other lines, was designed to investigate the geologic structure underlying a surface low and playa, which had been previously determined to be coincident with an electrical resistivity anomaly.

METHOD - The lines were recorded using Geological Associates' unique method combining both refraction and reflection recording systems. A heavy sledge hammer struck against a metal plate set on the ground was the seismic energy source. The results of two to three sledge hammer blows were summed at each seismic source point. The receiver array consisted of drag cables with twelve Mark Products self-orienting drag geophones attached at intervals of 10 meters (32.8 feet), so that the receivers were located at distances of 32.8, 65.6, 98.4, 131.2 . . . 393.6 feet behind the seismic source point. The seismic source points were 16.4 feet apart along each seismic line. This recording system produces 12-fold (1200%) CDP reflection data and multiply overlapping refraction profiles.

Recording was by a Geometrics ES-2401 multi-channel system, using 100-500Hz filters and both analog (paper) and digital recording, with 0.5 millisecond sampling rate for one-half second.

After completion of the field work, the data were returned to Albuquerque for processing, analysis and interpretation. The reflection data were processed using Geological Associates' software written specifically for this seismic system. The interpretation of the refraction data was done using Rimrock Geophysical's SIP program system.

After the data processing, analysis and interpretation were completed, reflection seismic sections and refraction depth sections were constructed, as were two structure contour maps, one with interpreted contours on the top of the

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redbeds and another with contours on an interpreted reflection horizon within the redbeds at a depth of about 350-400 feet.

A more detailed description of the seismic system and its application is given in Appendix A of this report.

RESULTS - The refraction data are considered to be of good to fair quality, but are of limited value. This was because of the presence of many short-extent refractors, some of high velocity, within the Tertiary strata above the redbeds, resulting in little refracted energy reaching the redbeds. The same short-extent refractors within the Tertiary generated a great deal of seismic noise, in the forms of diffractions and reflected refractions, which made the reflected data difficult to extract. Nevertheless, the reflection results are considered to be of good to poor quality, and are regarded as serving the purposes of the study well.

The locations of the seismic lines, the drill holes from which data was used and the location, shape and size of the proposed storage cell are shown on Figure 1. The open circles along the seismic lines denote each tenth seismic station. Note that the new drill holes, those drilled as part of the present geologic investigation of the area, are shown as solid circles. The older drill holes, drilled before the present investigation, are shown as open circles not located along the seismic lines.

The refraction results are shown on Figures 2 and 3. Figure 2 shows the refraction section for Line SL-1 in two parts, split at a match line, because the line is too long for practical presentation as a single section. The vertical exaggeration used is 2:1 to make the refraction data easier to see. The ground surface profile, marked with green, descends generally from northeast to southwest.

The top of the Triassic redbeds is commonly a reasonably good refractor with a primary wave velocity of 8,000-9,000 feet per second. For this reason it had been hoped that a good, fairly continuous refraction from the top of the redbeds would be detected here, allowing calculation of the depth to the redbeds. In this case, however, there is apparently no continuous or even intermittent refractor corresponding to the top of the redbeds (see Figures 2 and 3). Instead, there are many refractors, most of which persist for a distance of 500 feet or less. Many of these are of high velocity - over 10,000 feet per second. This condition suggests the presence of scattered local beds at varying depths.

The reflection data appear, for the most part, to consist mainly of seismic noise - mostly diffractions and reflected

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refractions, probably from the numerous discontinuous refractors at shallow depth. Special data processing techniques were required to bring out reflections. The first method tried was that of constructing 100% record sections, using only the nearest recording channel(Channel #12). The operative concept here was that the nearest geophone position to the seismic source should be relatively free of seismic noise traveling away from the source. The results were initially disappointing; there was still a great deal of seismic noise on the record sections.

A further step, that of compositing adjacent traces of the record sections, reduced the seismic noise sufficiently to make what is interpreted as reflection data visible. Ultimately, four to one horizontal compositing (4:1) produced what is felt to be the best very shallow seismic reflections contained in the data (e.g, Line SL-1, Figure 4). The top of redbeds reflection (red horizon, lower section of Figure 4) ties the tops of the Triassic redbeds from the five drill holes along the line satisfactorily, using a conversion velocity of 4,000 feet per second. This reflection, as shown on Figure 4 (Line SL-1), is regarded as of fair quality. The ridge centered at about Station 80, which has been previously mapped from drill hole data, is not nearly so steep as suggested by Figure 4; the 16:1 vertical exaggeration makes it appear to be far steeper than it really is.

Figure 5 shows the 100% record sections, also composited 4:1 laterally, for Lines SL-2 and SL-3. The top of redbeds horizon on Line SL-2 (sections on left), though of low amplitude, appears to be continuous and ties the two drill holes on it (DP-2 and RB-1), as well as Line SL-1, satisfactorily. The same horizon on Line SL-3 (sections on right) is less clear, but again ties the two drill holes (RB-2 and DP-3) and Line SL-1 reasonably well. The top of redbeds horizon on Line SL-2 is considered to be of fair quality, whereas that of Line SL-3 is regarded as of poor quality. The processing sequence for these 100% sections was re-sampling to 0.250 second, gathering of the nearest traces for successive records, re-filtering 100-500Hz, compositing (not mixing) of four traces into one and plotting of 0.125 second variable area. The dominant signal frequency is about 140Hz.

The top of redbeds reflection on Line SL-4 (see Figure 6) is the best of the four lines. It is shown without lateral compositing, and is considered to be of good quality. Migration of this record section, again using a velocity of 4,000 feet per second, yielded the result shown on the bottom section of Figure 6.

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Lines SL-1, SL-2 and SL-4 show what are interpreted as probable reflections from within the redbeds (see yellow horizons, Figures 4, 5 and 6).

The three seismic lines in the area of the proposed cell (Lines SL-1, SL-2 and SL-3) were also subjected to common-depth-point (CDP) stacking and then composited 4:1 laterally to determine whether reflections from deeper within the redbeds might be present. Line SL-4 did not produce events interpreted as reflections upon stacking; composited laterally, it became too short to be useful. Initially, Lines SL-1, SL-2 and SL-4 were stacked 12-fold CDP (1200%), but the farther traces proved to be so noisy that 6-fold CDP (600%) stacking, using the six traces nearest to the source, actually proved to be slightly better. The stacking velocity used was 5,500 feet per second, determined by stacking the lines with velocities ranging from 2,000 feet per second to 7,000 feet per second and comparing the results. The processing sequence here was re-sampling to 0.250 second, re-filtering 100-500Hz, muting to remove refraction breaks and groundroll, normal moveout removal at 5,500 feet per second, 600% CDP stacking, 4:1 lateral compositing (not mixing) and plotting 0.175 second variable area.

The resulting record sections are shown on Figures 7 and 8. These sections appear to be of very poor quality, but careful examination suggests that the horizons marked with yellow on Figures 9 and 10 may be reflections. One possible reflection is present on both Lines SL-1 and SL-3, between 0.125 and 0.150 second, and may possibly be present also on Line SL-2 (see Figures 9 and 10). Another, between 0.050 and 0.075 second, is present on Lines SL-2 and SL-3 (see Figure 10) but cannot be recognized on Line SL-1 (Figure 9).

In summary, the reflection data are considered to be of good (Line SL-4) to poor (Line SL-3) quality with regard to the top of the Triassic redbeds horizon; and of generally poor quality with regard to data from deeper within the redbeds, though there are useable events thought to be reflections from within the redbeds.

INTERPRETATION - As can be seen by examination of Figures 11 and 12, most of the refractions recorded came from within the Tertiary continental unit above the Triassic redbeds. These refractions are discontinuous and only locally extend more than 500 feet horizontally. Some display high velocities, over 10,000 feet per second. These features suggest that the Tertiary may contain lenses, likely representing stream bed deposits of limited extent, which contain clastic sediments some of which are probably well-cemented. This appears to be compatible with the results of drilling in the newer drill holes, and probably the older drill holes.

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The mean velocity of the material making up the Tertiary appears from both refraction and reflection to be about 4,000 feet per second, which is well within the rippable range. On the other hand, the presence of numerous local refractors of velocity higher than 6,000 feet per second (especially in the lower part of the unit) suggests that some beds within the Tertiary may not be rippable, unless they are thin and closely jointed.

The fact that the top of the redbeds is not a good refractor on these seismic lines, whereas it commonly is good elsewhere, may be caused by two factors. First, the large number of short-extent refractors in the overlying Tertiary produces a large amount of seismic noise, as noted earlier. Where refractors of velocity equal to or greater than the velocity of the top of the redbeds (here, approximately 8,600 feet per second) are present, these may effectively mask refractions from the top of the underlying redbeds. Second, and probably more important here, the top of the redbeds may be deeply and irregularly weathered, lowering its velocity and making it highly variable.

The possibility exists that a seismic source of much lower frequency might produce a reasonably continuous refraction from the top of the redbeds in this area; however, experience elsewhere in similar circumstances suggests that such a lower-frequency refraction would come from a variable depth below the actual weathered top of the redbeds, and hence might not reliably trace the contact.

Figure 13 is a structure contour map with contours on the top of Triassic redbeds, based on the seismic reflection data and the drill hole data from the drill holes shown. The contour interval is five feet and the elevations are in feet above sea level. The seismic horizon is that shown in red on Figures 11 and 12. This horizon is sufficiently constrained by drill hole data, and is of good enough quality on the seismic lines between drill holes, that it is regarded as reasonably reliable in the cell area.

The principle features shown in the cell area are a buried ridge which lies just south of the cell area and extends roughly east-west, and a roughly equidimensional hill occupying much of the cell area. The lower area between the ridge and the hill is interpreted as a buried stream valley (shown in blue) possibly draining eastward. The fact that these interpreted features are of low relief can be seen by examining Figures 11 and 12; even at a vertical exaggeration of 2:1, the gentle nature of this buried topography is evident.

Another possible buried stream valley is interpreted as present in the northeast part of the cell area. This

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possible paleo-stream is here shown as draining southeast and joining the paleo-stream from south of the hill, but this is not clear; it could, in fact, have drained to the northwest.

The top of redbeds reflection exhibits a step-like appearance on the north flank of the ridge on Line SL-1 (see Figure 4, Stations 80-120). These are thought most likely to represent the ledge-and-slope erosional form typical of the Triassic redbeds where exposed at the surface. A similar effect can be seen on the west flank of the hill, at Stations 10-50 on Line SL-3(Figure 5).

Line SL-4, northwest of the cell area, was recorded, as mentioned earlier, to investigate a small nearly circular valley containing an intermittent lake or playa. Various possibilities for the origin of this feature had been discussed, including that it was a "blowout" or wind deflation hollow, that it might be a sinkhole or collapse feature over a zone of dissolution or that it might be a low point over a shallow buried stream channel. An electrical resistivity survey, run earlier in the year, found that this position was one of a line of resistivity anomalies. The seismic results on Line SL-4 are, as mentioned earlier, of good quality. The refraction (see Figures 3 and 12) shows a flat refractor, mostly of high velocity, at a depth of only about 10 feet across the playa. This would seem to suggest that no collapse has occurred here within perhaps the last hundred thousand years.

The reflection data, however, appear to show a distinct low point at the top of the redbeds under the playa, and another under the north edge of the small valley (see Figure 6). The migrated section (lower part of Figure 6) shows, below the top of redbeds horizon, what is here interpreted as bearing strong suggestions of a buried stream channel or set of channels. The seismic evidence is therefor interpreted to support the concept that the playa, and the line of low points and resistivity anomalies, mark an ancient buried stream, at the base of the Tertiary and cut into the top of the underlying Triassic redbeds. Drill hole TP-1, north of the cell area, may have been drilled in or near this possible buried paleo-stream (see Figure 13). The actual age of this possible paleo-stream and its sediments is not clear at present; it could be anything from late Triassic to late Tertiary.

The presence of a line of topographic lows , presumably outlining the trace of the possible ancient stream, may suggest that there is at least locally some leakage of groundwater from the surface downward into the ancient paleo-stream sediments, and perhaps that the stream sediments still carry some groundwater.

Figure 14 shows interpretive contours of the thickness of the Tertiary of the cell area, somewhat generalized. The contour interval is five feet. An overall northeastward thickening of the Tertiary beds above the Triassic redbeds is shown. The average thickness of this unit can be seen to be about 50 feet. The lower half of the Tertiary may be more difficult to excavate than the upper half, because of the indicated presence of well-indurated beds in this part of the section.

Figure 15 is an interpretive structure contour map with contours drawn on a probable seismic reflection within the upper part of the redbeds, from a depth of about 350-400 feet below ground level, The contour interval is five feet and the elevations are in feet above sea level; the conversion velocity used was 5,500 feet per second. This map is based entirely on seismic reflection data; no drill holes in the cell area have penetrated to this depth.

The horizon mapped here is the seismic event, thought to be a reflection, between times of 0.125 and 0.150 second on Line SL-1 (Figure 9) and SL-3 (Figure 10). This event is very questionable on Line SL-2 (Figure 10), but does appear to show the same general form as does the event on Line SL-3 (see Figure 10). Despite these limitations, Figure 15 is thought to show something near the true form of structure within the upper part of the Triassic redbeds, within the cell area. The feature shown is a very gentle anticline striking northeast. The dip on the northwest flank, as interpreted, is about one and one-half degrees. The possible anticline may plunge northeast.

An important consideration here is that, neither at the top of redbeds horizon nor at any of the deeper events thought likely to be reflections, does the writer see in the seismic data any evidence which he interprets as suggesting faulting. As viewed at low vertical exaggeration, these horizons appear to be gentle and smooth, with no abrupt offsets (see Figures 11 and 12).

<u>CONCLUSIONS</u> - The following conclusions are believed merited on the bases of the seismic and drill hole evidence:

A. The Tertiary strata overlying the Triassic redbeds in the area of the proposed cell appear to thicken from southwest to northeast, with an average thickness of about 50 feet.

B. Numerous discontinuous refractions, some of high velocity, from within the lower part of the Tertiary, suggest the presence of well-indurated beds, probably of fluviatile origin and possibly not rippable.

C. The surface on which the Tertiary lies, the eroded top of the Triassic redbeds, is apparently deeply weathered and marked by an east-west ridge to the south and a hill to the north, evidently separated by an east-west buried stream valley, which may have drained eastward. The cell area is located mostly over the buried hill.

D. The seismic reflection data from the top of the redbeds is considered not to indicate faulting of this horizon.

E. The seismic line to the northwest, recorded across a small playa valley, is interpreted as indicating that the playa overlies a buried set of paleo-stream channels cut into the top of the redbeds.

F. Though of poor quality, seismic events considered probably reflections from within the top few hundred feet of the redbeds are interpreted to indicate that the structure within these beds, below the Tertiary-Triassic unconformity, is that of a gentle northeast-striking anticline, possibly plunging northeast, and apparently unfaulted.

RECOMMENDATION - The following recommendation is respectfully offered:

The drilling of a test hole to the top of the Triassic redbeds at a location about 700 feet northwest of the intersection of seismic Lines SL-1 and SL-3 is recommended, to confirm or disprove the existence of the hill mapped in that area, as an aid to excavation planning.

Respectfully submitted,

Charles B. Reynolds

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Registered Geologist (AR)
Certified Professional Geologist

Albuquerque, New Mexico November 1, 2001

15 Figures

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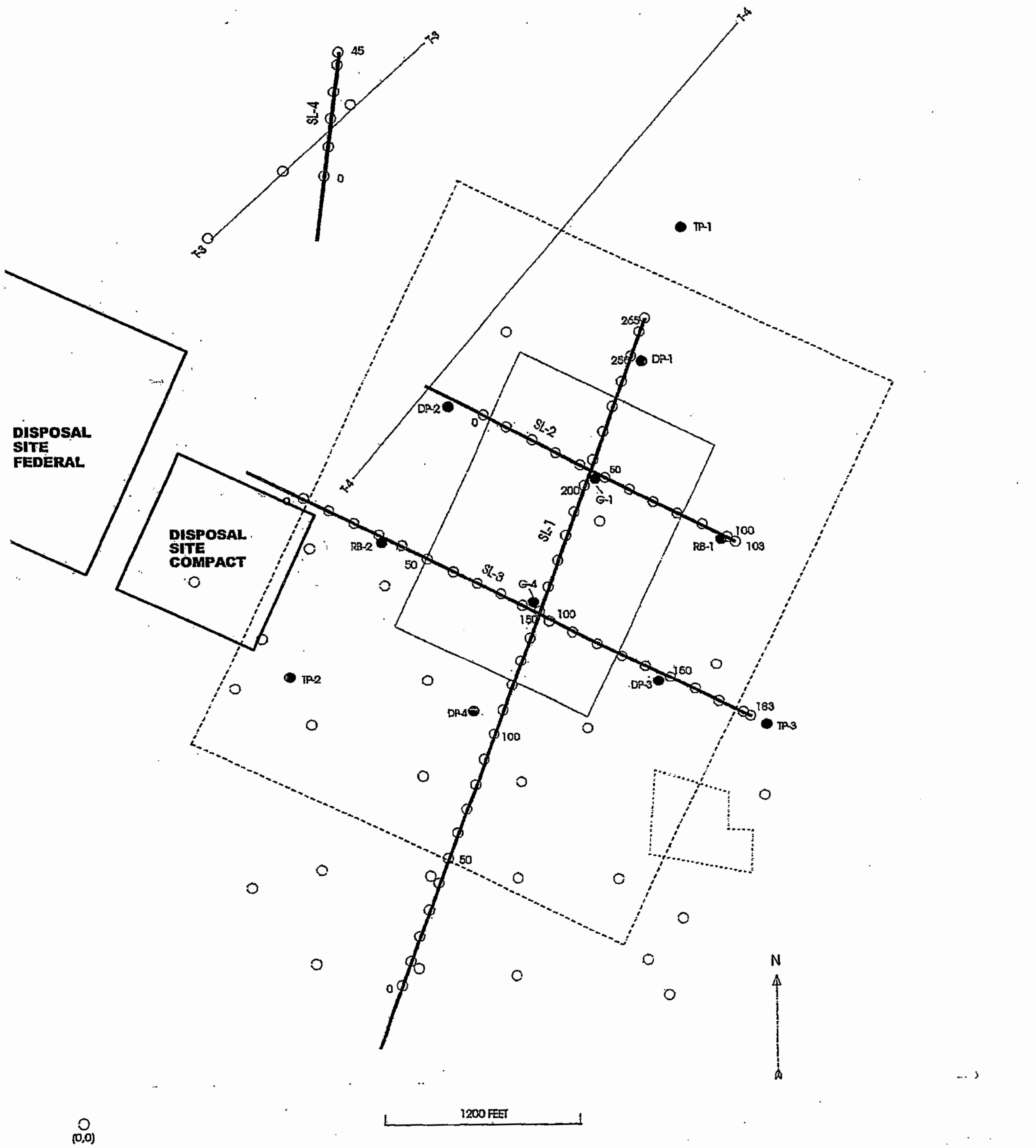


FIGURE 1 - Map showing locations of Seismic Lines SL-1 through SL-4 (red). Seismic line stations are shown as circles along lines. Solid circles are new drill holes. Open circles not on seismic lines are older drill holes. Lines T-3 and T-4 are resistivity lines. Solid rectangle is proposed cell. Dashed rectangle is 800' operational setback. Position (0,0) is origin for plotting.

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BOUNDARIES ADDED BY CJI, INTERA MAY 2005.

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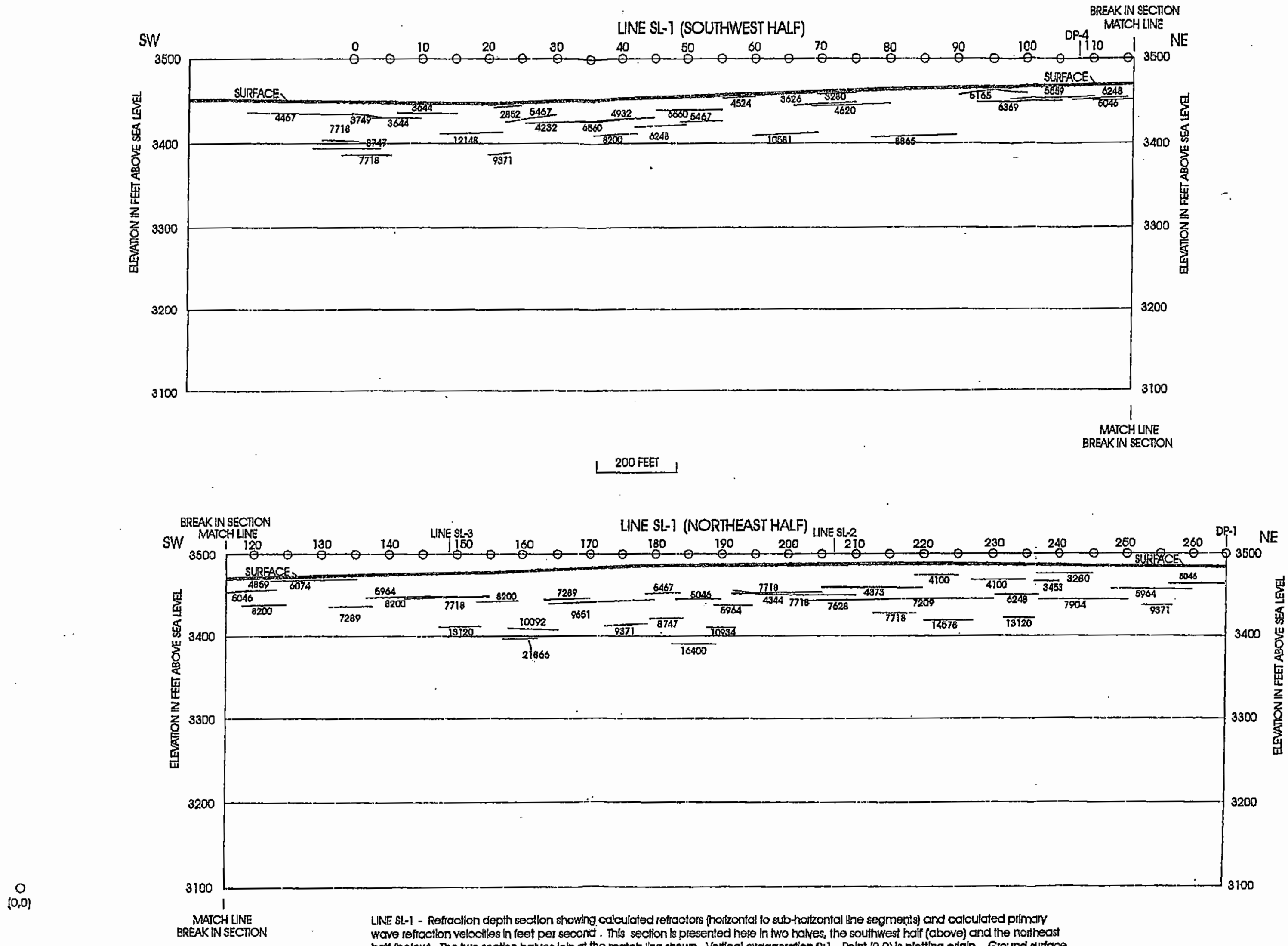
FIGURE 1




LINE SL-1 - Refraction depth section showing calculated refractors (horizontal to sub-horizontal line segments) and calculated primary wave refraction velocities in feet per second . This section is presented here in two halves, the southwest half (above) and the northeast half (below). The two section halves join at the match line shown. Vertical exaggeration 2:1. Point (0,0) is plotting origin. Ground surface marked green. Note that most of the observed refractors persist for only a short distance

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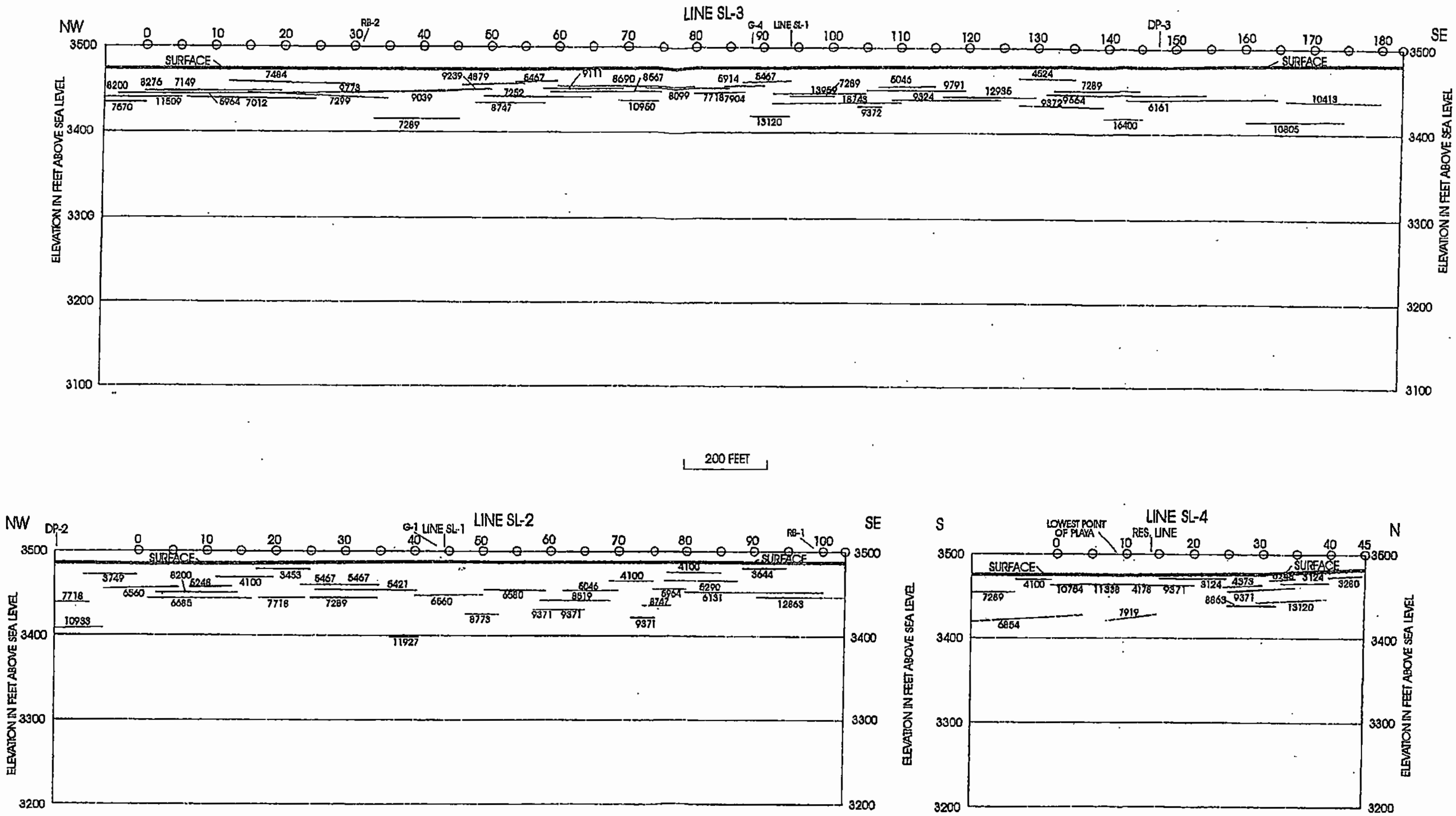
FIGURE 2




LINES SL-2, SL-3 AND SL-4 - Refraction depth sections showing calculated refractors (horizontal to sub-horizontal line segments) and calculated primary wave refraction velocities in feet per second. Vertical exaggeration 2:1 Point (0,0) is plotting origin Ground surface marked green Note that most of the observed refractors persist for only a short distance

(0,0)

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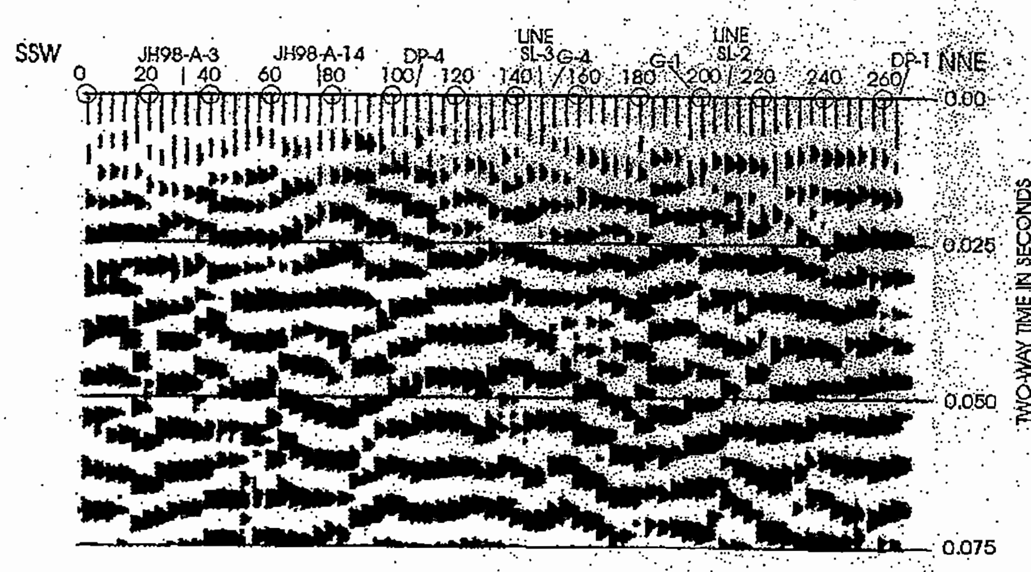
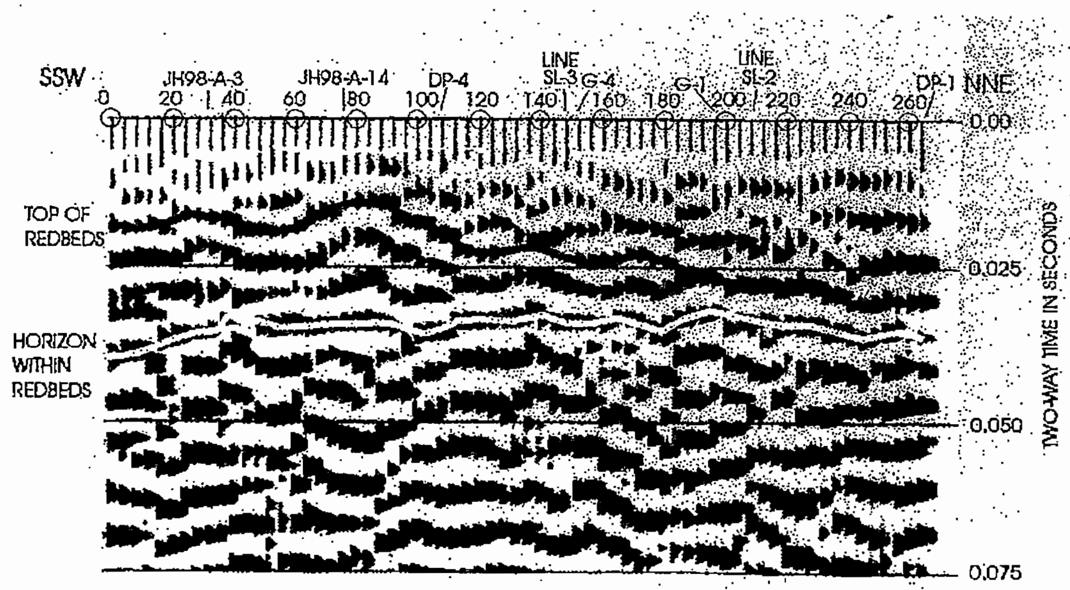
FIGURE 3




LINE SL-1 - Record section, made with nearest trace only (Channel 12), edited, filtered 100-500hz and composited 4:1 to reduce dominant noise.




LINE SL-1 - Same record section as above, but showing interpreted horizon for top of redbeds and an interpreted reflection within upper part of redbeds. The top of redbeds horizon is controlled by the drill holes shown. Conversion velocity from surface to top of redbeds is 4,000 ft/sec. Vertical exaggeration approximately 16:1.

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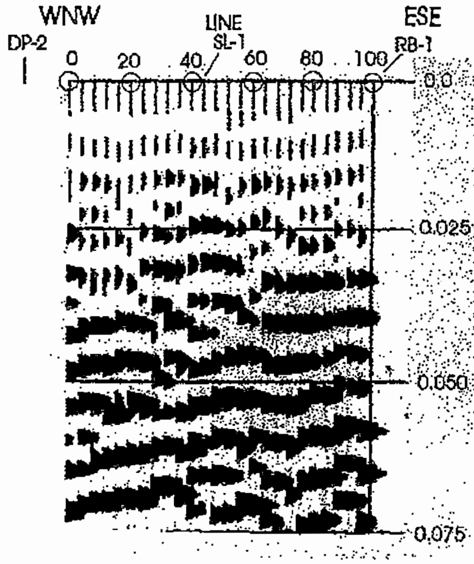
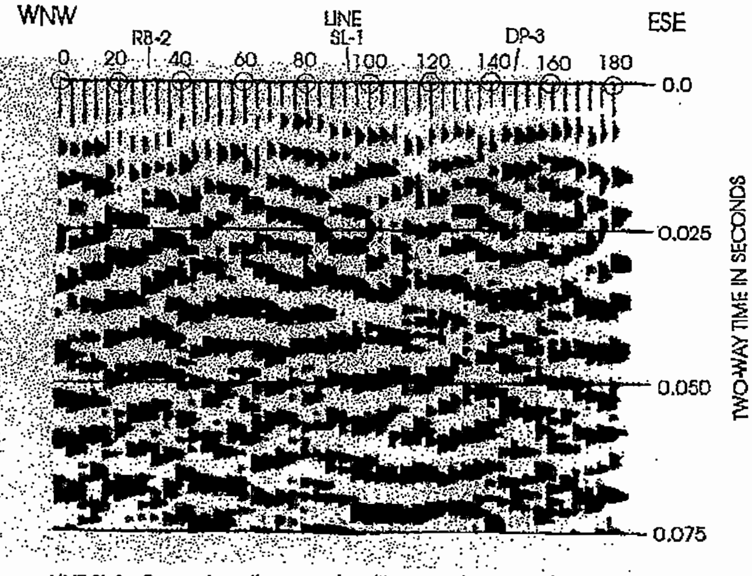
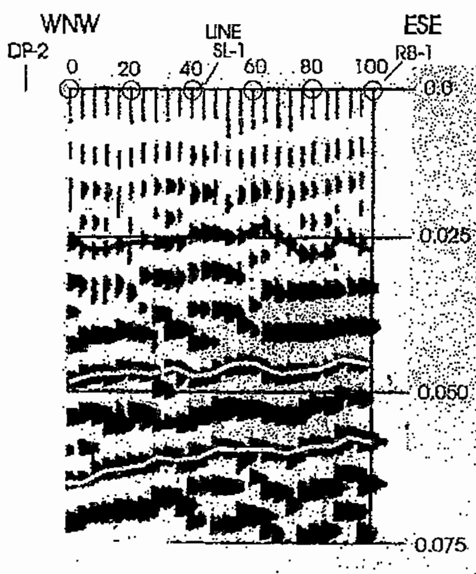
FIGURE 4



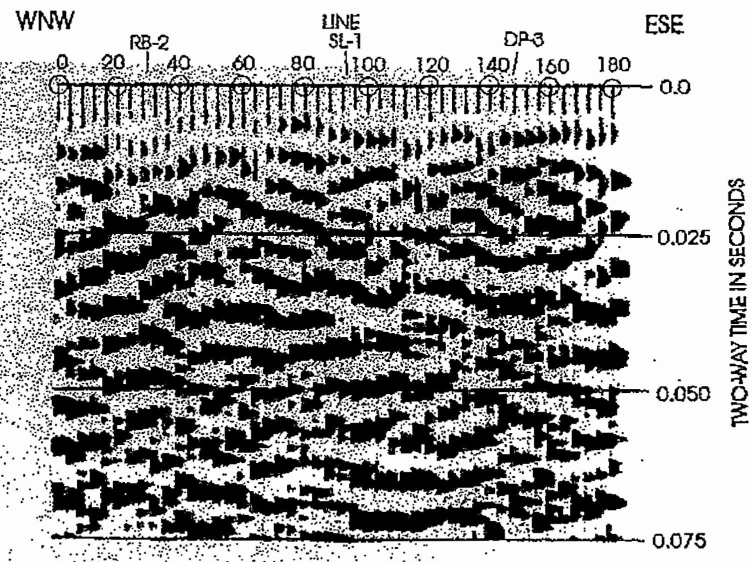

LINE SL-2 - Record section, made with nearest trace only (Channel 12), edited, filtered 100-500hz and composited 4:1 to reduce dominant noise.



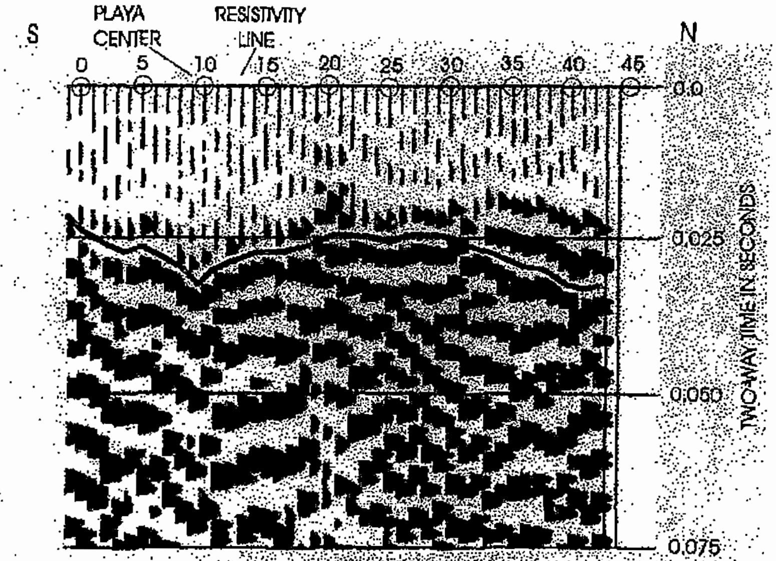

LINE SL-3 - Record section, made with nearest trace only (Channel 12), edited, filtered 100-500hz and composited 4:1 to reduce dominant noise.



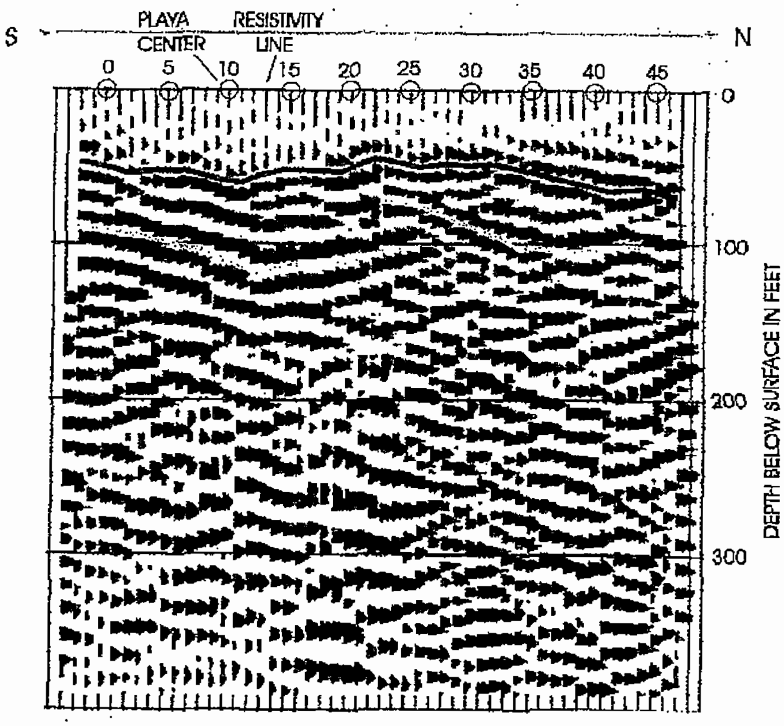

LINE SL-2 - Same record section as above, but showing interpreted top of redbeds (red) and interpreted reflections within upper part of redbeds (yellow). The top of redbeds horizon is controlled by the drill holes shown and by Line S-1.. Conversion velocity from surface to top of redbeds is 4,000 ft/sec. Vertical exaggeration 16:1.



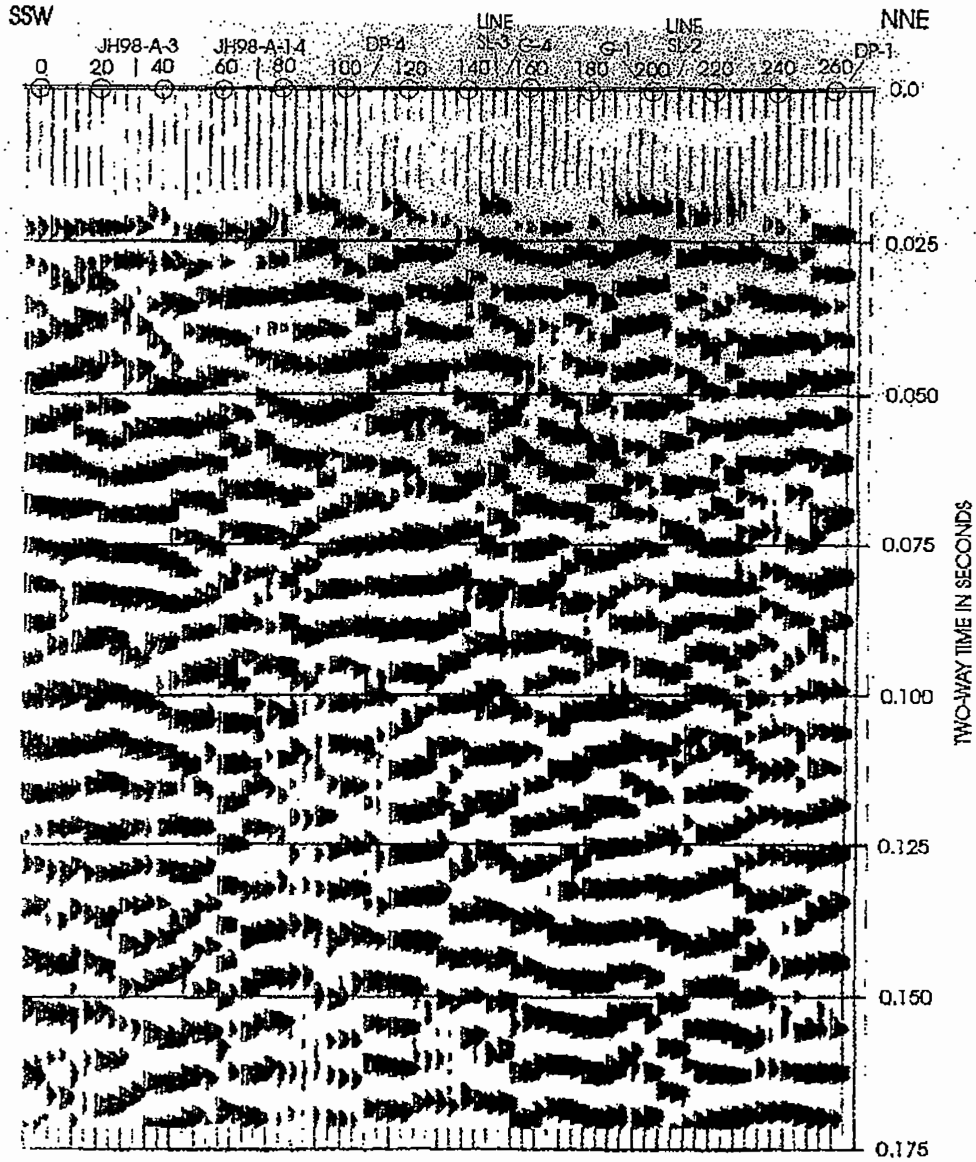

LINE SL-3 - Same record section as above, but showing interpreted top of redbeds (red). The top of redbeds horizon is controlled by the drill holes shown and Line S-1.. Conversion velocity from surface to top of redbeds is 4,000 ft/sec. Vertical exaggeration is approximately 16:1. This is considered the poorest of the seismic lines.




LINE SL-4 - Record section, made with nearest trace only (Channel 12), edited and filtered 100-500hz. Event thought likely to be top of redbeds reflection marked with red; trough picked here in absence of well control. Vertical exaggeration approximately 4:1.




LINE SL-4 - Record section of near trace only, as above, but migrated. Event believed likely to represent top of redbeds marked with red. Events interpreted as suggesting that this sub-playa feature may be a buried stream channel or set of buried stream channels marked with yellow. Migration velocity 4,000 ft/sec. Vertical exaggeration approximately 2:1.




LINE SL-1 - Reflection record section, stacked 600% CDP and composited 4:1 laterally to reduce dominant noise. Stacking velocity 5,500 ft/sec.

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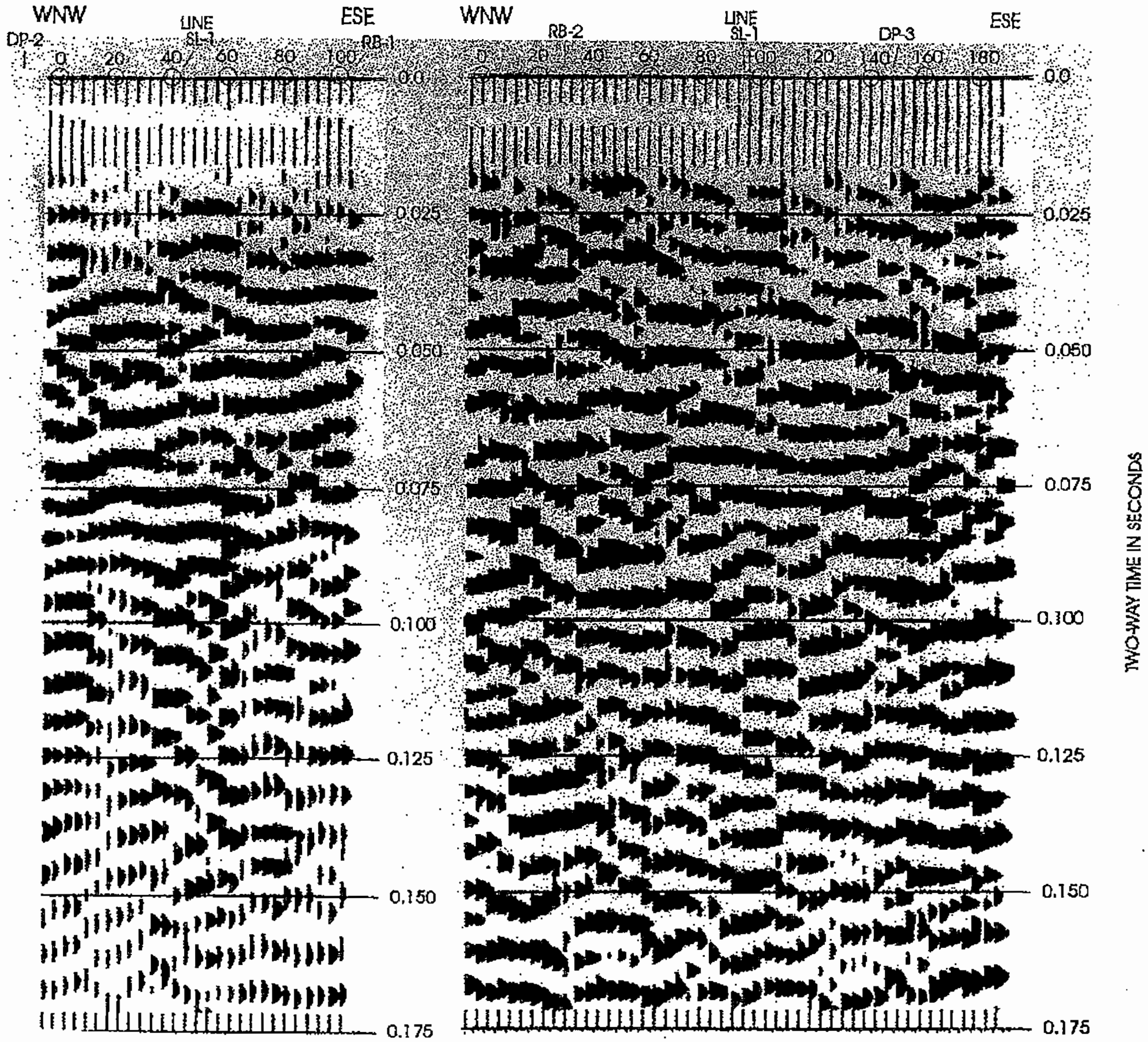
FIGURE 7




LINE SL-2 - Reflection record section, stacked 600% CDP and composited 4:1 laterally to reduce dominant noise. Stacking velocity 5,500 ft/sec. Vertical exaggeration about 16:1.

LINE SL-3 - Reflection record section, stacked 600% CDP and composited 4:1 laterally to reduce dominant seismic noise. Stacking velocity 5,500 ft/sec. Vertical exaggeration about 16:1.

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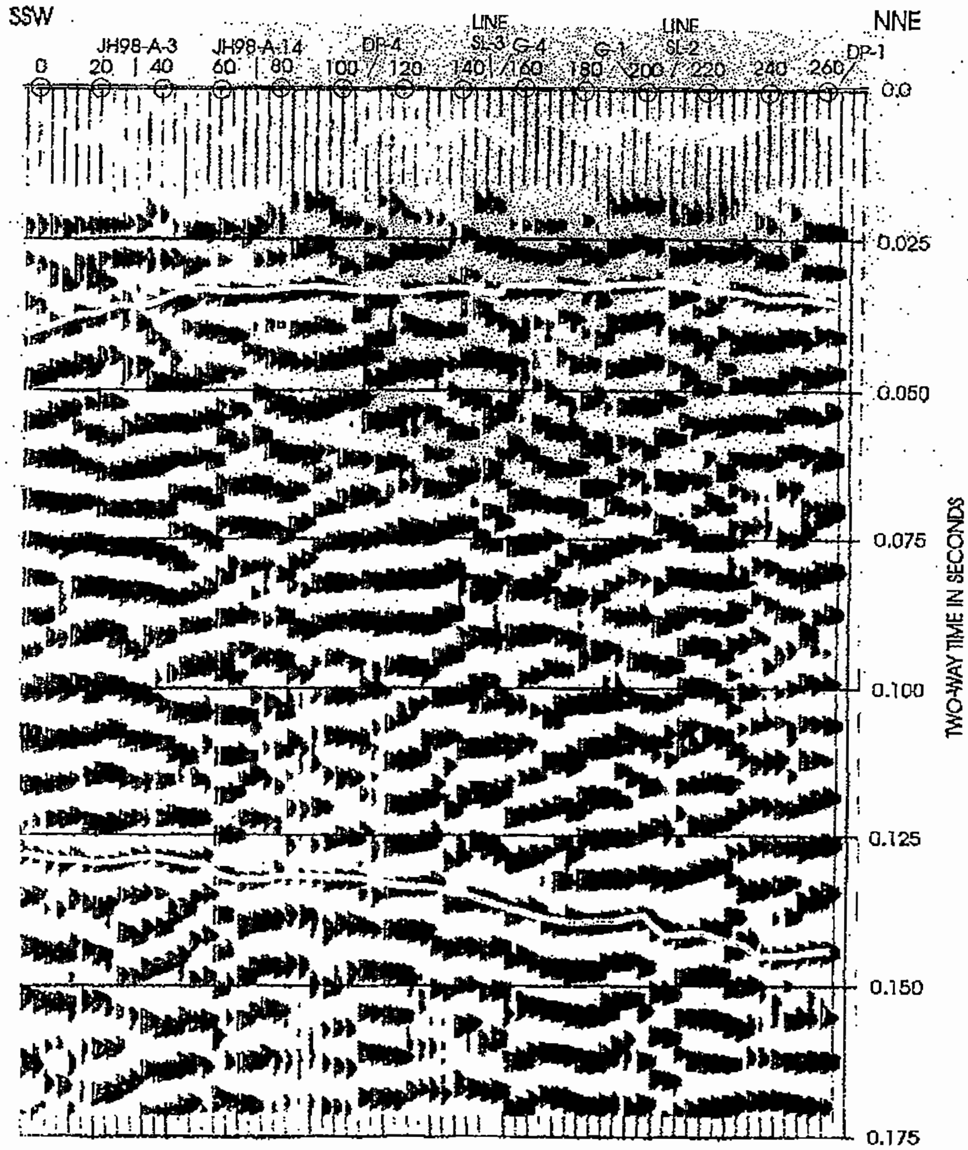
FIGURE 8




LINE SL-1 - Reflection record section, stacked 600% CDP and composited 4:1 laterally to reduce dominant noise. Stacking velocity 5,500 ft/sec. Events believed to be reflections from within redbeds marked with yellow. The shallower (earlier) event is probably from about 100 feet of depth. The deeper (later) event is probably from about 350-400 feet of depth. The dip of the later event, which appears to be steep, is actually less than one degree; it appears steep because of the 16:1 vertical exaggeration. The earlier event is also present on Lines SL-2 and SL-3 but is much poorer. The later event is present on Line SL-3 also, but is very questionable on Line SL-2. Other events between these two on this line are greatly obscured by seismic noise.

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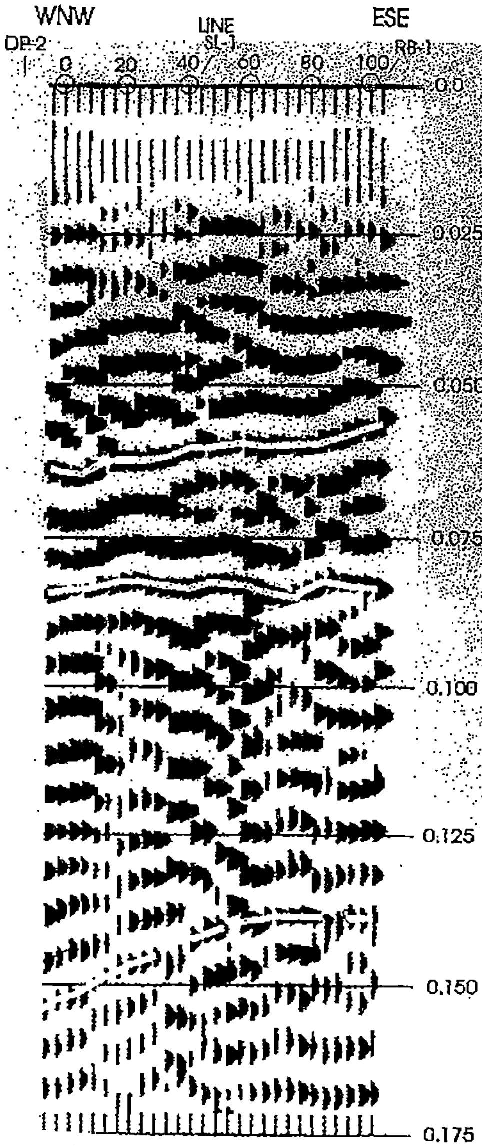
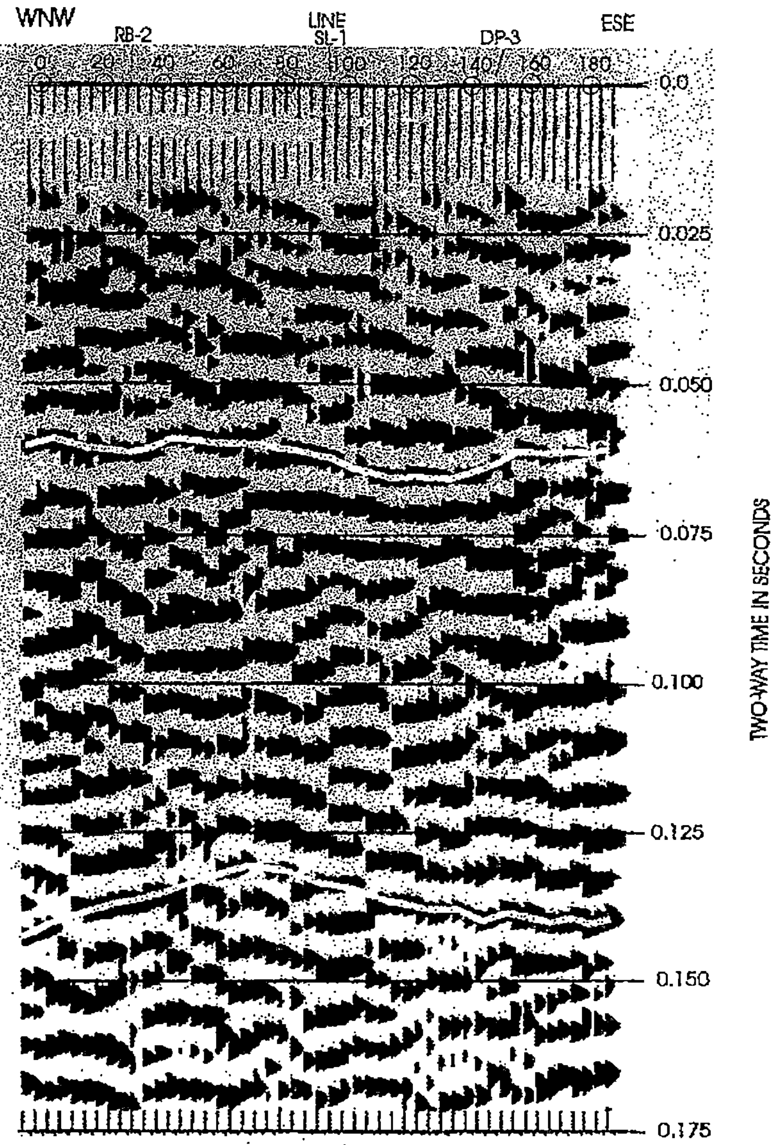
FIGURE 9




LINE SL-2 - Reflection record section, stacked 600% CDP and composited 4:1 laterally to reduce dominant noise. Stacking velocity 5,500 ft/sec. Events believed to be reflections from within redbeds marked with yellow. The actual dip of the event between 0.050 and 0.075 second is just over one degree, but is made to look steep by the vertical exaggeration of about 16:1.




LINE SL-3 - Reflection record section, stacked 600% CDP and composited 4:1 laterally to reduce dominant seismic noise. Stacking velocity 5,500 ft/sec. Vertical exaggeration about 16:1. Events believed to be reflections from within the redbeds marked with yellow. All dips indicated are less than two degrees, but appear steep because of the large vertical exaggeration.

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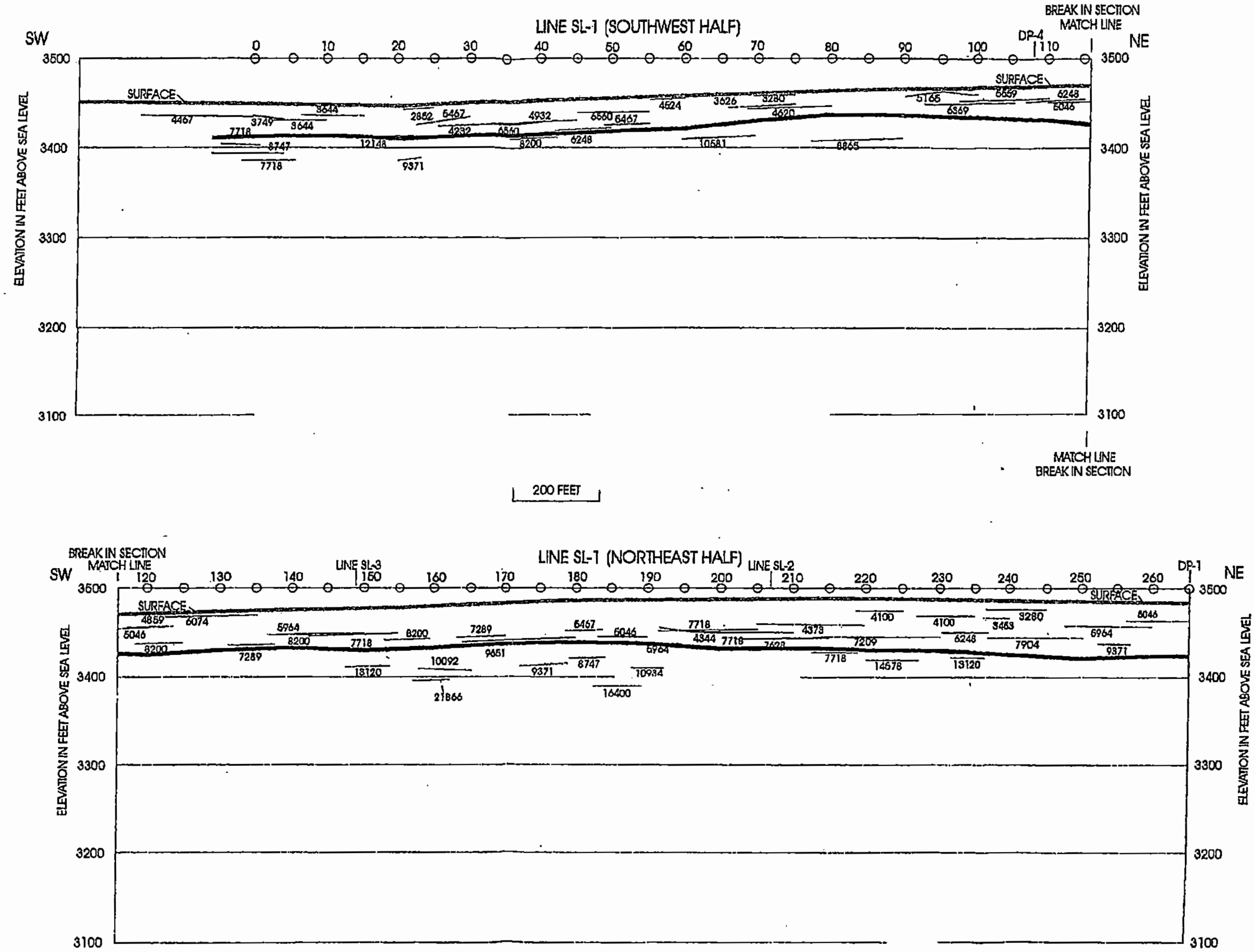
FIGURE 10




LINE SL-1 - Refraction depth section showing calculated refractors (horizontal to sub-horizontal line segments) and calculated primary wave refraction velocities in feet per second. Note that section is presented in two halves, the southwest half (above) and the northeast half (below). The two section halves join at the match line shown. Vertical exaggeration 2:1. The top of Triassic redbeds horizon, as interpreted from reflection seismic and drill hole tops, is shown in red. Events believed to be reflections from within the redbeds are shown in yellow. Note that most refractions, including some of high velocity, come from within the Tertiary strata above the top of the Triassic redbeds.

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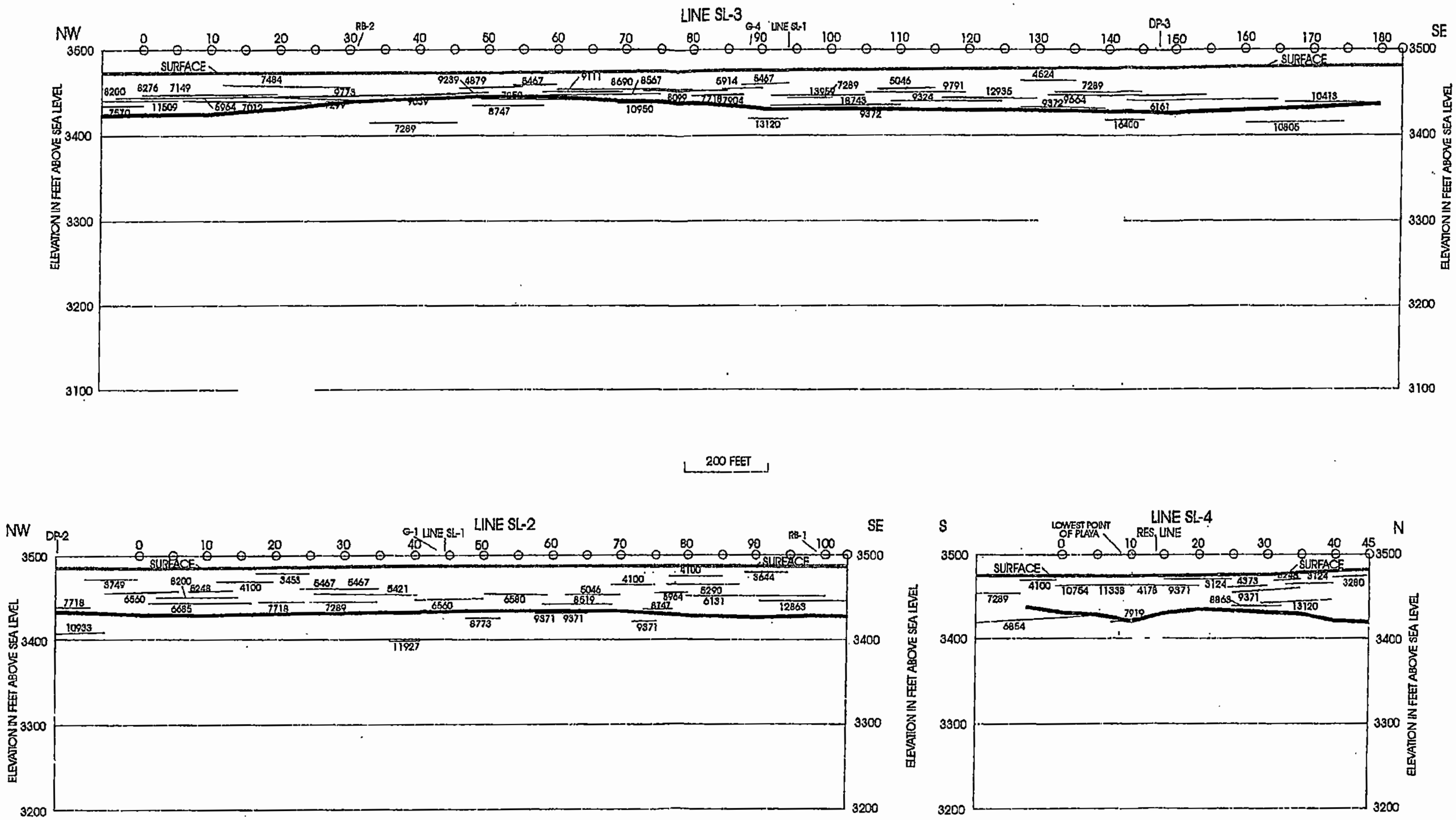
FIGURE 11






LINES SL-2, SL-3 and SL-4 - Refraction depth sections showing calculated refractors (horizontal to sub-horizontal line segments) and calculated primary wave refraction velocities in feet per second. Vertical exaggeration 2:1. The top of Triassic redbeds horizon, as interpreted from reflection seismic and drill hole tops, is shown in red. Events believed to be reflections from within the redbeds are shown in yellow. Note that most refractions, including some of high velocity, come from within the Tertiary strata above the top of Triassic redbeds.

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FIGURE 12

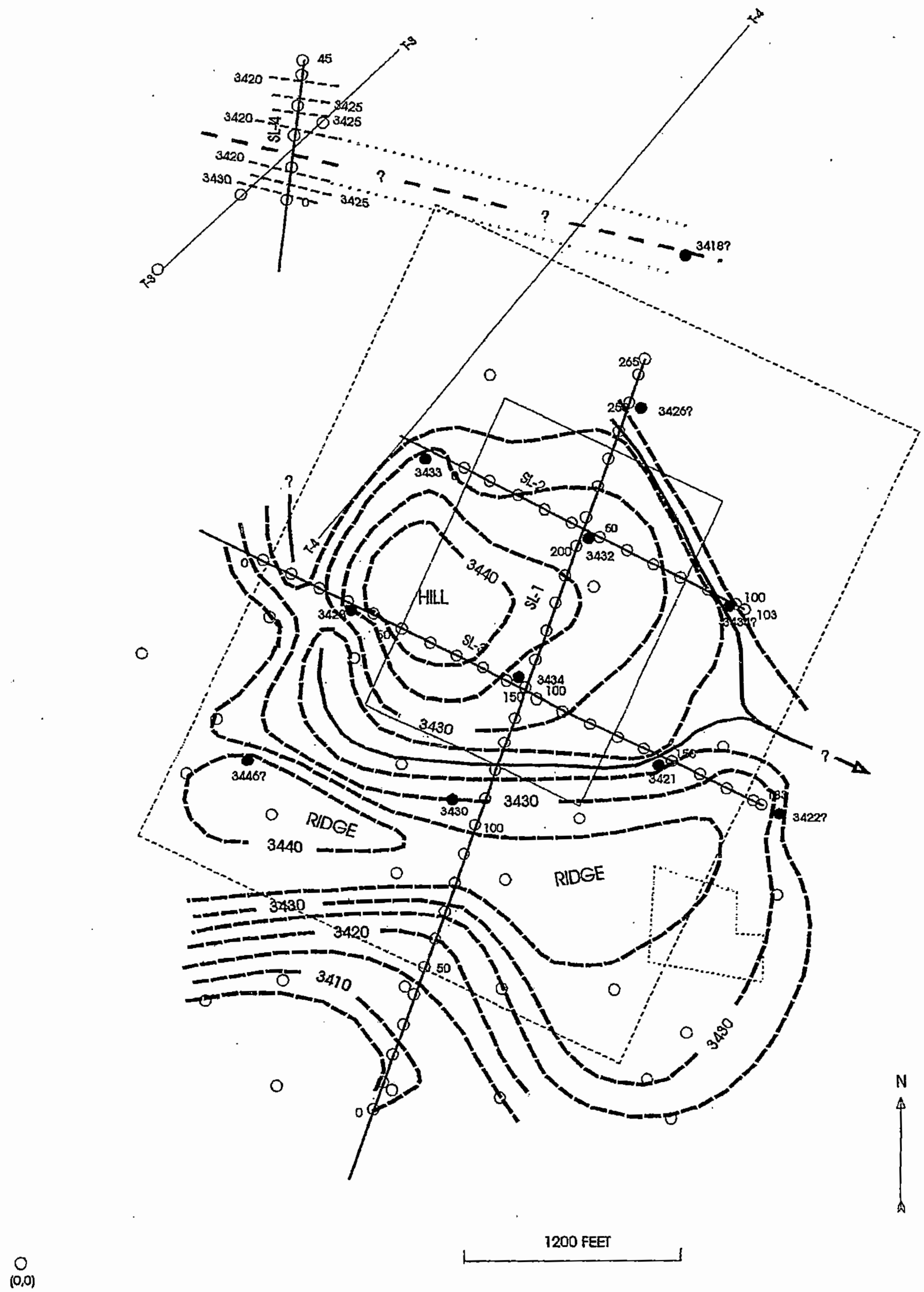


FIGURE 13 - Elevation contour map with contours on top of Triassic redbeds. Interpretation based on seismic reflection data and drill hole data. Tops from older drill holes honored but not shown. Contour interval five feet. Elevations in feet above sea level. Interpreted buried stream channels shown in blue.

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FIGURE 13

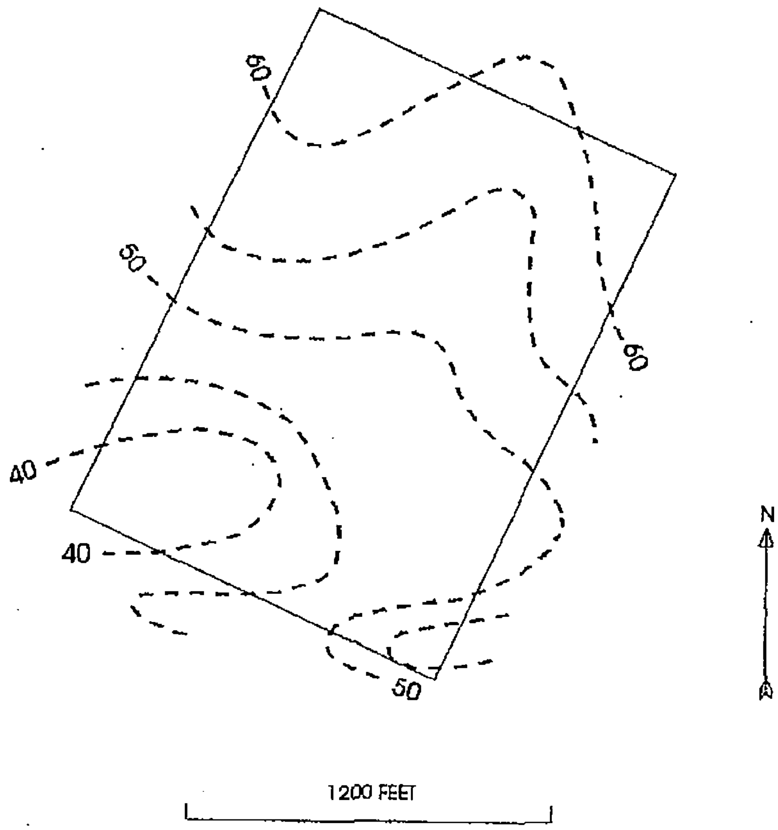


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FIGURE 14 - Generalized map of thickness of Tertiary beds above Triassic redbeds, based on seismic and drill hole data. Contour interval five feet. The thickness of the Tertiary is shown as increasing from southwest to northeast.

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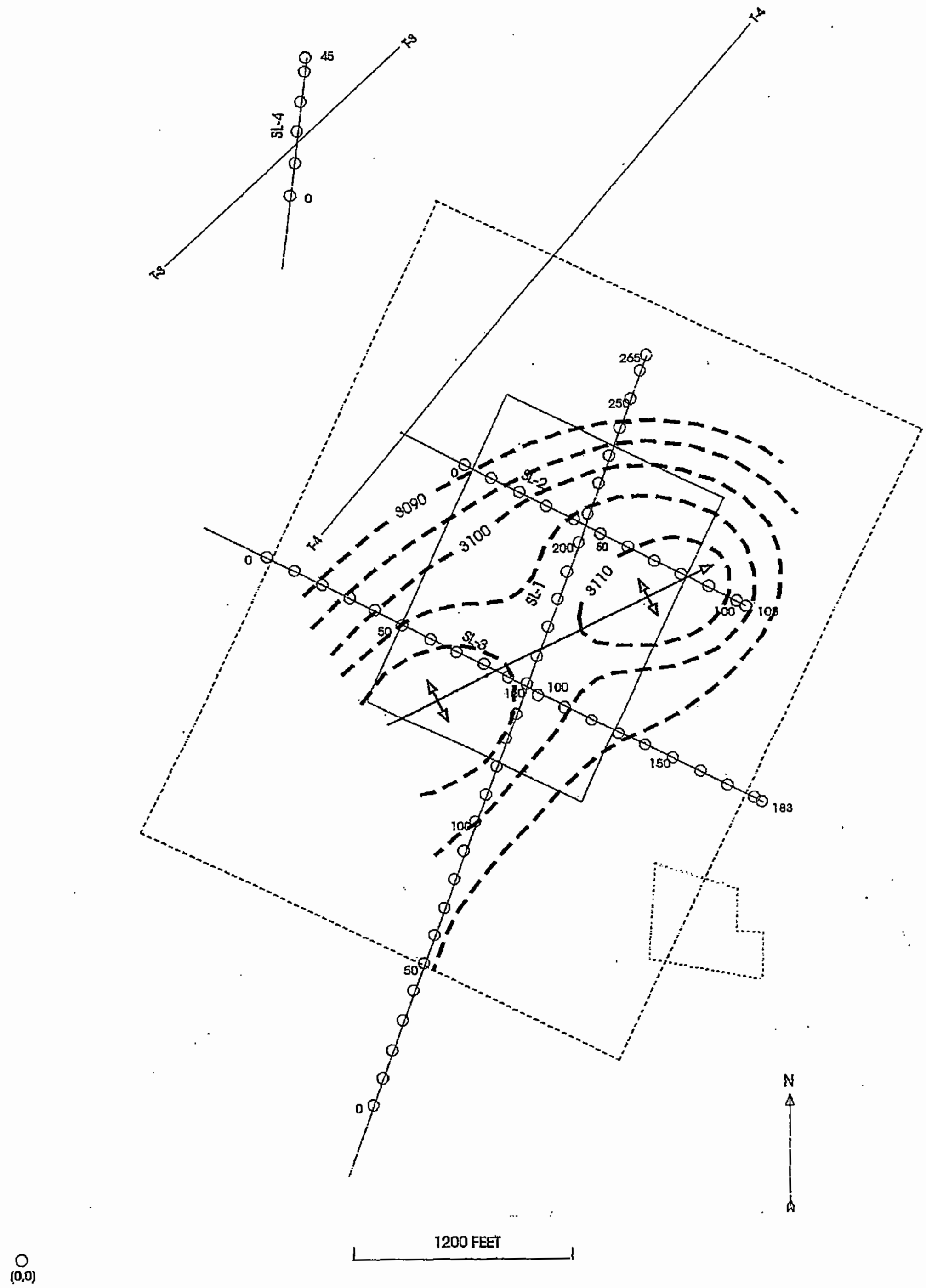


FIGURE 15 - Structure contour map with contours on an interpreted seismic reflection horizon within the Triassic redbeds, at a depth of about 350-400 feet. The suggested structural form shown is a gentle anticline, possibly plunging northeast. Compare with top of Triassic map, Figure 13. Contour interval five feet. Elevations in feet above sea level.

# APPENDIX A
## Seismic System Description

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The seismic system used by Geological Associates is designed to produce both reflection and refraction information from shallow depths. Refraction data are normally obtained from the top 100 feet, and reflection data from the top 300-400 feet.

FIELD SYSTEM - The recording technique used is a single-vehicle operation which involves two people. One person, the instrument operator, drives a four-wheel drive truck which tows the seismic cables, which have Mark Products G-21 gimbal-mounted self-orienting geophones or receivers attached at intervals of 32.8 feet (10 meters) at distances of 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110 and 120 meters behind the truck and source point. The second person walks behind the truck, helps measure the interval distances between source points, and operates the seismic energy source, which is a heavy sledge hammer struck against a metal plate set on the ground.

The truck is stopped each 16.4 feet (5 meters) along each seismic line so that a seismic recording can be made. This yields 1200 percent (12-fold) CDP (common depth point) stacked reflection data and a new refraction profile from each source position. Both analog (paper) and digital (3.5 inch diskette) records are made at each seismic source point position. The seismic intruments used are a Geometrics ES-2401 multiple channel seismograph system.

The returns from multiple source blows (blows of the heavy sledge hammer against the metal plate) are recorded and summed in the seismograph. The number of blows summed at each position is determined from the instrument operator's examination of the refraction returns as shown by the instrument monitor. The multiple blows summed at a given source point increase the total source power and reduce ambient noise. Recording is for one-half second with one-half millisecond sample interval and 100-500Hz passband. The dominant signal frequency is usually about 150Hz, which is excellent for refraction and reflection resolution. The operator also keeps daily field notes, detailing the survey's progress and special items such as line intersections, drill holes passed and tied into the seismic line and weather conditions.

A wooden stake marked with the line and source point designation (e.g., Line CD-1, R30) is driven into the ground at each tenth station or source point position, to make later surveying possible. Spray-paint marking can be used instead, if stakes are undesirable. After completion of the field recording, the lines are normally surveyed by plane table and alidade, to provide an early map of the survey lines.

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DATA PROCESSING - The seismic data resulting from the field recording are processed for both refraction and reflection information.

The refraction returns are analyzed using Rimrock Geophysical's SIP refraction computer program system. This program set is particularly useful in that it provides the interpreter with excellent visual presentation of the data, allowing clearer and more rapid analysis than was formerly possible. The output includes event times, velocities and refractor depth solutions by delay times.

Because the seismic recording system used here produces a new refraction profile each 16.4 feet along the seismic line and each profile provides about 180 linear feet of refractor coverage, the system offers many-fold redundancy. This can result in unusually great detail and reliability of refraction information. In practice, line intervals which appear to be anomalous can be examined in close detail with close-spaced analyses, and intervals which appear to be straight-forward can be studied in less detail. The refraction data are also used in correcting the reflection data.

The reflection data basically are contained in those seismic returns which arrive at the geophones after the passage of the first or refraction arrivals. These data are passed through a sequence of computer programs which are designed to achieve specific steps in arriving at data which present possible reflections in as clear a form as the data permit. This software was written by ourselves specifically for this seismic system.

INTERPRETATION AND REPORTING - The seismic data are carefully analyzed and interpreted by geologists with many years of experience in seismic interpretation in the geologic framework. A final report is produced, usually six to eight pages in length, which gives complete details of data recording, processing and interpretation with appropriate illustrations and maps.

# EXHIBIT 5-4 B
# GEOPHYSICAL SURVEY RESULTS
# WCS ANDREWS SITE, ANDREWS COUNTY, TEXAS, 2001

# Geophysical Survey Results

# WCS Andrews Site

*Andrews County, Texas*

June 25, 2001

*Prepared for:*

PMC Environmental
Rockville, Maryland

*Prepared by:*

ADVANCED GEOLOGICAL SERVICES
3 Mystic Lane
Malvern, PA 19355

AGS Project No. 01-143-1

TABLE OF CONTENTS

LIST OF FIGURES

## *1.0 Introduction*

This report provides the results of a geophysical investigation that was conducted at the WCS Site in Andrews County, Texas. The areas of investigation included four linear transects that crossed important sections of a proposed landfill site. The survey area was located in a flat, relatively open plain that contained minor amounts of low brush and vegetation. The field activities for this investigation were completed by AGS on March 6, 2001 through March 12, 2001.

## *2.0 Objectives*

The primary objective of this investigation was to determine the depth to the top of the Red Bed Unit (sometimes referred to as the Dockum Group), which is a red, red-brown, or yellow mudstone or clay unit along the four geophysical transects. In conversations with the client and a review of existing borehole information, it was anticipated that this interface was between 10 and 100 feet below ground surface (bgs) in the areas of interest. Our survey design was based on this information.

Secondary objectives that were described to AGS personnel included the locations of potential saturated zones, discontinuities, depressions, valleys, or offsets in the geologic formations underlying each transect. The electrical resistivity (E/R) method was chosen as the primary technique for delineating the top of the Red Bed Unit. AGS anticipated that a measurable or strong electrical contrast would exist between the sediments above the Red Bed Unit and the Red Bed Unit. The ground-penetrating radar (GPR) method was used as a secondary technique. The preliminary information that we reviewed indicated that the sediments overlying the Red Bed Unit were sands and caliche deposits, which, in a dry environment, transfer radar energy very efficiently. If these conditions are present, an image from the top of the Red Bed Unit could be observed.

## *3.0 Survey Locations*

Based on discussions with PMC, it was determined that four strategically-placed geophysical profile lines would provide a representative picture of the top of the Red Bed Unit in the area of interest. Their line designations (T1, T2, T3, and T4), lengths, and locations have been surveyed and placed on a site map provided by PMC (Figure 1). There were no man-made structures or natural features that could be used as survey datum points, so a global positioning system (GPS) was used to identify the start and end points of each line. The southern stakes from lines, T1 and T4 were placed at boring locations JH93-B-50 and JH93-B-53, respectively. In addition, flagged stakes were placed at 60-meter intervals along each line to allow for easy reoccupation in the future. The station points for each line were surveyed in by West Texas Consultants and placed on the map. The total E/R survey length was 9,030 linear feet.

For each E/R spread, a linear series of fifty-six electrodes were placed into the ground at 19.7-foot (6 meter) intervals. Each E/R spread length was 1,083 feet (330 meters), and upon completion of each spread, the first 34 electrodes were removed and placed ahead of the end electrodes from the previous spread. In this manner, a rollalong or "leapfrog" movement of the electrodes occurred for each successive spread. The overlap between E/R spreads was 22 electrodes, or 413 feet (126 meters). The overlapping spreads along each line were merged in the office so that a continuous resistivity model could be constructed for each line. GPR profiles were collected along the same E/R line positions to enable a direct correlation of data sets.

### *4.0 Electrical Resistivity Method*

Electrical resistivity (E/R) methods are used to measure the resistivity structure of subsurface materials using a direct current electrical source. Typically, a linear series of 56 electrodes (metal stakes) are placed into the ground at a constant and known distance. Each resistivity measurement involves the activation of only four of the electrodes. A direct current signal is injected into the ground between two transmitting (current) electrodes, and the resulting voltage drop is then measured between two receiving (potential) electrodes. The measured voltage drop is converted into apparent resistivity using equations that take into account the geometry of the electrode array and the measured voltage and current at each station point. The automatic switching relay in the system moves to the next series of electrodes, and the process is repeated until a complete data set is acquired.

For this investigation, the dipole-dipole profiling-sounding electrode configuration and the Schlumberger electrode configuration were implemented. Among the various electrode arrays, these two are commonly used for detecting horizontal or sub-horizontal geologic layers, and for locating lateral variations in geologic conditions. AGS used the dipole-dipole configuration for Line T1, then switched to the Schlumberger configuration for the remaining lines. We found that the data acquisition time was significantly lower using the Schlumberger configuration but that the data quality is very similar even though there are fewer data points associated with the Schlumberger configuration.

Apparent resistivity is a function of the porosity, permeability, water content, lithology, and ionic make up of the subsurface materials. Consequently, soils or rocks that contain a high percentage of clay minerals and a high water content generally have a low apparent resistivity. On the other hand, a dry clean sand with few free ions, or a very dry clayey material will have a relatively high apparent resistivity. AGS anticipated that the Red Bed Unit would possess resistivity values that were either 1) much lower than the sand and gravel units overlying the Red Bed Unit due to the increased ionic activity of clays, or 2) higher than the sand and gravel units overlying the Red Bed Unit if the clay was very dry.

Surface resistivity data was collected using a Sting R-1 resistivity meter and a Swift automatic multi-electrode system. The Sting R-1 resistivity meter is manufactured by Advanced Geosciences, Inc. of Austin Texas. The Sting R-1 resistivity meter is a self contained battery operated resistivity meter that is capable of monitoring data quality using predetermined statistical parameters, numerical stacking of measured data to increase the signal to noise ratio, spontaneous potential cancellation, and data storage for downloading to a PC.

The Swift automatic multi-electrode system used in this investigation consisted of 56 electrodes. The Swift controller is connected directly to the Sting R-1 resistivity meter which was pre-programmed to collect data using the dipole-dipole and Schlumberger configurations. Again, the electrodes were spaced 19.7 feet (6 meters) apart to provide an anticipated depth of investigation of approximately 200 feet below the ground surface. Upon completion of the electrode array set-up, electrode tests were conducted to ensure that all electrodes were correctly attached and that the resistance between the ground and the electrodes were within an acceptable range. Upon completion of the electrode test, the resistivity meter was set to automatically sample the dipole-dipole and Schlumberger data.

The resistivity data was analyzed using the commercially available computer program, RES2DINV. The resulting model presents resistivity as a function of depth. The E/R depth model values were then compared to existing borehole information to provide a "cross check" on the actual depths to the geologic interfaces. The boring log information was not used, however, to constrain the resistivity model during processing.

## *5.0 Ground Penetrating Radar Method*

Ground penetrating radar (GPR) data was collected along each E/R line to compliment and confirm the results of the E/R data. As stated, this method was chosen as a secondary technique to observe the top of the Red Bed Unit. It was anticipated that the likelihood of success with this method would be much lower than the E/R method. The presence of conductive materials such as water or thin saturated clay units may attenuate the radar signals, and prohibit the imaging of the Red Bed Unit. AGS collected the radar profiles during the E/R data acquisition process in the event that usable data could be observed in the field, or viewed in the office after processing and removal of noise. The GPR field procedure involved (1) instrument calibration, (2) test run completion, (3) production profile collection and recording, (4) data storage for subsequent processing and analysis in the office, and (5) on site evaluation of GPR records.

The GPR method is based upon the transmission of repetitive, radio-frequency EM pulses into the subsurface. When the down-going wave contacts an interface of dissimilar electrical character, it returns to the surface in the form of a reflected signal. This reflected signal is detected by a receiving transducer within the GPR unit and added to the data file. The GPR anomaly remains prevalent as long as the electrical contrast between media is present and constant. Any lateral or vertical changes in the electrical properties of the subsurface result in an equivalent change in the GPR signature. The system records a continuous image of the subsurface by plotting two-way travel time versus distance traveled along the ground surface. Two-way travel time values are then converted to depth using known soil velocity functions. A Geophysical Survey Systems SIR-2 System was used to collect the GPR data. A 100 megahertz

(MHz) antenna and 400 nanosecond (ns) recording window was used for data acquisition. Typically, the depth of penetration increases as the frequency of the transmitting antenna decreases, and as the resistivity of the geologic units increases. Unfortunately, as the transmitting frequency decreases, so does the vertical and horizontal resolution.

## *6.0 Field Procedure*

The field procedure for each instrument involved (1) before survey calibration and equipment checkout, (2) test run(s) completion, (3) production profile recording and data storage, and (4) data storage to disk for subsequent processing in the office. Data were examined each evening for consistency, repeatability, and accuracy of measurement. Anomalous readings were carefully observed in the field, and detailed field notes were taken to aid in the interpretation and presentation of all data sets. Each evening, geophysical contour plots were generated to assess data quality, and to perform preliminary interpretations.

## *7.0 Geologic Overview*

In general, the uppermost formation underlying the survey area is the Quaternary Blackwater Draw Formation, which is a reddish brown, clayey fine sand, with soft sandy caliche. Below, the "Caprock" Caliche is present in variable thickness. It is a hard, laminated, pisolitic caliche that contains a fine sand matrix and some chert nodules. The Ogallala Formation may be present below the caliche and is composed of clean, well-sorted, very fine to fine sand/sandstone (quartzarenite), and a fine-to-medium sand/sandstone (sublitharenite) with sparse chert granules. The Antlers Formation may also be present below the caliche, and is composed of medium-grained white-to-yellow quartzose sand and chert pebble gravel and quartzite. The Red Bed Unit of the Dockum Group (Chinle Formation) underlies the Ogallala or Antler Formations, and is composed of a red, red-brown, or yellow mudstone and siltstone.

## *8.0 Resolution of Geologic Features*

The ability to resolve a particnlar geologic interface or discrete geologic structure or body using the E/R method depends on several factors. It is important that a measurable electrical contrast exists between the overlying beds and the geologic interface of interest. As the electrical contrast increases, the target interface will become more distinct and traceable on the modeled profiles.

Another important factor is the electrode configuration and the electrode spacing. The dipole-dipole and Schlumberger configurations are typically used for delineating a horizontal or sub-horizontal geologic interface such as the Red Bed Unit. The electrode spacing defines the depth of investigation and resolution of the interface. The closer the electrode separation, the greater the horizontal and vertical resolution, but the shallower the depth of investigation. It is important to define a balance between resolution and depth to the target interface, and project costs. AGS determined that given the relatively flat nature of the Red Bed Unit (boring log information) and the desire to collect as much E/R data as possible over the site, that a 56 electrode array and a 19.7 foot (6 meter) electrode spacing would provide the best information at the most economical cost.

The horizontal resolution observed for the data set collected at the WCS Site was equal to the electrode spacing, which is 19.7 feet (6 meters). This value provided excellent lateral control on the Red Bed Unit. Based on the manner in which E/R data is collected, the vertical resolution is highest near the ground surface, and decreases as the depth of investigation increases. In other words, the vertical distance between E/R data points increases with depth. This translates to an approximate vertical resolution of 3 feet from 0 to 20 feet bgs, 5-6 feet near the top of the Red Bed Unit (30 to 60 feet bgs), and 15-18 feet at 150 feet bgs. The E/R depth models can be compared to nearby well information to increase the resolution by up to 150 per cent. Only those geologic features that are larger in size than the aforementioned horizontal and vertical resolution limitations can be observed on the resistivity cross sections.

## *9.0 Results and Discussion*

AGS has included Figures 1 and 2 with this report. Figure 1 is a site map that shows the locations of the E/R profiles superimposed on topography contours. The contour interval is 2 feet, and the topography is very flat for the most part. Figure 2 shows the four electrical resistivity models that were generated for this investigation. AGS has included annotated interpretations on the plots and the approximate locations of existing borings. The results of the geophysical survey are summarized below.

### *9.1 Red Bed Unit*

The Red Bed Unit was detected on all of the E/R profiles. Figure 2 shows the modeled E/R cross-sectional images, approximate elevation and trend of the Red Bed Unit below each traverse location, and other interpreted features. The E/R data from Lines T1, T2, and T3, indicates that the Red Bed Unit is very flat for the most part, with a slight apparent dip to the north/northwest. The Line T1 data indicates a decrease in elevation of the top of the Red Bed Unit of approximately 18 feet over a distance of approximately 2,400 feet. Line T2 indicates a decrease in elevation of approximately 12 feet over 1,500 feet, and Line T3 indicates a decrease in elevation of approximately 10 feet over 1,740 feet. The Line T4 profile indicates the Red Bed Unit is very flat along the line. There is a slight increase in elevation of only about 5 feet over 3,800 feet. The top of the Red Bed Unit exhibits very subtle undulations along the lines, as seen in Figure 2. It is possible to view these undulations, and the subtle apparent dip to the north, more clearly by looking obliquely along each profile and observing the changes.

Following an analysis of the data, AGS determined that the Red Bed Unit interface possesses an identifiable electrical character along all four lines. First, the E/R data indicates that the Red Bed Unit is universally more resistive than the overlying units. Typically, this would indicate that the clay unit is very dry and impermeable, and the geotechnical data from several borings corroborates these findings. As an example, the data from boring JH93-B-47 indicates that the moisture content of the Red Bed clay is only 7.8 per cent, the permeability is $7.66 \times 10^{-9}$, and the plastic limit is 23 per cent. This information suggests that the clay is very dry, impermeable, and in a semi-solid state. Laboratory samples of the Red Bed Unit clay from several other borings indicate similar results.

Second, the top of the Red Bed Unit was traced across relatively constant, subhorizontal resistivity contours for the most part. Any slight variations in resistivity are due to changes in local conditions, such as thickness changes in the overlying units, slight changes in the resistivity of the units, or small changes in water content. The subhorizontal character and the relative changes from low resistivity materials above the Red Bed Unit, to higher resistivity materials within the Red Bed Unit remain a constant. Lateral variations in the actual resistivity values and contrasts may be apparent, but again, the relation between the low-resistivity unit above the Red Bed Unit and higher-resistivity Red Bed Unit holds.

Third, an analysis of the data indicated that the Red Bed Unit was continuous in all areas, with the possible exception of stations 1700 to 2050 on Line T4 that is designated "Electrically Resistive Area". This area is approximately 350 feet wide and represents a marked change in the resistivity structure of the units overlying the Red Bed Unit. There is a "break" in the continuity of the low-resistivity sands and gravels above the Red Bed Unit that may be due to a lateral change in materials, a decrease in water content, or an obliquely-oriented channel feature. There are reported occurrences of a very dry limestone unit, the Fort Terret Formation, within the Ogallala or Antlers Formations that is present sporadically throughout the site. This electrically-resistive unit may be the source, as well.

### *9.2 Formations Overlying The Red Bed Unit*

The E/R profiles indicate a distinct resistivity layering in the formations above the Red Bed Unit. The Blackwater Draw and the "Caprock" Caliche Formations appear to have a similar, and consistently high resistivity character along the E/R survey lines. Typically, they appear within zero to 20-35 feet bgs on the lines. There are some lateral elevation changes that can be discerned on the plots. The sands and gravels above the Red Bed Unit appear to have a slightly lower electrical resistivity profile. As stated earlier, this unit may have a slightly higher water content than either the overlying Blackwater Draw and "Caprock" Caliche Formations, or the underlying Red Bed Unit. It is possible to ascertain areas of varying thickness on the E/R profiles.

The E/R data indicated the presence of areas of decreased resistivity within the sands and gravels above the Red Bed Unit on Lines T1, and T4. These areas may indicate the existence of increased water saturation above the Red Bed Unit. It was critical to observe and compare the actual data points with the contoured results to ensure that a "thin" zone, such as the areas of increased water saturation, contained actual data points, rather than being a function of the contouring process.

### *9.3 Surface Depression*

Line T3 was collected directly over a subtle surface depression that was 8 to 10 feet below the surrounding plain. It is located from station 625 to station 1250 on the third panel in Figure 2. AGS noticed that low bushes, grasses, and vegetation were more prominent in this area than surrounding areas. The data from Line T3 indicated the presence of a low resistivity zone coincident with, and directly below the surface depression. It extends to a depth of approximately 15 feet bgs and covers a lateral distance of approximately 625 feet. It is apparent that this depression acts as a "catch zone" for rain and surface runoff, and it has affected the water content of the underlying sediments.

The surface depression is significantly larger than the buffalo wallow that was detected along Line T1. Both areas indicate the presence of lower resistivity materials in the shallow subsurface, which may be due to an increase in water content. The increase in vegetation and grasses in both areas would support this assumption.

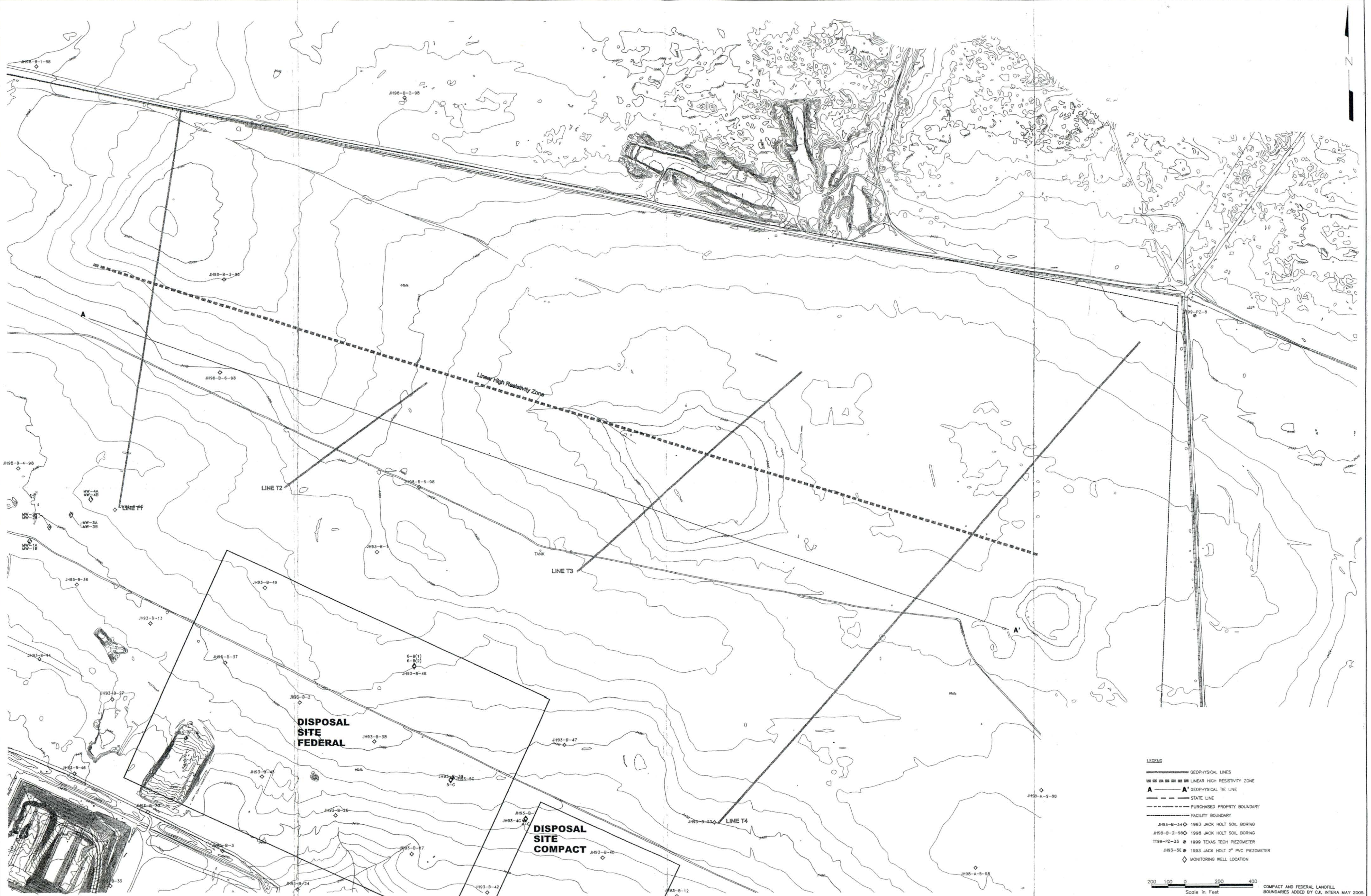
### *9.4 Linear High Resistivity Zone And Interpreted Clay Unit*

AGS detected a deep, linear high resistivity zone on lines T1, T3, and T4. The trace of this feature is shown on Figure 1, and the electrical images are present on Figure 2. This zone is characterized by a significantly higher electrical resistivity, relatively abrupt flanks, and a uniform width of approximately 250 feet. Furthermore, it appears to extend beyond the depth limits of this investigation. The alignment of the Linear High Resistivity Zone connects two surface depressions within the survey area, a third depression to the north of Baker Spring, and several depressions to the east of our survey area. The nature of the Linear High Resistivity Zone is uncertain, however, it appears to be coincident with a series of surface depressions.

The Linear High Resistivity Zone appears to cut through a very low resistivity, horizontal-to-subhorizontal layer that is located at a depth of approximately 130-210 feet bgs. This layer coincides with gronndwater elevation data obtained from Terra Dynamics Incorporated, Figure VI.A.24, Cross-Section A-A', boring 11-D, and boring JH93-B-48 that shows groundwater at a depth of approximately 150-190 feet bgs. AGS believes that the very low resistivity values (10 Ohm-m) are due to the presence of saturated clays or sands, as opposed to the dry clays that are associated with the Red Bed Unit.

## *10.0 Data Quality*

The E/R data quality was excellent for this project. The inverse model resistivity sections exhibited very low RMS errors in the computations, and the data was very consistent, and continuos along the lines. AGS used a few existing borings to constrain the models where possible. Unfortunately, the GPR data did not penetrate more than 10-15 feet bgs and the data did not add to the final site interpretation.




| NO. | DATE | APPR. | REVISION | NO. | DATE | APPR. | REVISION |
|---|---|---|---|---|---|---|---|

**PMC Environmental**
**WCS Andrews Site**
**Andrews County, Texas**
**June 25, 2001**

ADVANCED GEOLOGICAL SERVICES

| CHECKED | DATE |
|---|---|
| DESIGN ENGINEER | |
| PROJECT GEOLOGIST | |
| PROJECT MANAGER | |
| APPROVED | |
| APPROVED | |

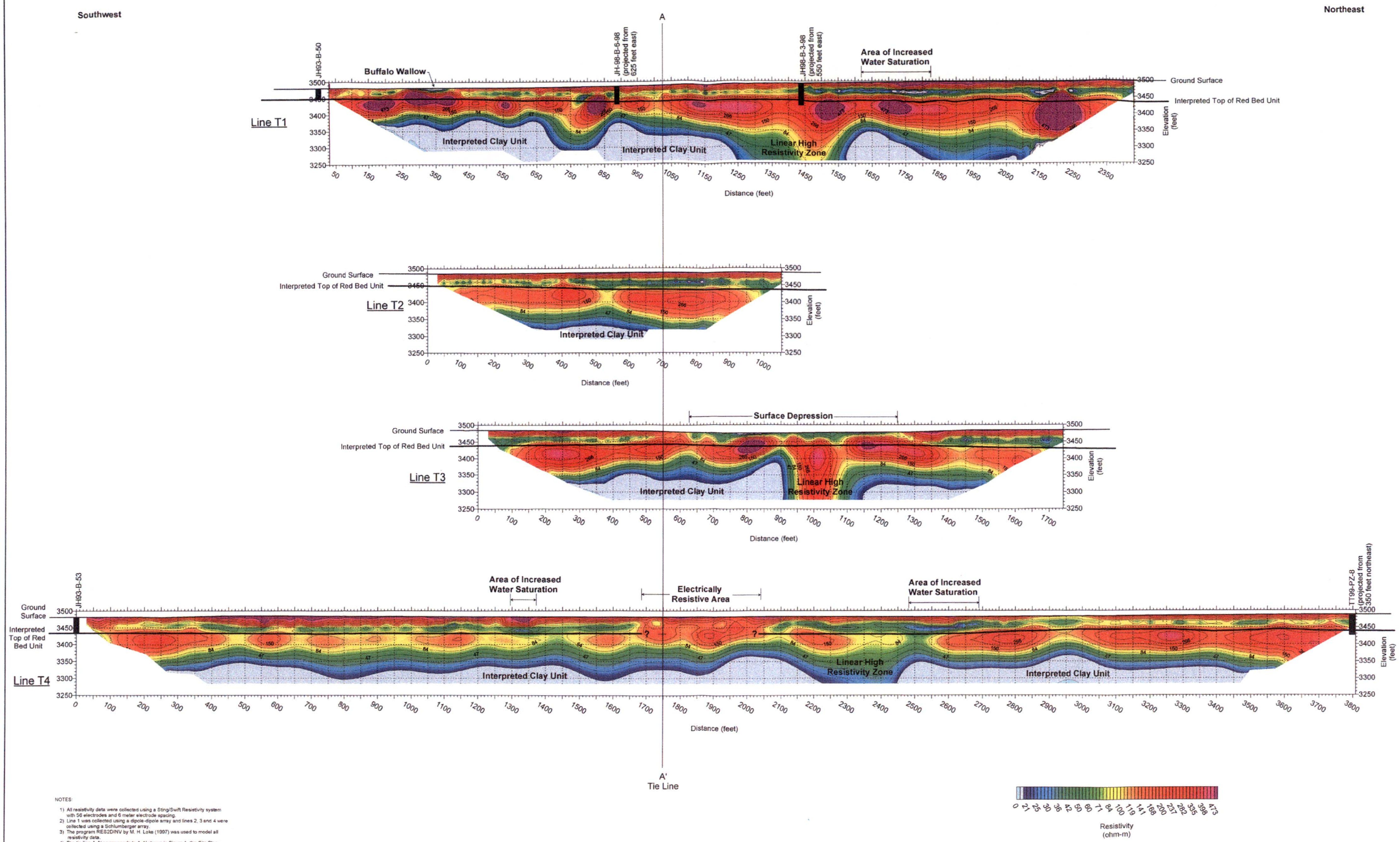
**Figure 1**
**Site Map and Geophysical Line Location**

| DRAWN MK BOND/MKB | DATE 03.27.01/06.25.01 | CLIENT APPROVAL | |
|---|---|---|---|
| SCALE 1" = 200' | W.O. No. 29000.01/1409/1C | ISSUED FOR | DATE |

DRAWING NO.

REV. NO.

SHEET OF




NOTES:

1) All resistivity data were collected using a Sting/Swift Resistivity system with 56 electrodes and 6 meter electrode spacing.
2) Line 1 was collected using a dipole-dipole array and lines 2, 3 and 4 were collected using a Schlumberger array.
3) The program RES2DINV by M. H. Loke (1997) was used to model all resistivity data.
4) The tie line A-A' corresponds to A-A' shown in Figure 1, the Site Plan.
5) The trace of the "Linear High Resistivity Zone" is shown in Figure 1.

| Figure 2<br>Electrical Resistivity Models<br>AGS Lines T1, T2, T3 and T4<br>Red Bed Unit Survey | PMC Environmental<br>WCS Andrews Site<br>Andrews County, Texas | June 25, 2001 | ADVANCED GEOLOGICAL SERVICES |
| --- | --- | --- | --- |