

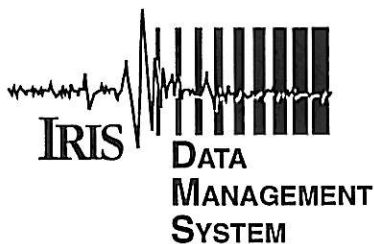
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Seismic Imaging in the Skunk Canyon and Fox Glen areas of
Flagstaff, Arizona

Submitted By

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U.S. Geological Survey

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INTRODUCTION

This report presents data and acquisition parameters for seismic surveys in the Skunk Canyon and Fox Glen areas of Flagstaff, Arizona. The data were acquired in July, 1996, as part of a program to image faults and fractures in search of usable water supplies for the City of Flagstaff.

Water supplies for the City of Flagstaff are derived from a regional aquifer using deep (~300 to 600 m) wells. In the Flagstaff area, the top of the regional aquifer occurs within the Coconino Sandstone or Supai Group at depths between about 300 m and 530 m (900 ft and 1600 ft) below ground surface (bgs) (Don Bills, pers. comm., 1995). Due to low permeability of the aquifer rocks, many water wells previously sited by the City do not yield enough water to justify the appreciable cost of drilling.

Study of existing water wells in the Flagstaff area shows that the most productive wells are located where permeability has been increased by significant faulting and fracturing of subsurface rocks. In 1994, at the request of the City of Flagstaff, scientists from the U.S. Geological Survey (USGS) began a program of geologic mapping to locate areas that have a high density of faults and/or fractures at the surface (Gary Mann, pers. comm., 1995). Three of the highest priority areas were identified by the City of Flagstaff in eastern and southern Flagstaff. In this report, we refer to those areas as: (1) the Bottomless Pits (Continental) area, (2) Skunk Canyon, and (3) Fox Glen (Figs. 1A and 1B). This report focuses on the Skunk Canyon and the Fox Glen areas. A separate report for the Bottomless Pits (Continental) area is given by Catchings et al. (1997).

Because each of the preferred sites lies within an alluvial basin, the location and complexity of faulting was not known from surface mapping. Furthermore, at sites with significant surface faulting, the locations of highly fractured and faulted rocks are generally different at the surface than at the depths of the regional aquifer (Fig. 2). For these reasons, the USGS acquired seismic reflection and refraction data during July, 1996, at each of the high-priority sites. In August and September, 1996, City of Flagstaff engineers located wells, in part, on the basis of fault and fracture patterns imaged in the seismic sections. At the time of the writing of this report, wells are being drilled at each of the sites. Preliminary indications are that the rocks are highly fractured at the depths of the regional aquifer in a manner similar to that imaged by the seismic techniques.

GEOLOGY

As described by Blakey (1990), the Pennsylvanian and Permian stratigraphy of Northern Arizona consists of the Supai Formation, Schnebly Hill Formation, Coconino Sandstone, Toroweap Formation and the Kaibab Formation.



Figure 1A. Landsat satellite image of the Flagstaff, Arizona area with locations of study areas.

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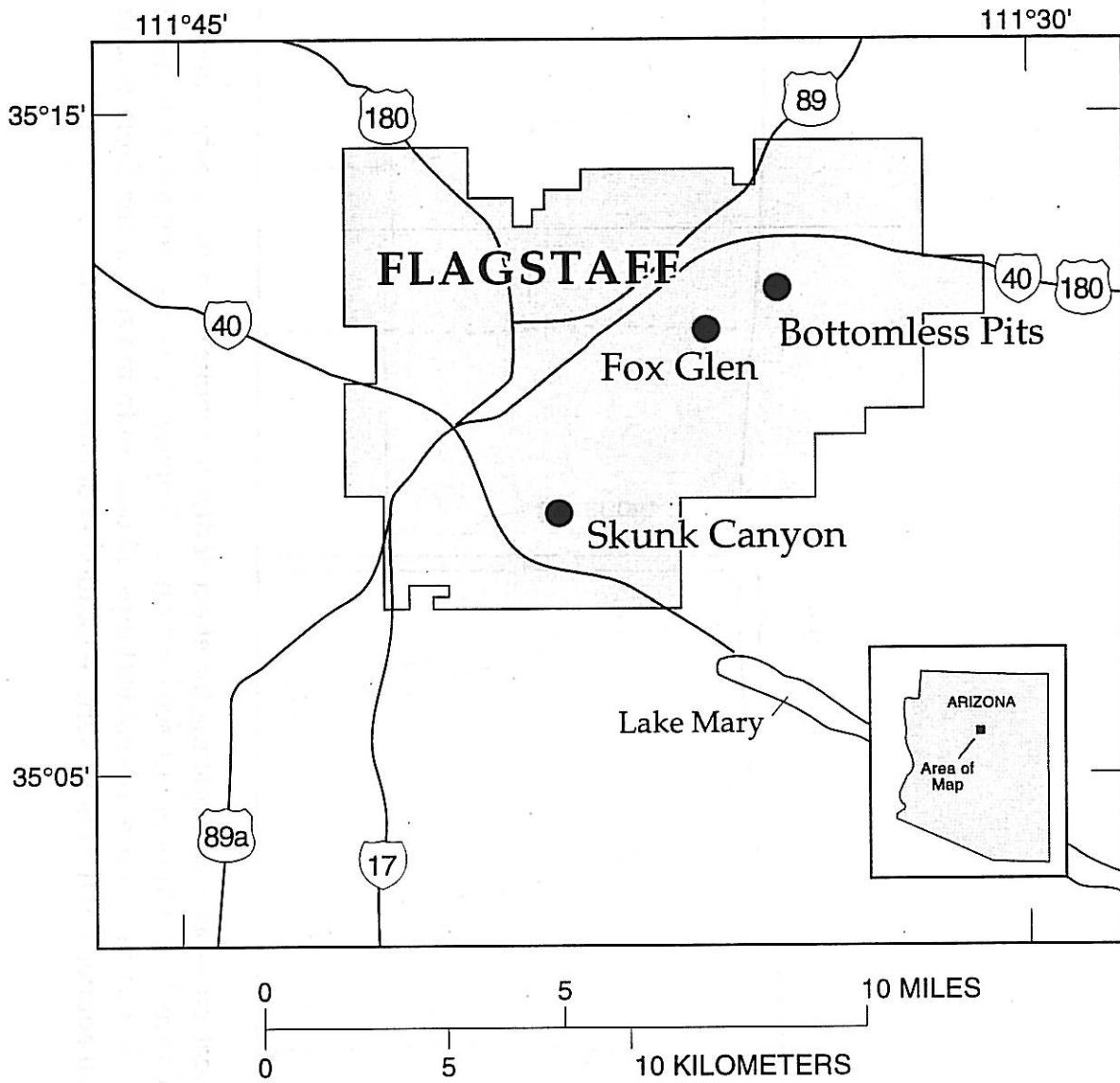


Figure 1B. Map of the Flagstaff, Arizona area and locations of study areas.

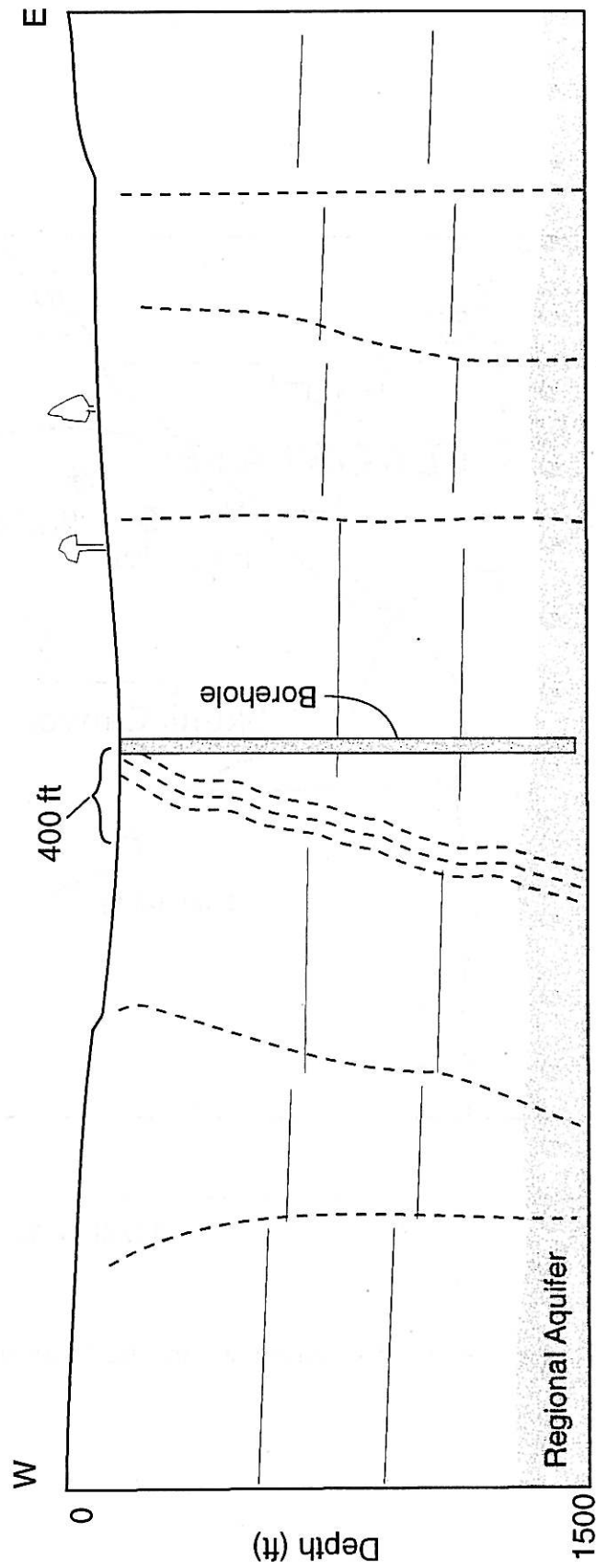


Figure 2. Hypothetical cross section depicting the effect of dipping faults/fractures (dashed lines) in locating drill sites. If vertical wells are drilled into the surface locations of dipping faults, the well may not intersect the fractured part of the aquifer. For a fault/fracture system that dips 15 degrees from vertical, the fault/fracture system would intersect the regional aquifer 400 ft from its surface location at depths of 1500 ft.

Setting of the Skunk Canyon area

The Skunk Canyon area (Figs. 1A, 1B), located about 4.5 km south-southeast of downtown Flagstaff, lies at the intersection of two topographic depressions (Fig. 3). The depressions are oriented NE-SW and NW-SE and contain a thin (<10 m) infilling of sediments. Kaibab Limestone, which is exposed at the surface on the adjacent hills, underlies the infill and is in turn underlain by Coconino Sandstone or Supai Group.

The Skunk Canyon area is considered an ideal site for water exploration because 1) it is located in the flow direction of the regional aquifer, 2) it lies at the intersection of two topographic depressions, suggesting abundant faulting and fracturing, and 3) the depth to the regional aquifer in this area is estimated to be less than 300–400 m (900–1200 ft) bgs. The elevation along the seismic lines varies by less than ~30 m (90 ft).

Setting of the Fox Glen area

The Fox Glen area, located about 5.5 km east of downtown Flagstaff (Figs. 1A, 1B), also lies at the intersection of two sediment-filled, topographic depressions that contain a thin sediment infilling (Fig. 4). The depressions are oriented NE-SW and NNW-SSE. The Rio de Flag, one of the major surface-water drainages in Flagstaff, flows through the NE-SW-oriented depression. Alluvial fill within the depressions is commonly less than 35 m thick. Kaibab Limestone, exposed at the surface on the adjacent hills, underlies the sediment infill. In the Fox Glen area, the regional aquifer occurs within the underlying Coconino Sandstone or Supai Group.

The Fox Glen area is considered an ideal site for water exploration for the same reasons cited above for Skunk Canyon, but the estimated depth to the regional aquifer is between 400–500 m (1200–1500 ft) bgs. The elevation along the seismic lines varies by ~35 m (105 ft).

SEISMIC ACQUISITION TECHNIQUES

Geologists and geophysicists from the USGS employed several other geophysical techniques at the high-priority sites, including gravity measurements, ground-penetrating radar, and square-array resistivity, but due to the depths of the regional aquifer and the resolution needed, city of Flagstaff officials also chose to use seismic-reflection techniques. We simultaneously acquired seismic reflection and refraction data to minimize the cost and maximize our understanding of the subsurface. With narrow targets such as faults and fractures, vertical water wells have to be sited within a few meters of the intersection of the fault/fracture system and the water table (Fig. 2). Seismic reflection methods are the best of the available geophysical methods to achieve the required resolution at the depth of the regional aquifer.

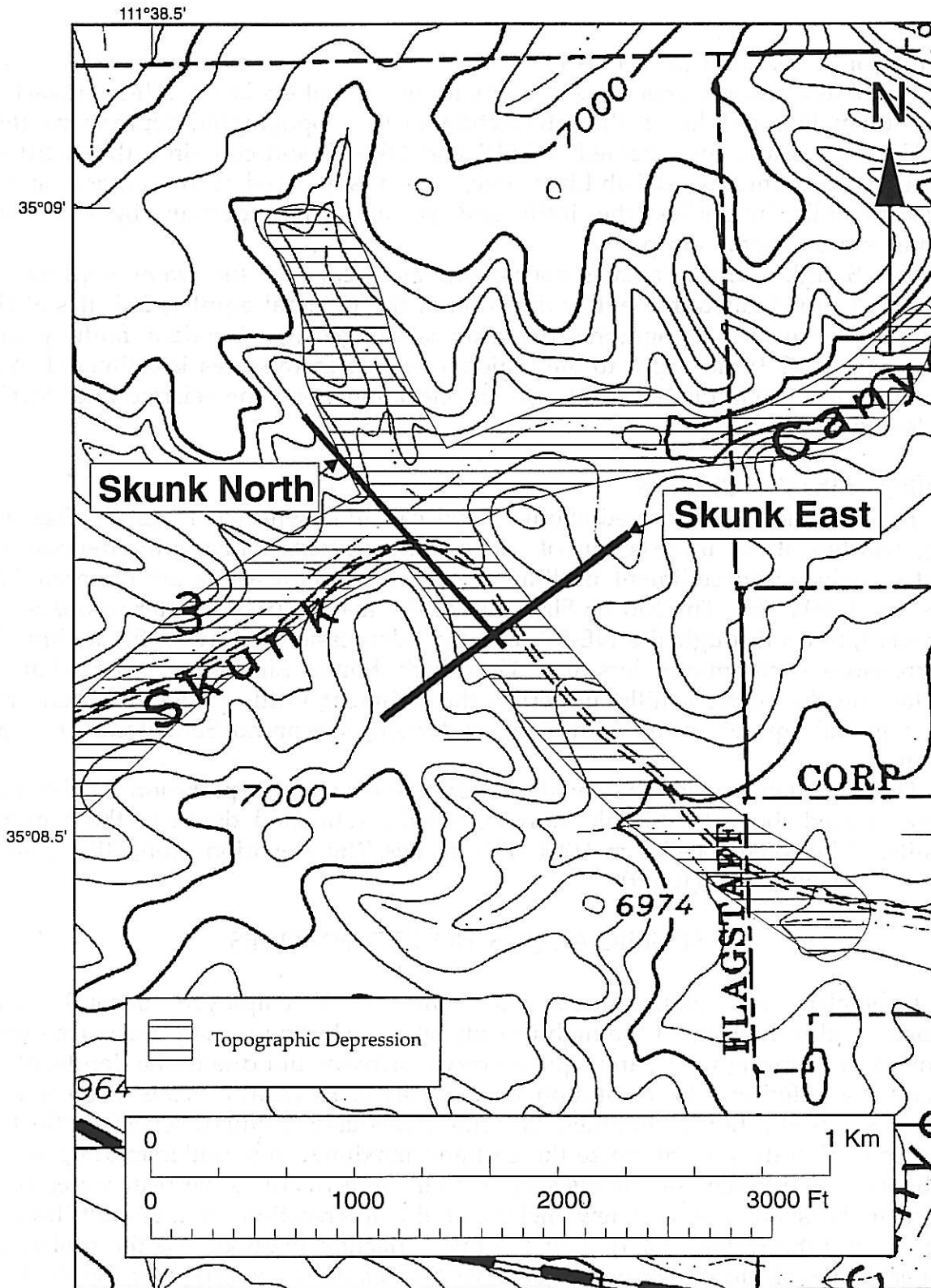


Figure 3. Topographic map of the Skunk Canyon area showing location of seismic lines (solid lines) and topographic depressions (striped areas). Contours in feet above sea level; contour interval is 20 ft.

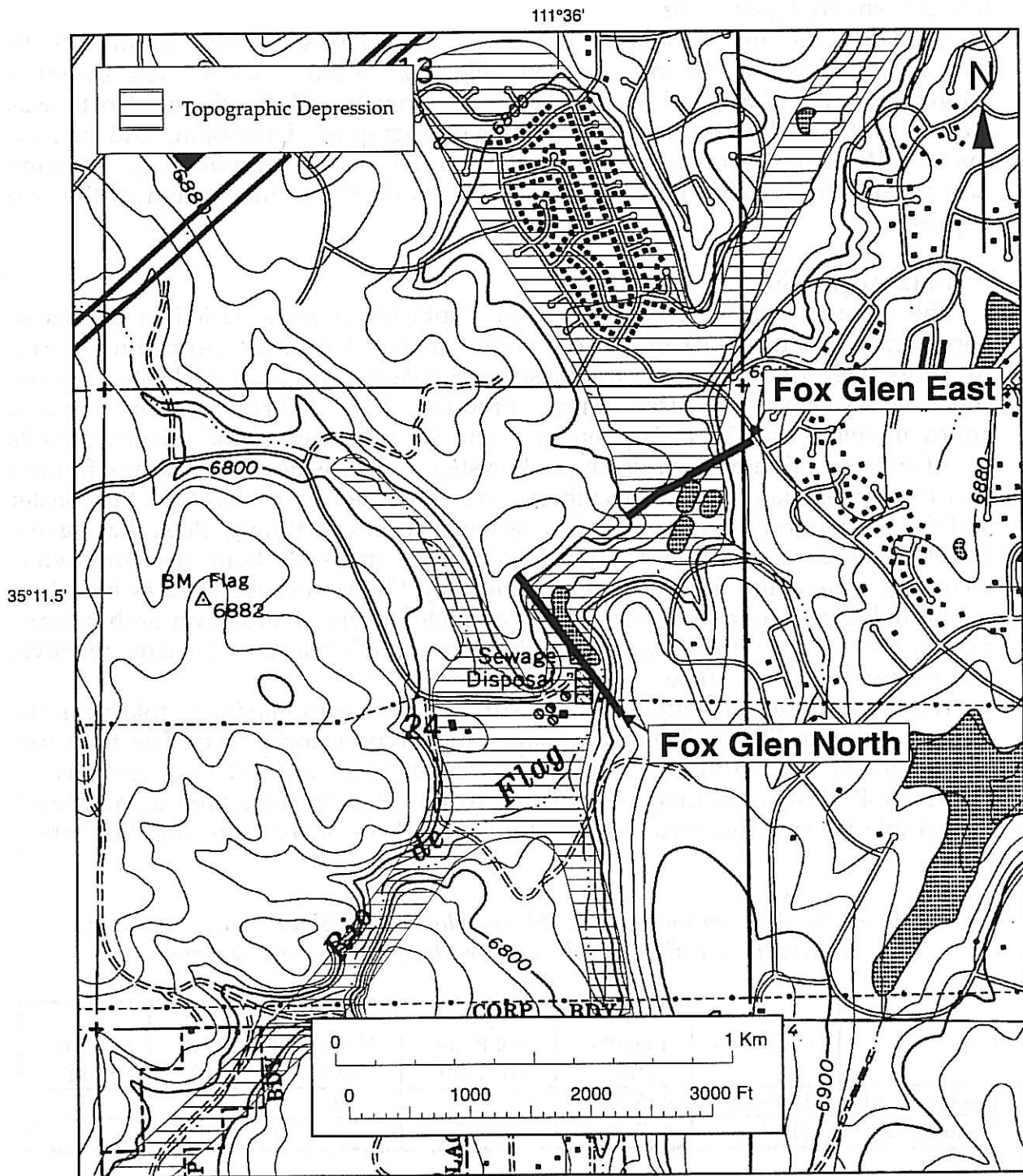


Figure 4. Topographic map of the Fox Glen area showing the locations of the seismic lines, topographic depressions, and cultural features. Contours in feet above sea level; contour interval is 20 ft. Dark-shaded areas are man-made lakes or ponds.

SEISMIC SURVEYS

Skunk Canyon Seismic Survey

The USGS acquired data along two perpendicular seismic lines (Skunk North and Skunk East) at Skunk Canyon (Fig. 3). Skunk North was oriented approximately NW-SE, and Skunk East approximately NE-SW. Skunk North was located partly within the NW-SE-trending topographic depression, and crossed the NE-SW depression near the intersection of the two depressions (Fig. 3). Skunk East crossed the NW-SE-trending depression south of the intersection of the two depressions.

Data Acquisition

The seismic data were acquired using explosive sources buried to depths of approximately 3 m (10 ft) and spaced approximately 5 m apart (Appendix A and B). Shots were fired using electric blasting caps detonated with a USGS-designed shooting system. We used Mark Products L-40 (40-Hz) sensors, spaced approximately every 2.5 m (Appendix A and B) and recorded the seismic records on a Geometrix Strataview seismograph system. The seismograph was configured as a 180-active-channel system with sensors connected by cable. Both the blaster and the seismograph were controlled by a synchronized timing clock that gave a 1-volt pulse at each minute. The 1-volt pulse triggered both the Strataview recording system and the blaster simultaneously. Shots were recorded as field files in chronological order; and acquisition parameters were recorded on each seismic record. We used 4-mm tapes to store the data in SEG-Y format for later retrieval and processing in the office.

We used a "shoot-through" seismic survey in order to maximize fold near the centers of the profiles and to obtain tomographic-type velocity data. The total line lengths for Skunk North and Skunk East were 445.3 m and 442.5 m, respectively. A total of 47 shots were fired along Skunk North; 52 shots were fired along Skunk East (Table 1). Each shot was recorded for 5 seconds using a 0.5-ms sampling rate.

Table 1. Acquisition parameters for Skunk North and Skunk East. Distances are relative to the first geophone of each of the recording arrays

	Orientation	Total Length (m)	Length of Shot Point Array (m)	No. of Shots	No. of CDP's	Maximum Fold
Skunk North	NW-SE	445.34	243.39	47	320	47
Skunk East	NE-SW	442.49	257.12	52	323	52

Skunk Canyon Locations

Skunk North

Prior to data acquisition, shot and receiver locations were determined using a measuring tape and compass. Shot holes were then drilled using a 2-inch-diameter drill bit. Recording sites were determined to maintain a 1-m distance from the shot line. After the data were acquired, shot and sensor locations were more precisely determined using an electronic distance meter. The locations (distance and elevation) were measured to within 0.001 m (Appendix A and B).

Skunk North was acquired using a single deployment of 180 geophones. The seismic array originated at the northwestern end of the profile and extended to the southeast. A plot of geophone elevation variations for Skunk North is shown in Figure 5. The relative elevations along the seismic line vary by approximately 15 m. Due to siting errors prior to drilling shot holes and due to obstacles (trees, standing water, etc.), the recording array did not form a perfectly straight line; however, geophone locations varied from a straight line (connecting the endpoints) by not more than 3.5 m along the approximately 445-m-long profile (Fig. 6).

Shot points were not located along the first and last ~100 m of the seismic line. Figure 7 shows shot point elevation as a function of distance along Skunk North. Because shot points were located prior to making electronic measurements, the line of shot points also varied from a straight line. There was about 3 m variance from a straight line along the approximately 245-m-long array of shots (Table 1, Fig. 8). We estimate that these variations in locations lead to an error in depth and location within the subsurface of less than about 2 m.

Skunk East

Skunk East was acquired using a single deployment of 180 geophones that originated at the northeastern end of the line (Fig. 3). The elevation of the recording sites varied by about 24 m along the seismic profile (Fig. 9, Appendix B). Relative to a line connecting its endpoints, geophone locations varied from a straight line by 6.5 m along the approximately 440-m-long profile (Fig. 10).

Shot points were not located along the first and last ~93 m of the seismic line. Shot points varied in elevation along the seismic line by about 17 m (Fig. 11), and varied from a straight line by about 4 m along the approximately 260-m-long profile (Table 1, Fig. 12). We estimate that these variations in locations lead to an error in depth and location within the subsurface of less than about 2 m.

Fox Glen Seismic Survey

In the Fox Glen area, data were acquired along two seismic profiles referred to as Fox Glen North and Fox Glen East (Fig. 4). Fox Glen North had a NW-SE trend, approximately parallel to the NNW-SSE-oriented topographic depression and perpendicular to the NE-SW depression. Fox Glen East was oriented approximately ENE-WSW, crossing the NE-SW-trending depression at a 20° angle (Fig. 4).

Skunk North

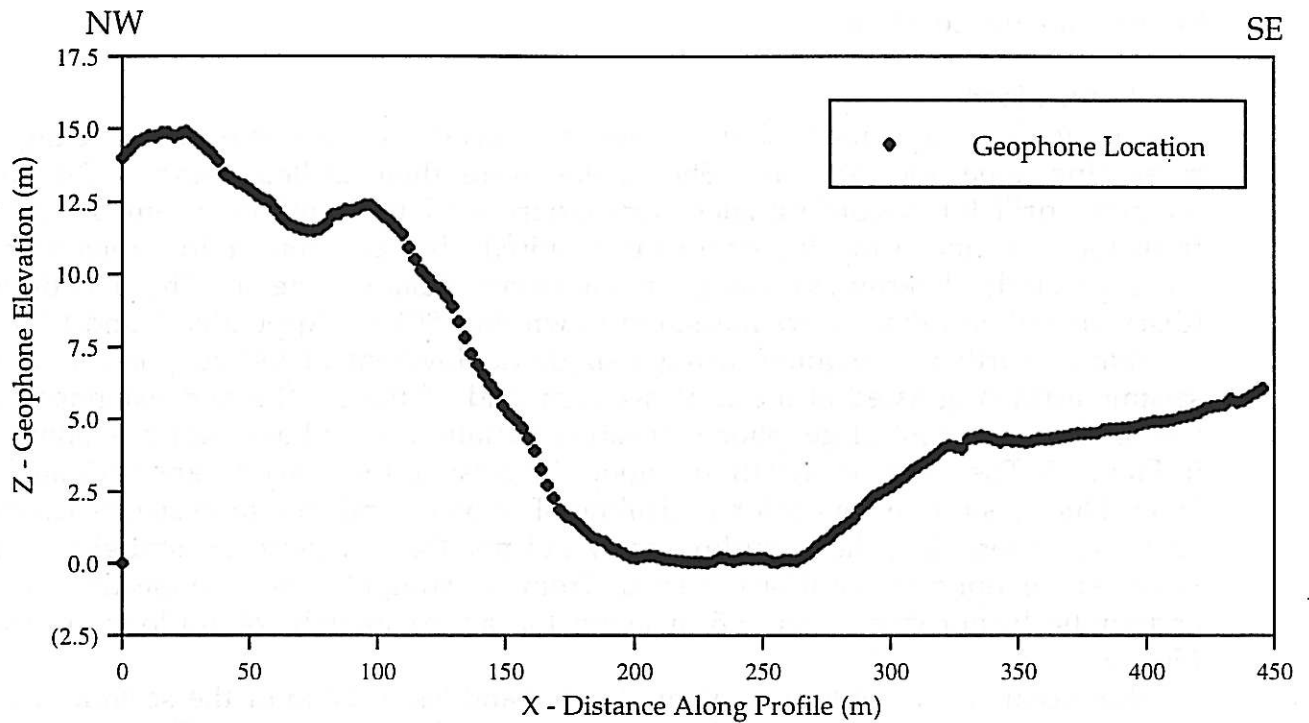


Figure 5. Relative geophone elevations as a function of distance along Skunk North. Elevation is relative to the topographically lowest geophone location. Distance is relative to the first geophone location on the northwestern end of the line.

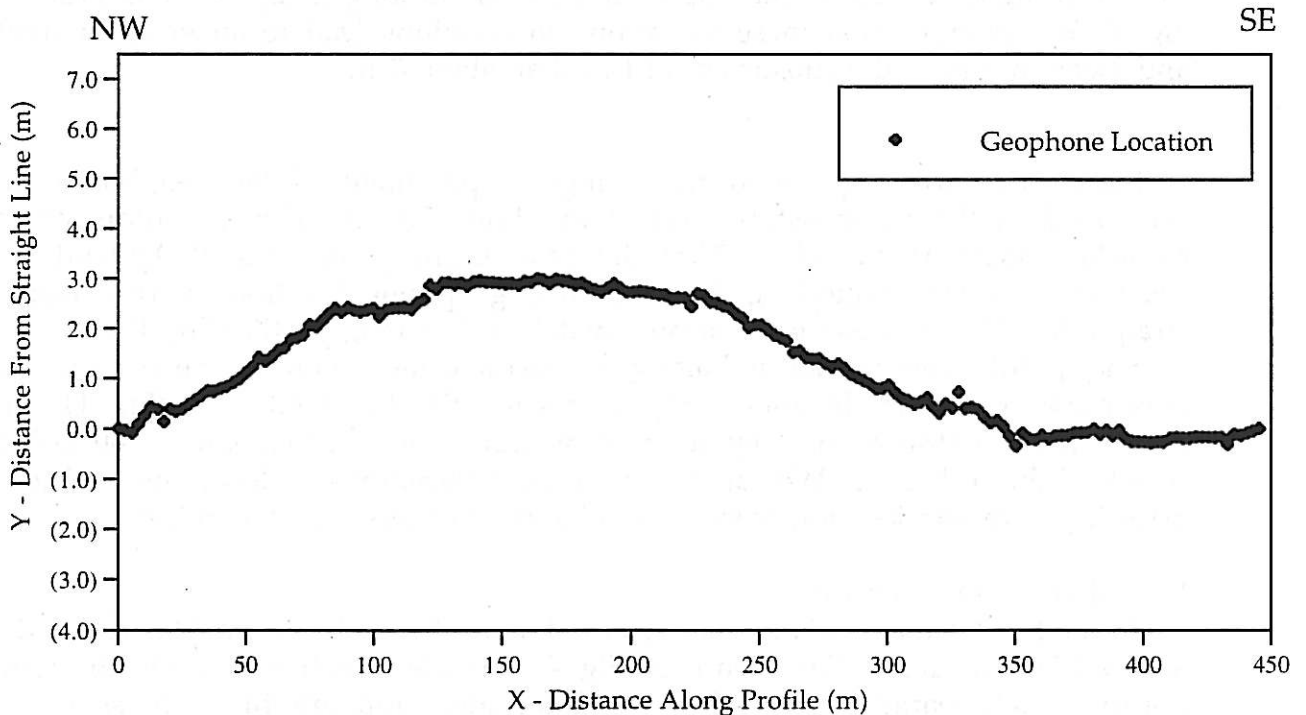


Figure 6. Geophone variation from a straight line connecting the first and last geophone along Skunk North.

Skunk North

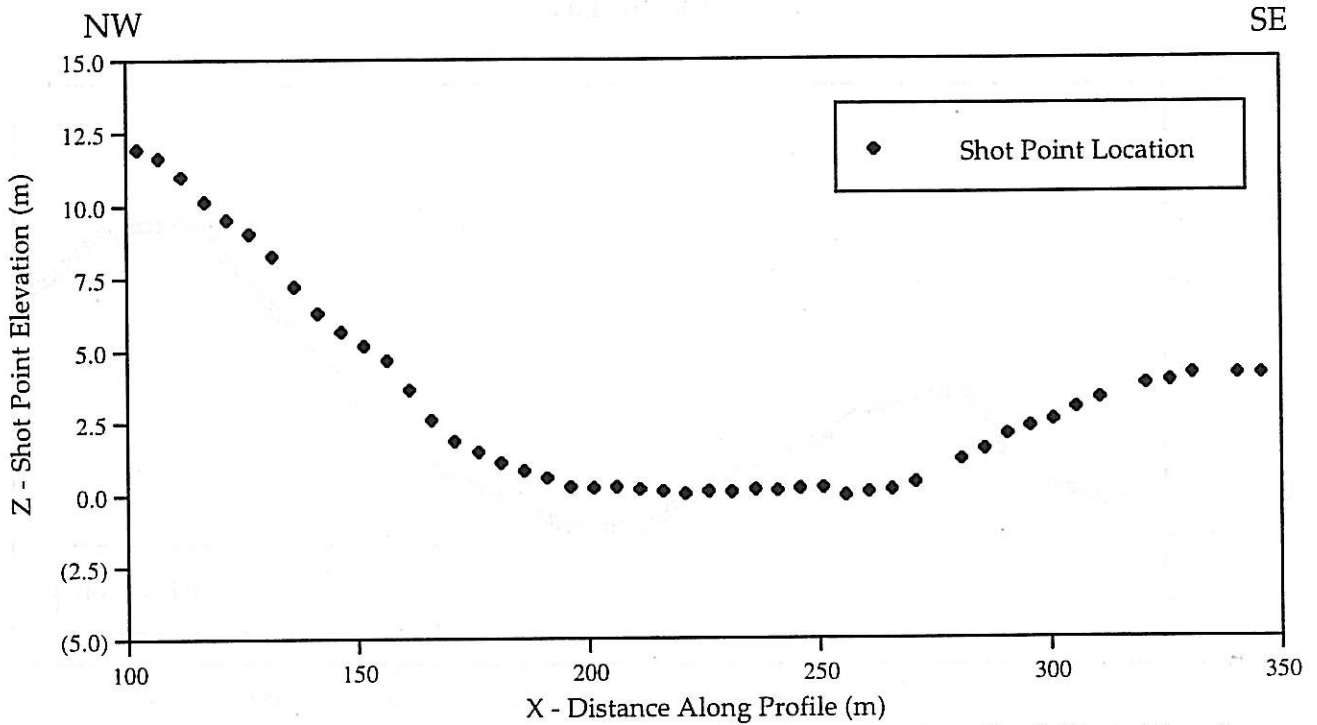


Figure 7. Relative shot point elevations as a function of distance along Skunk North. Elevation is relative to the topographically lowest geophone location. Distance is relative to the first geophone location on the northwestern end of the line.

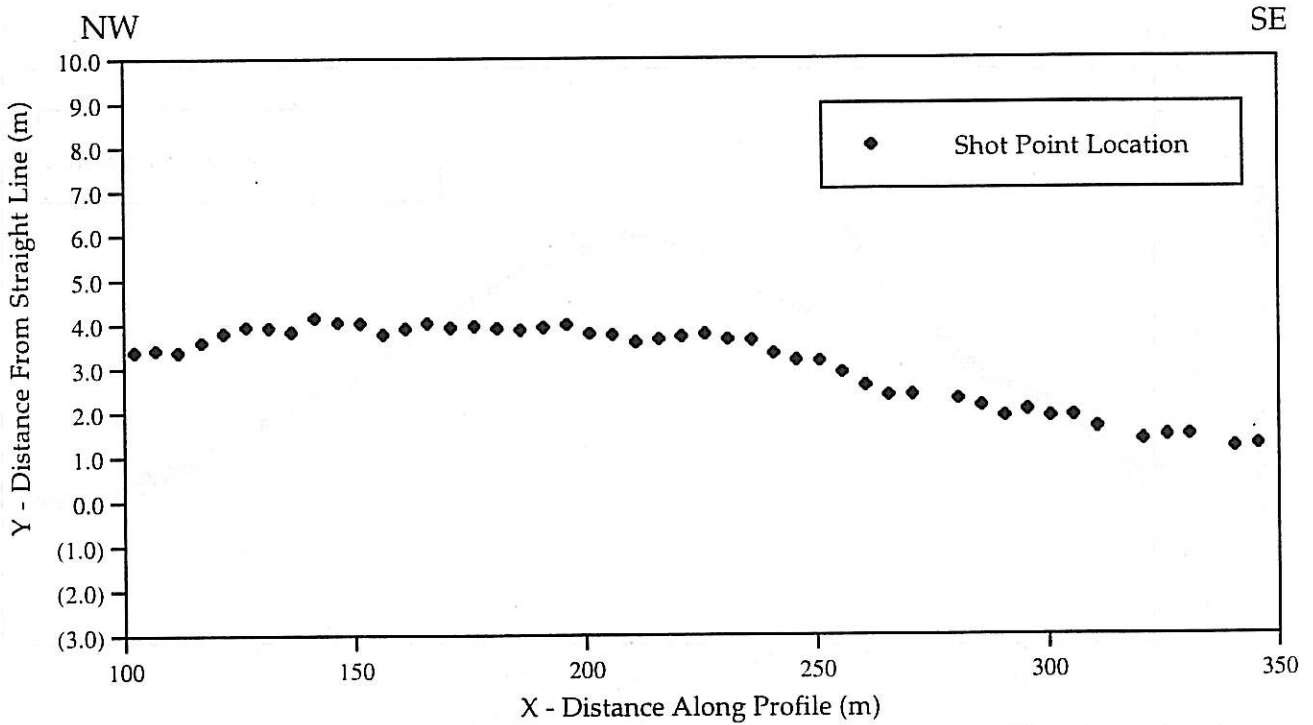


Figure 8. Shot point variation from a straight line connecting the first and last shot point along Skunk North.

Skunk East

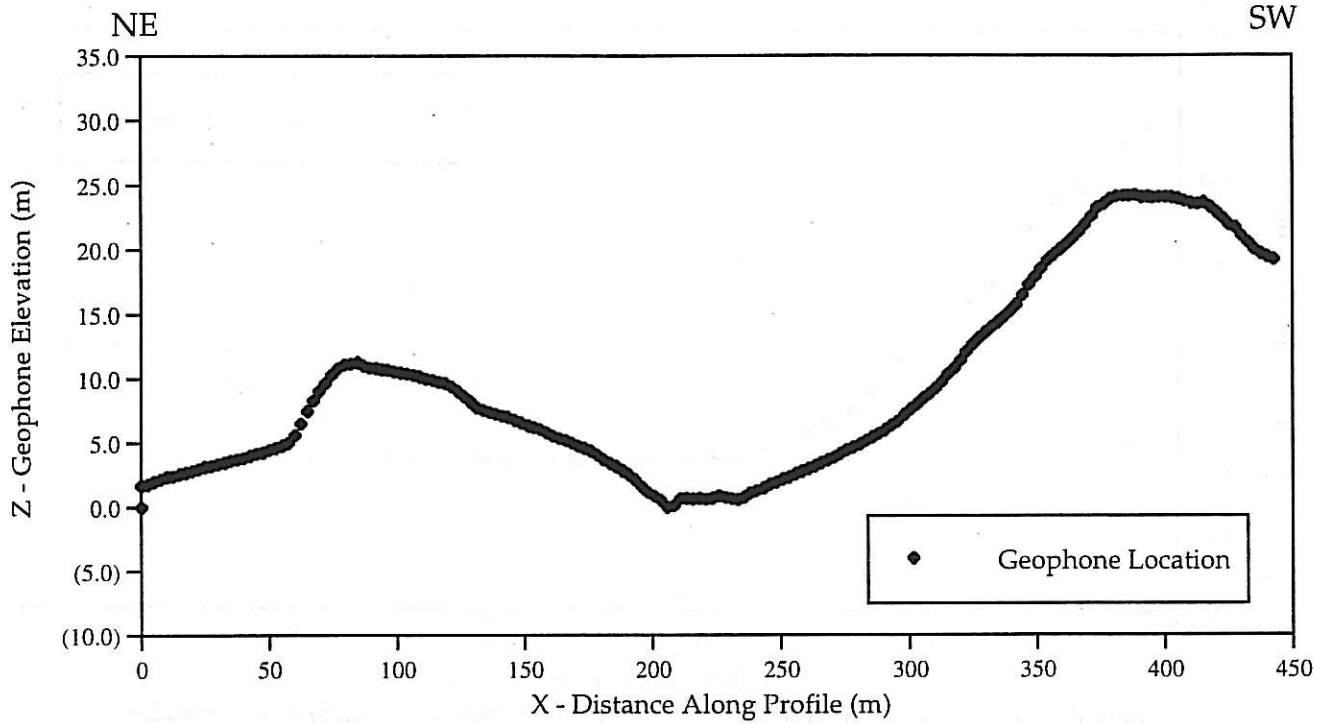


Figure 9. Relative geophone elevations as a function of distance along Skunk East. Elevation is relative to the topographically lowest geophone location. Distance is relative to the first geophone location on the northeastern end of the line.

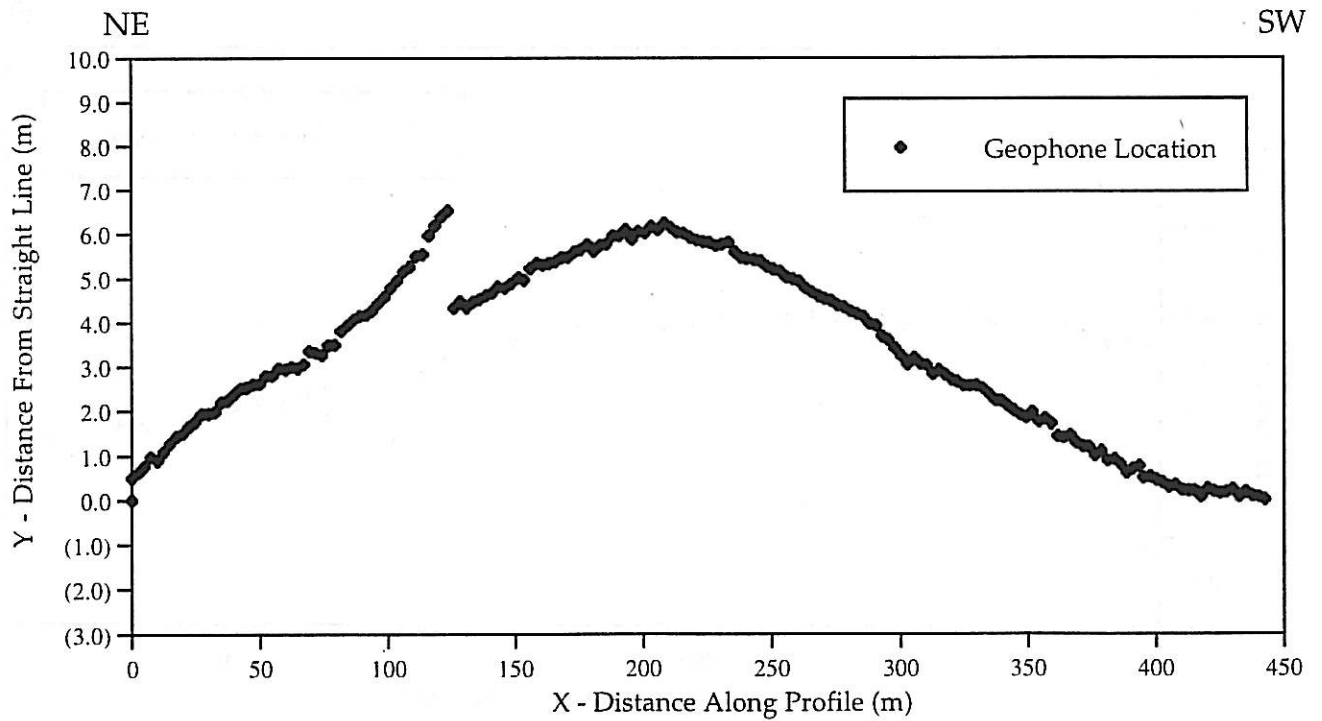


Figure 10. Geophone variation from a straight line connecting the first and last geophone along Skunk East.

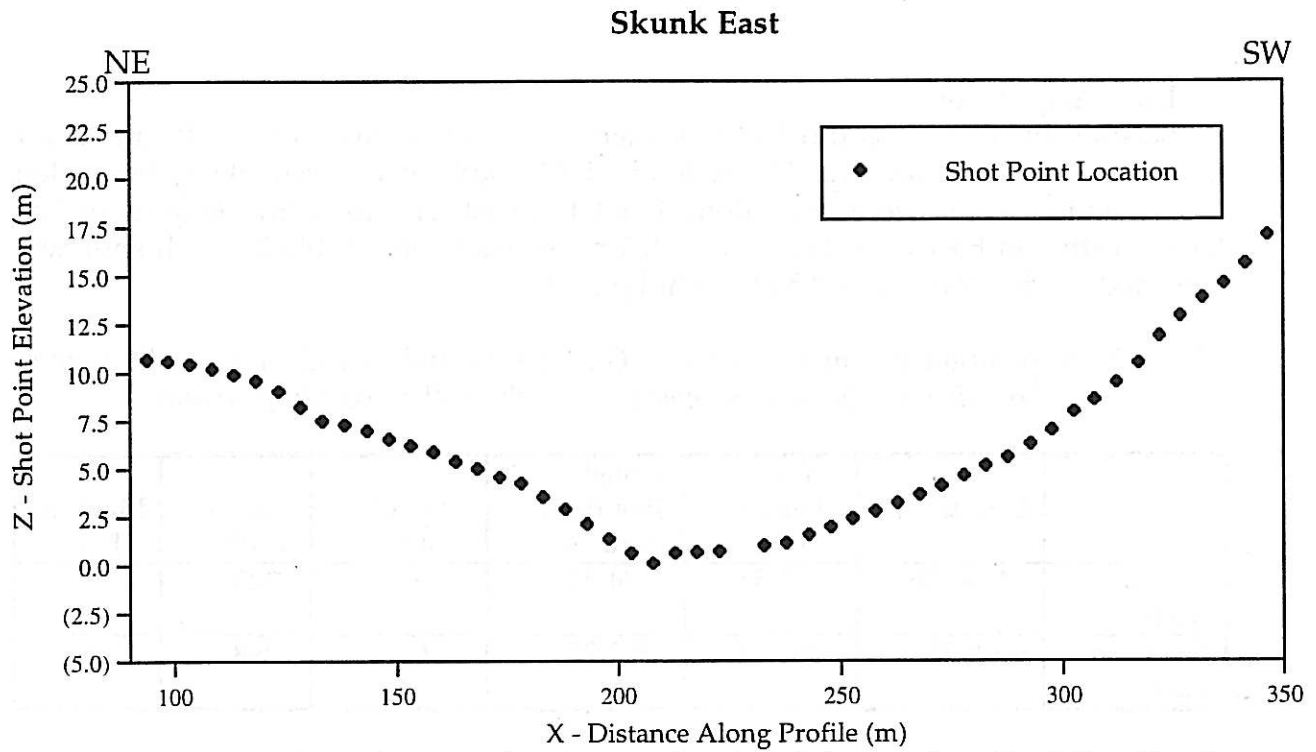


Figure 11. Relative shot point elevations as a function of distance along Skunk East. Elevation is relative to the topographically lowest geophone location. Distance is relative to the first geophone location on the northeastern end of the line.

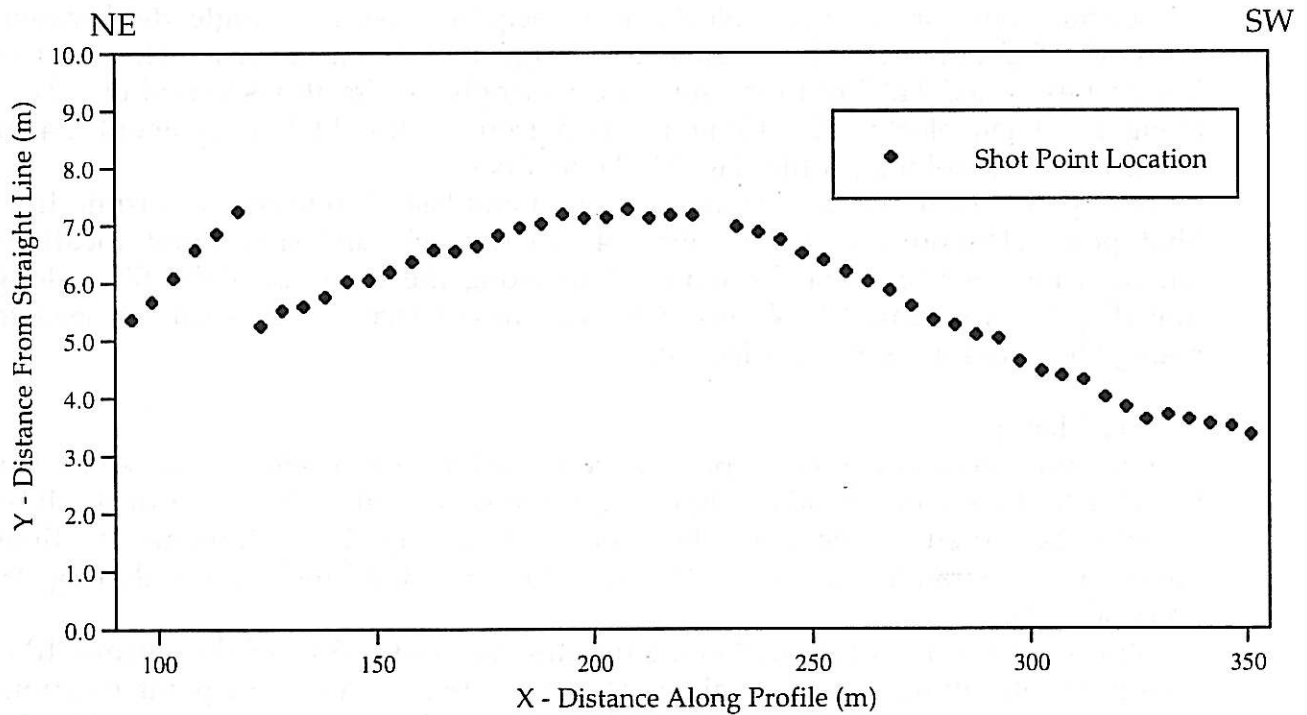


Figure 12. Shot point variation from a straight line connecting the first and last shot point along Skunk East.

Data Acquisition

Seismic data were acquired at Fox Glen in the same manner as described for the Skunk Canyon area (p. 11). A total of 54 shots were fired along Fox Glen North, and 61 shots were fired along Fox Glen East. The total line lengths of Fox Glen North and East were 442.5 and 368.5 m, respectively (Table 2). Each shot was recorded for 5 seconds at a 0.5 ms-sampling rate.

Table 2. Acquisition parameters for Fox Glen North and Fox Glen East. Distances are relative to the first geophone of each of the recording arrays

	Orientation	Total Length (m)	Length of Shot Point Array (m)	No. of Shots	No. of CDP's	Maximum Fold
Fox Glen North	NW-SE	442.51	274.21	54	323	54
Fox Glen East	ENE-WSW	368.45	322.75	61	298	61

Fox Glen Locations

Fox Glen North

Seismic data for Fox Glen North were acquired using a single deployment array of 180 geophones. The seismic line originated at the northwestern end of line and extended 442.5 m to the southwest. Geophone elevations varied by ~21 m along Fox Glen North (Fig. 13) and varied from a straight line by about 1.4 m along the 442.5-m-long profile (Fig. 14, Appendix C).

Shot points were not located along the first and last ~100 m of the seismic line. Shot point elevations varied by about 4.8 m (Fig. 15), and shot point locations varied from a straight line by about 0.5 m along the approximately 275-m-long line (Fig. 16, Appendix C). We estimate that these variations in locations lead to negligible errors in depth and location.

Fox Glen East

One hundred and eighty geophones were used to record seismic data along Fox Glen East. The seismic profile originated at the east-northeastern end of the line. Geophones varied in elevation by about 13.7 m (Fig. 17); geophone locations varied from a straight line by about 1.4 m along the 368.5-m-long profile (Fig. 18, Appendix D).

Shot points were not located along the first and last ~93 m of the seismic line. Shot point elevations varied by about 11 m (Fig. 19), and the shot point locations varied from a straight line by about 1 m along the 323-m-long line (Fig. 20, Appendix D). We estimate that these variations in locations lead to negligible errors in depth and location.

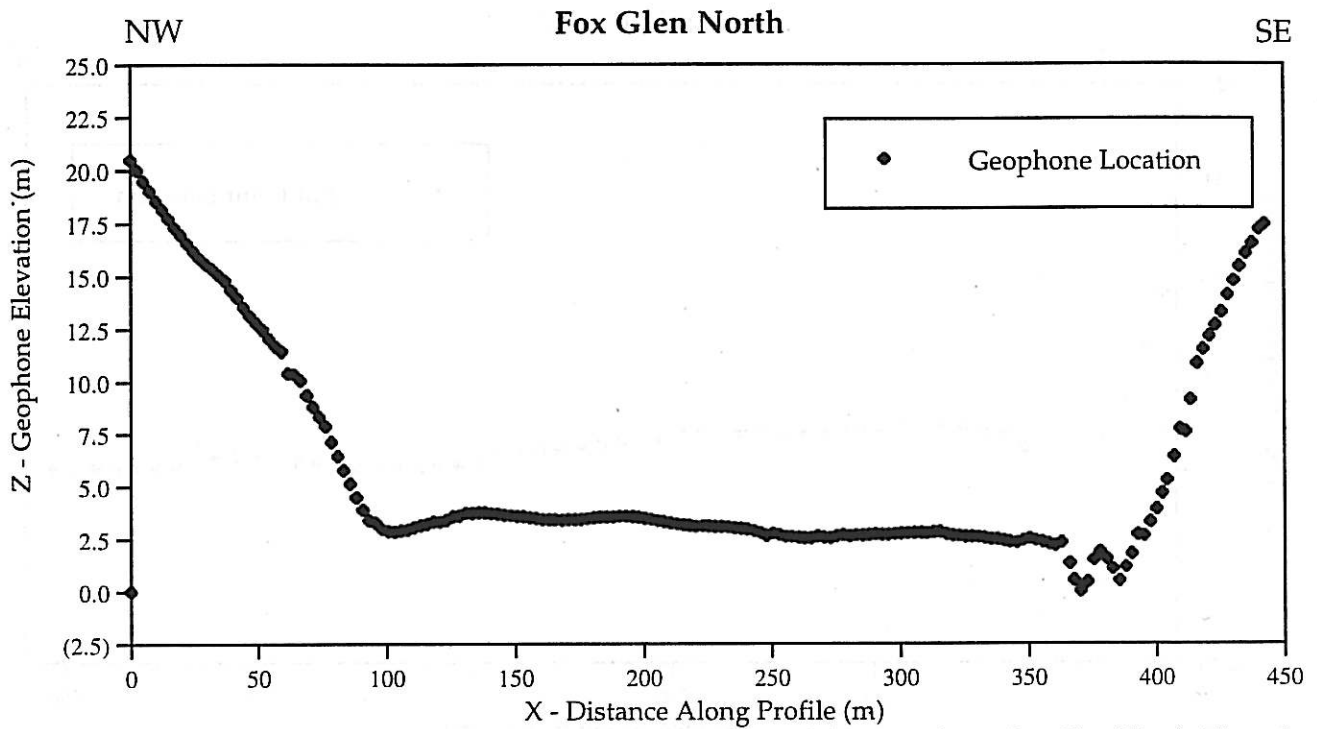


Figure 13. Relative geophone elevations as a function of distance along Fox Glen North. Elevation is relative to the topographically lowest geophone location. Distance is relative to the first geophone location on the northwestern end of the line.

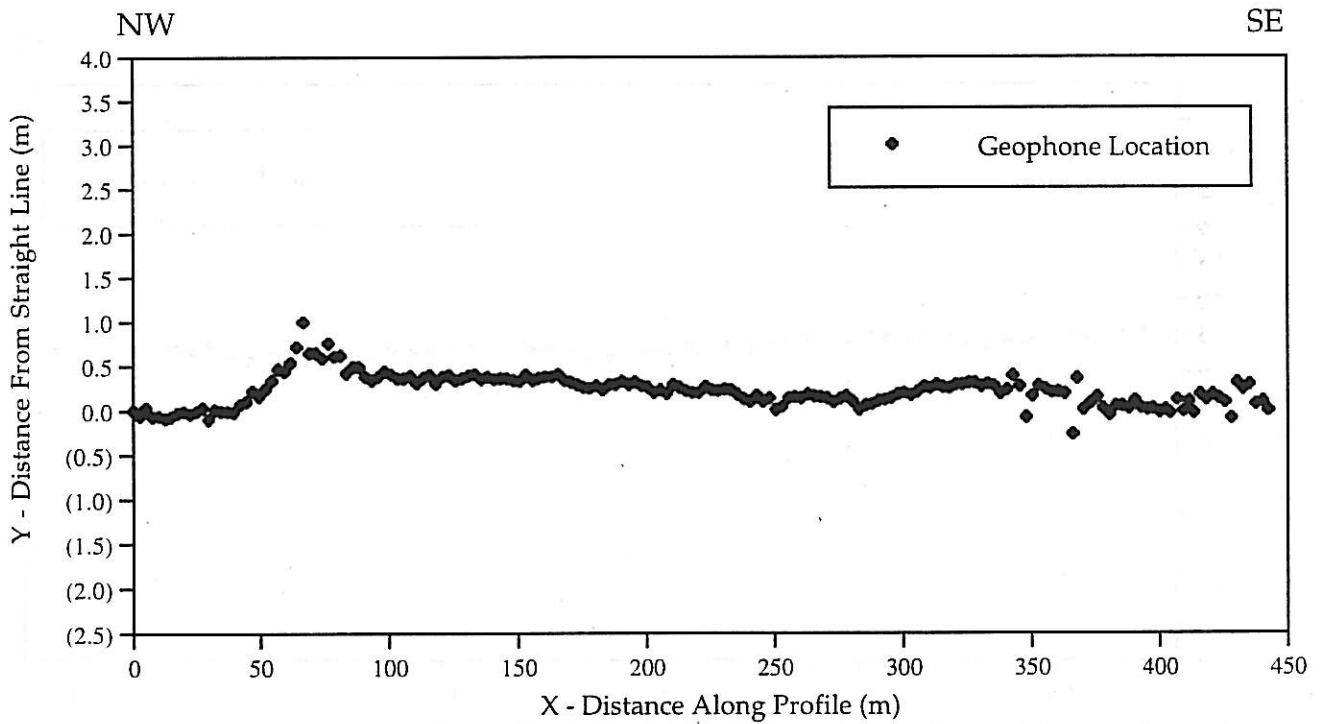


Figure 14. Geophone variation from a straight line connecting the first and last geophone along Fox Glen North.

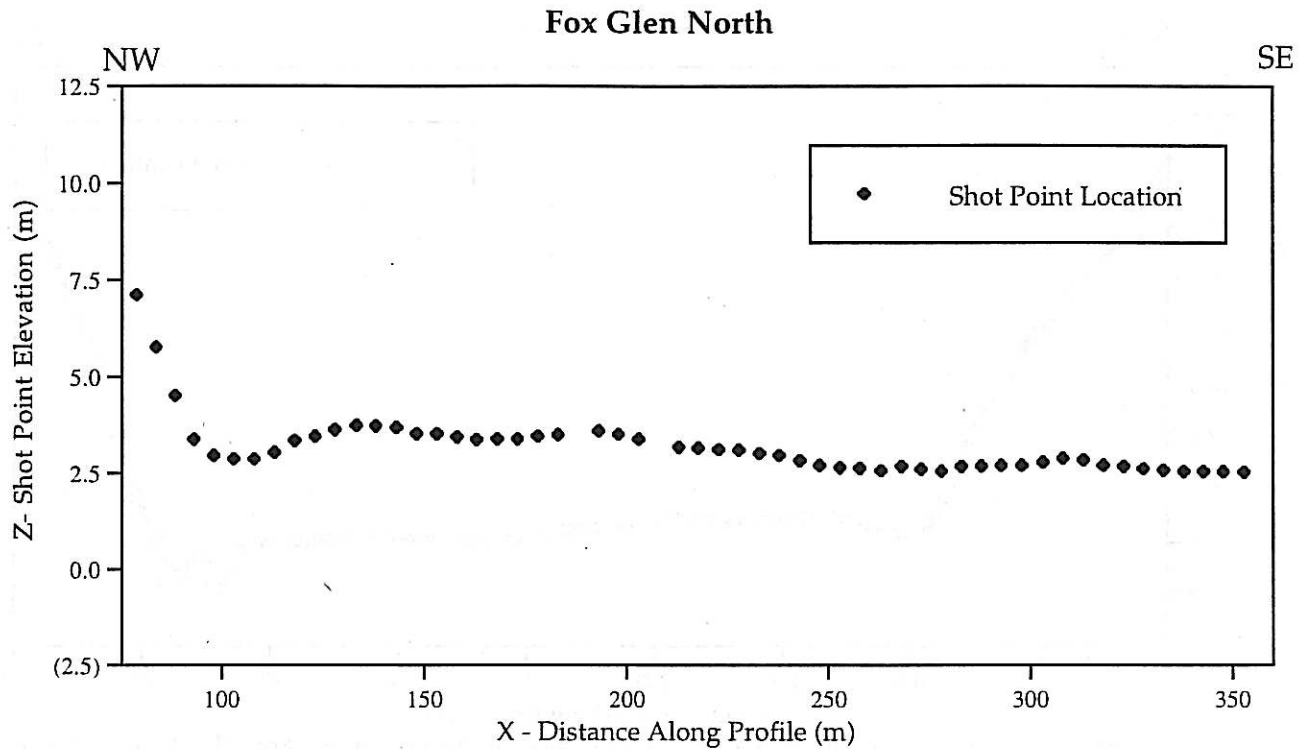


Figure 15. Relative shot point elevations as a function of distance along Fox Glen North. Elevation is relative to the topographically lowest geophone location. Distance is relative to the first geophone location on the northwestern end of the line.

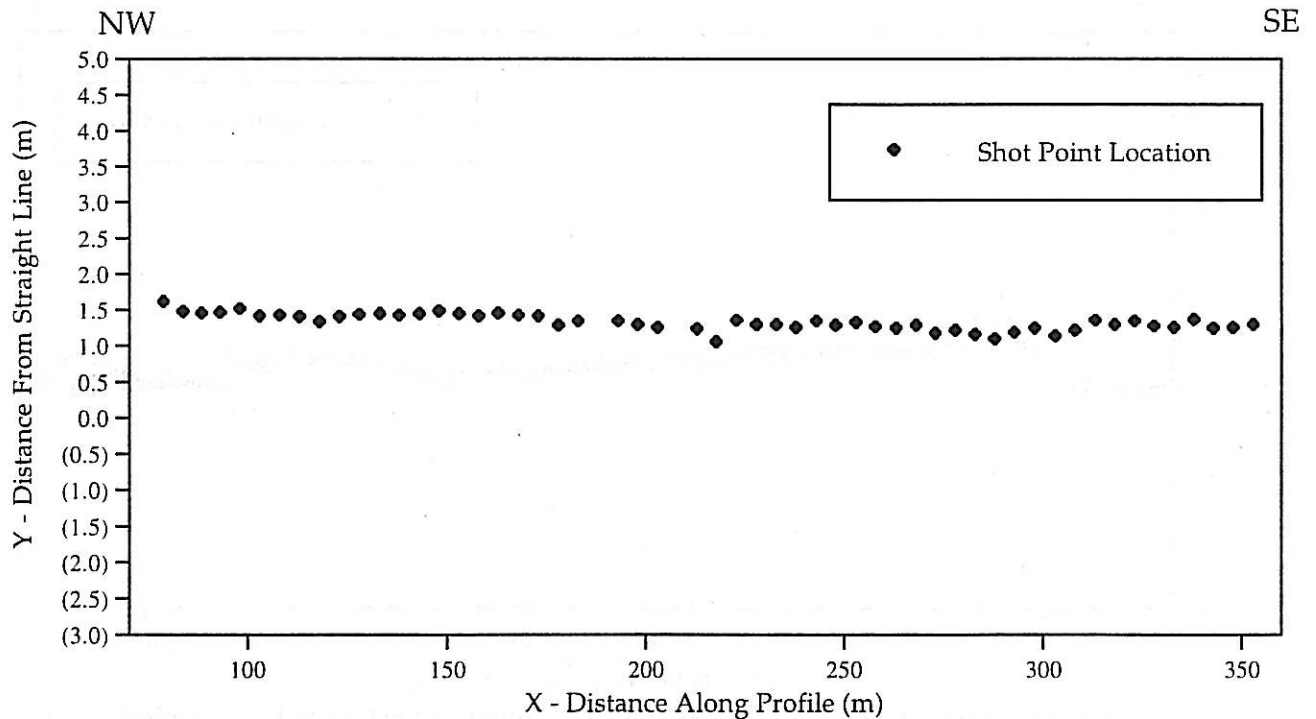


Figure 16. Shot point variation from a straight line connecting the first and last shot point along Fox Glen North.

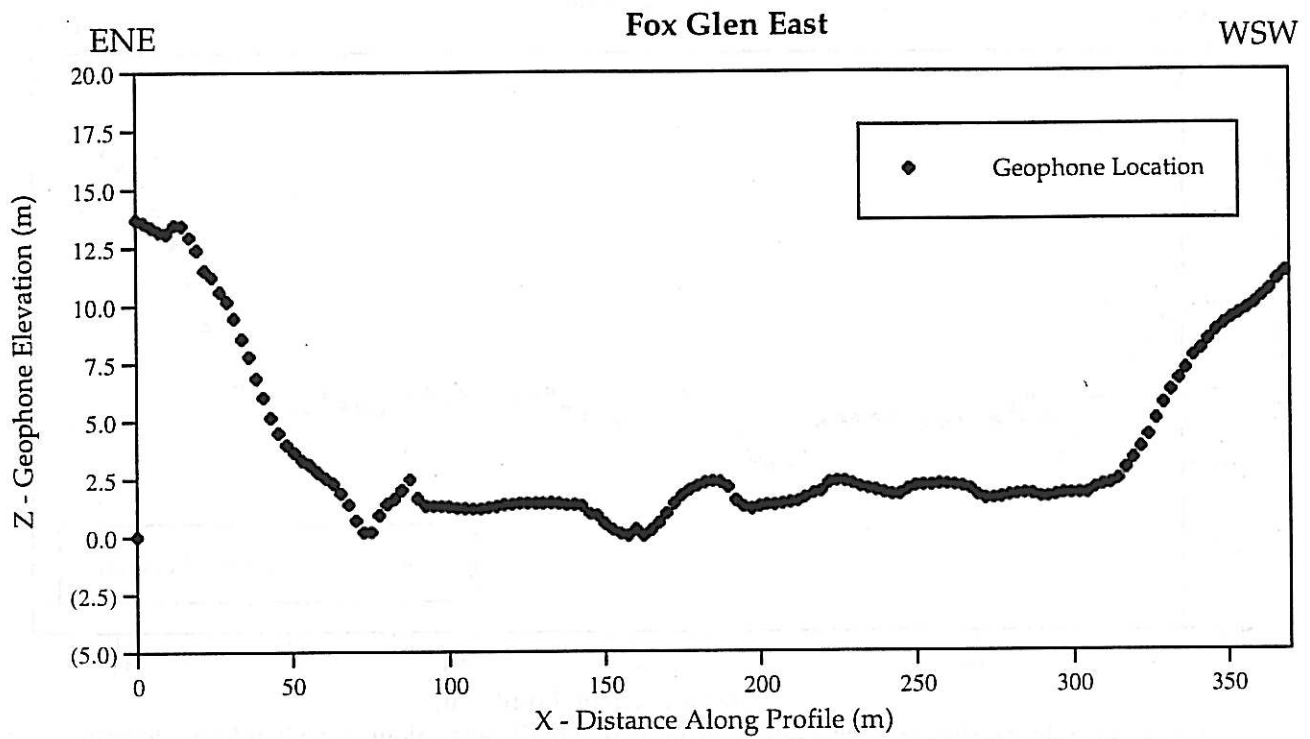


Figure 17. Relative geophone elevations as a function of distance along Fox Glen East. is relative to the topographically lowest geophone location. Distance is relative to the first geophone location on the east-northeastern end of the line.

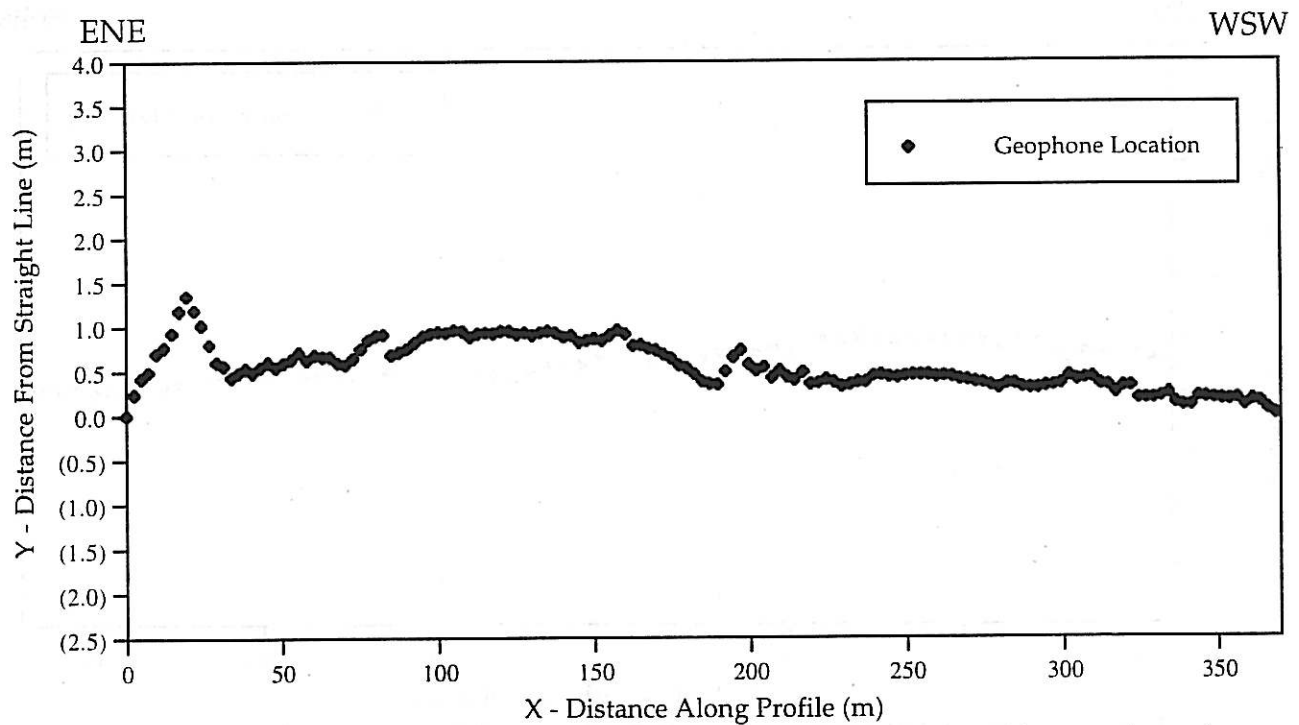


Figure 18. Geophone variation from a straight line connecting the first and last geophone along Fox Glen East.

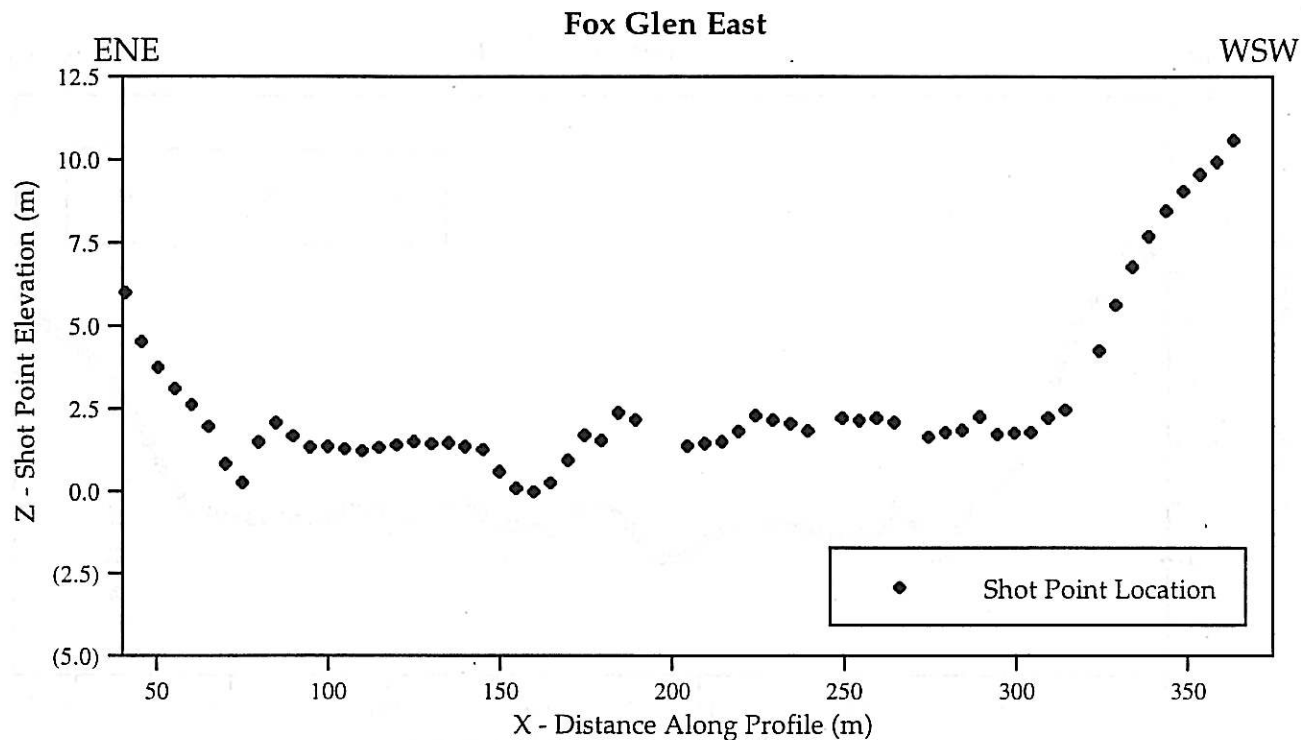


Figure 19. Relative shot point elevations as a function of distance along Fox Glen East. Elevation is relative to the topographically lowest geophone location. Distance is relative to the first geophone location on the east-northeastern end of the line.

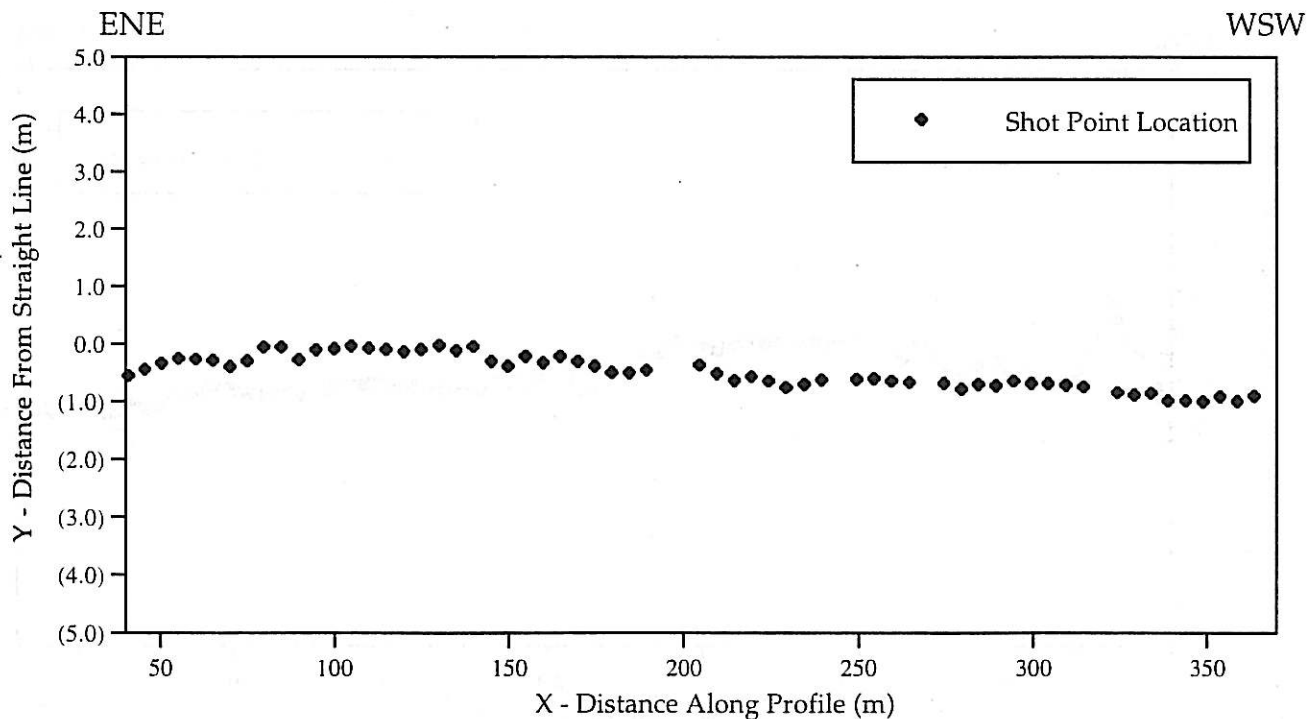


Figure 20. Shot point variation from a straight line connecting the first and last shot point along Fox Glen East.

DATA PROCESSING

The seismic data were processed using a Promax processing system at our office in Menlo Park, Calif. The following steps were involved in data processing:

- | | | | | | |
|-----|-----------------------|------|--------------------|-----|---------------|
| i | Geometry installation | v | Velocity analysis | ix | Muting |
| ii | Trace editing | vi | Moveout correction | x | F-K filtering |
| iii | Bandpass filtering | vii | Velocity inversion | xi | Stacking |
| iv | Timing corrections | viii | Elevation statics | xii | Migration |

The locations determined from the electronic-distance-meter surveys were imported directly into the Promax processing routine. Due to poor coupling between the geophones and the earth, malfunctioning geophones, and/or local noise sources along the seismic line, some unusually noisy traces had to be removed. The affected traces often varied from shot to shot; thus, separate trace edits were employed for each shot gather. We used bandpass filtering with a low cut of 30 Hz to remove most surface waves, shear waves, and cultural noise. A high cut of about 250 Hz was used to remove wind noises and other high-frequency noises.

Fold

Using the "shoot-through" acquisition method, the fold varied along the seismic profile. The maximum fold along Skunk North was 47 (Fig. 21) and along Skunk East, the maximum fold was 52 (Fig. 22). The fold for both Fox Glen North and Fox Glen East surveys varied systematically from about 1 at the ends of the line to a maximum fold of 54 and 61, respectively near the center of the line (Figs. 23, 24).

STACKED SEISMIC IMAGES

Skunk North

A stacked seismic image of the uppermost 700 meters of the subsurface along Skunk North is shown in Figure 25. Numbers along the horizontal axis refer to Common Depth Points (CDP). Typically, each CDP is about 1.25 m. The elevation of the first recording geophone is used as the datum. Numerous faults are inferred throughout the profile. There appears to be appreciable structural variation in the shallow (<200 m) subsurface, mostly along the southeastern part of the profile.

Skunk East

Figure 26 shows a stacked seismic image of the uppermost 600 meters of the subsurface along Skunk East. Extensive faulting is inferred along the entire length of the profile, including the shallow subsurface areas.

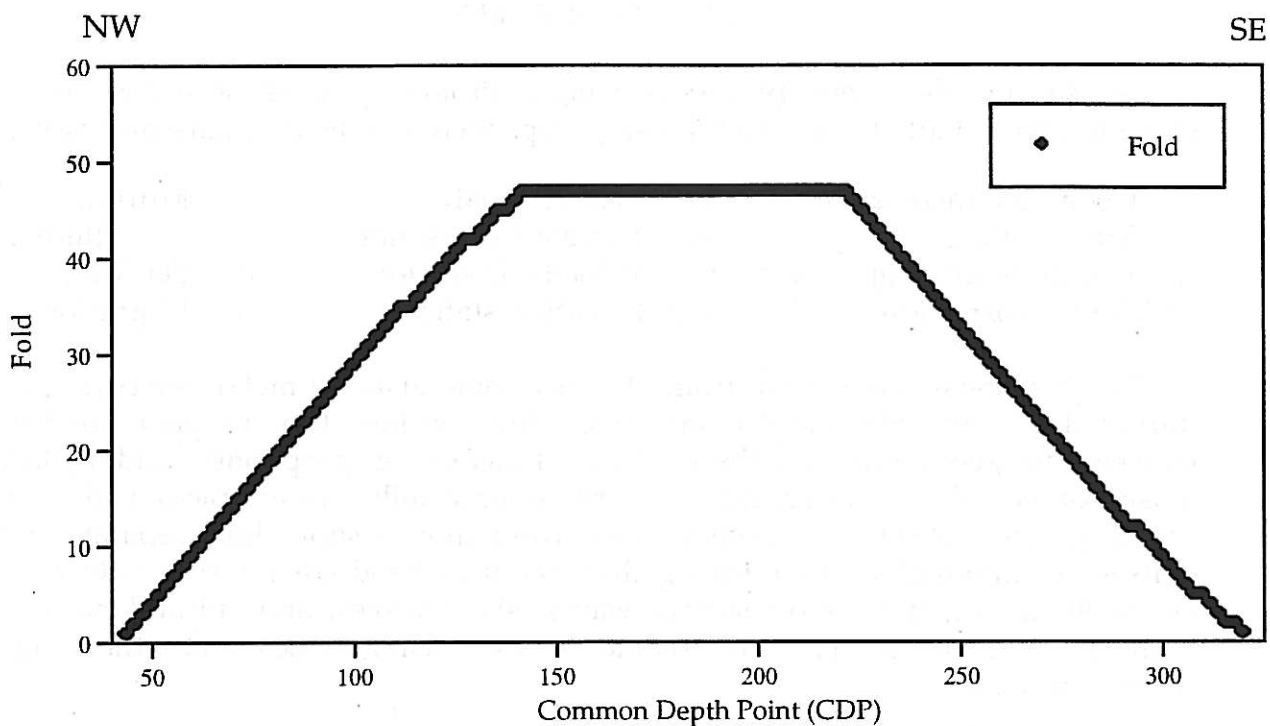


Figure 21. Fold as a function of common depth point along Skunk North. Distance is relative to the first geophone on the northwestern end of the line.

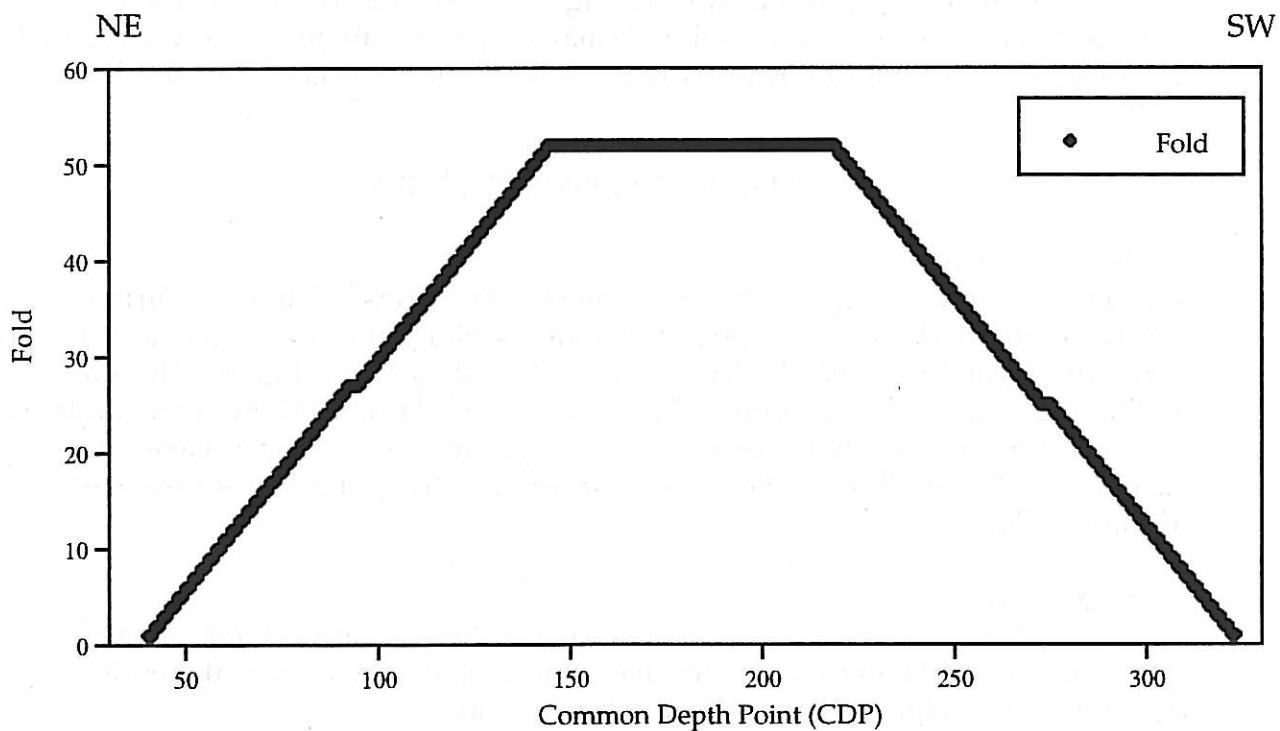


Figure 22. Fold as a function of common depth point along Skunk East. Distance is relative to the first geophone on the northeastern end of the line.

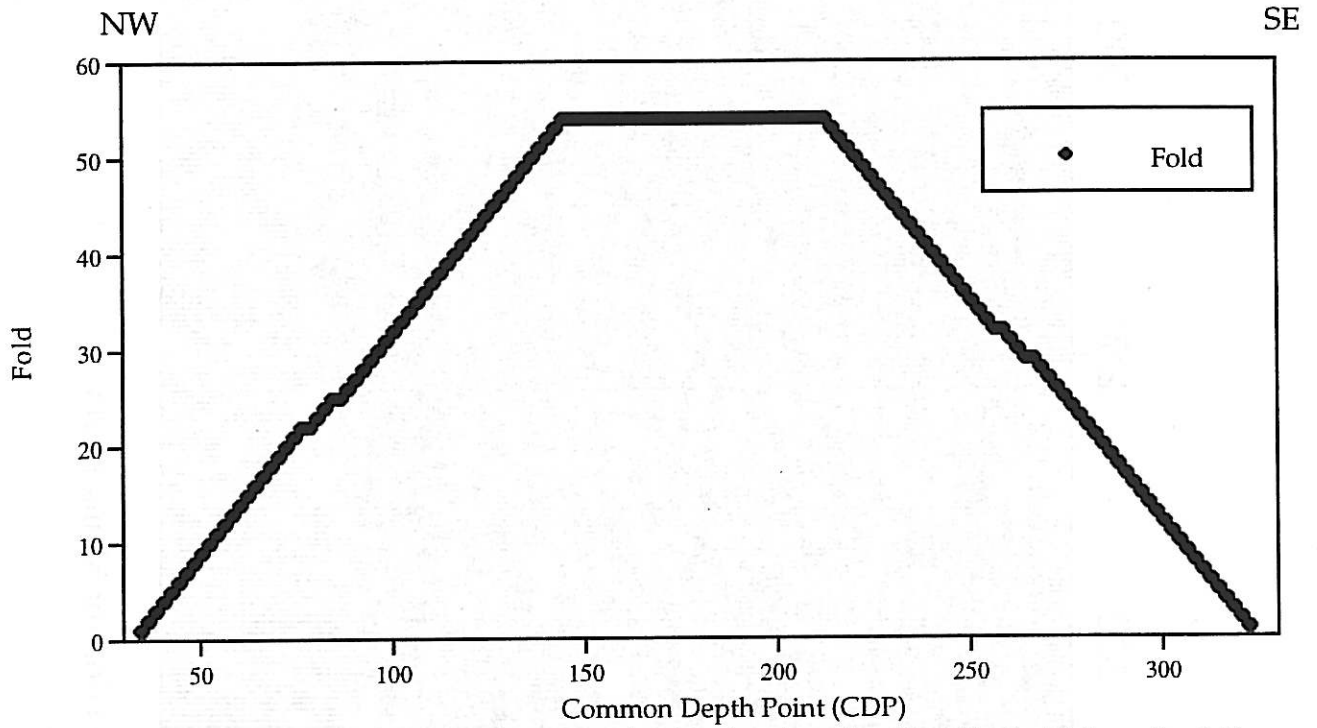


Figure 23. Fold as a function of common depth point along Fox Glen North. Distance is relative to the first geophone on the northwestern end of the line.

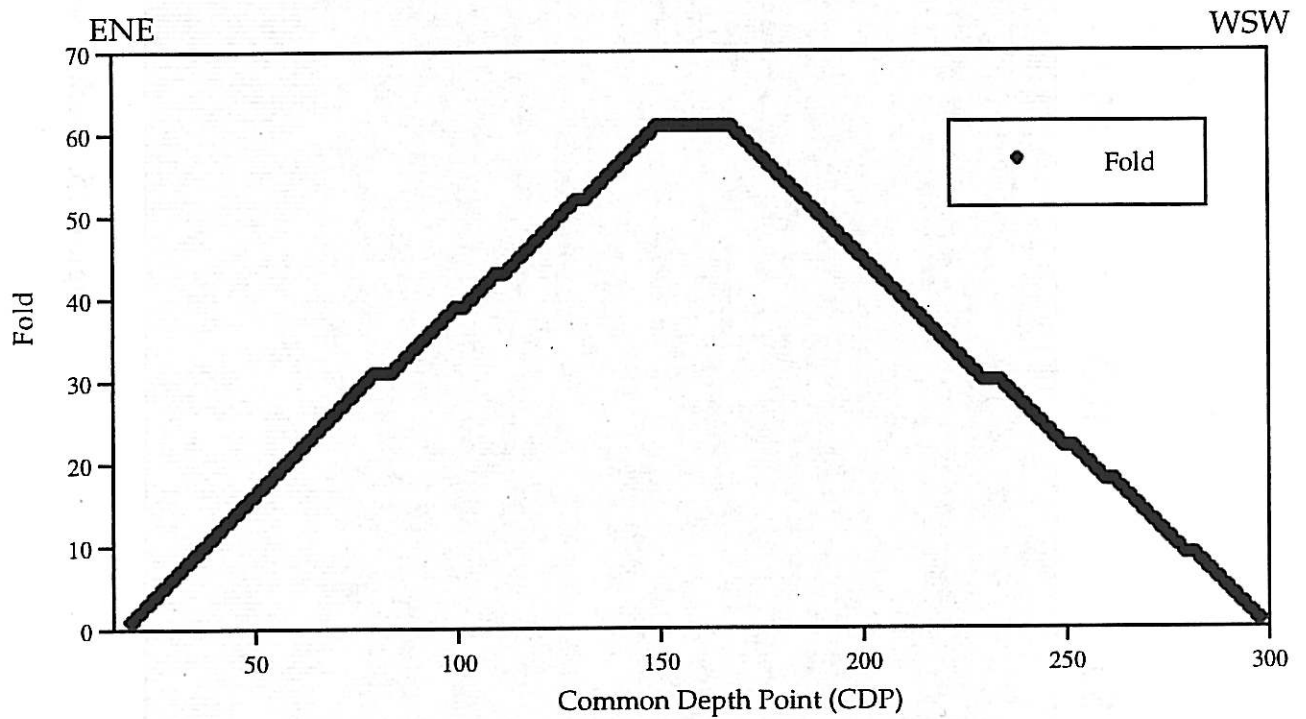


Figure 24. Fold as a function of common depth point along Fox Glen East. Distance is relative to the first geophone on the east-northeastern end of the line.

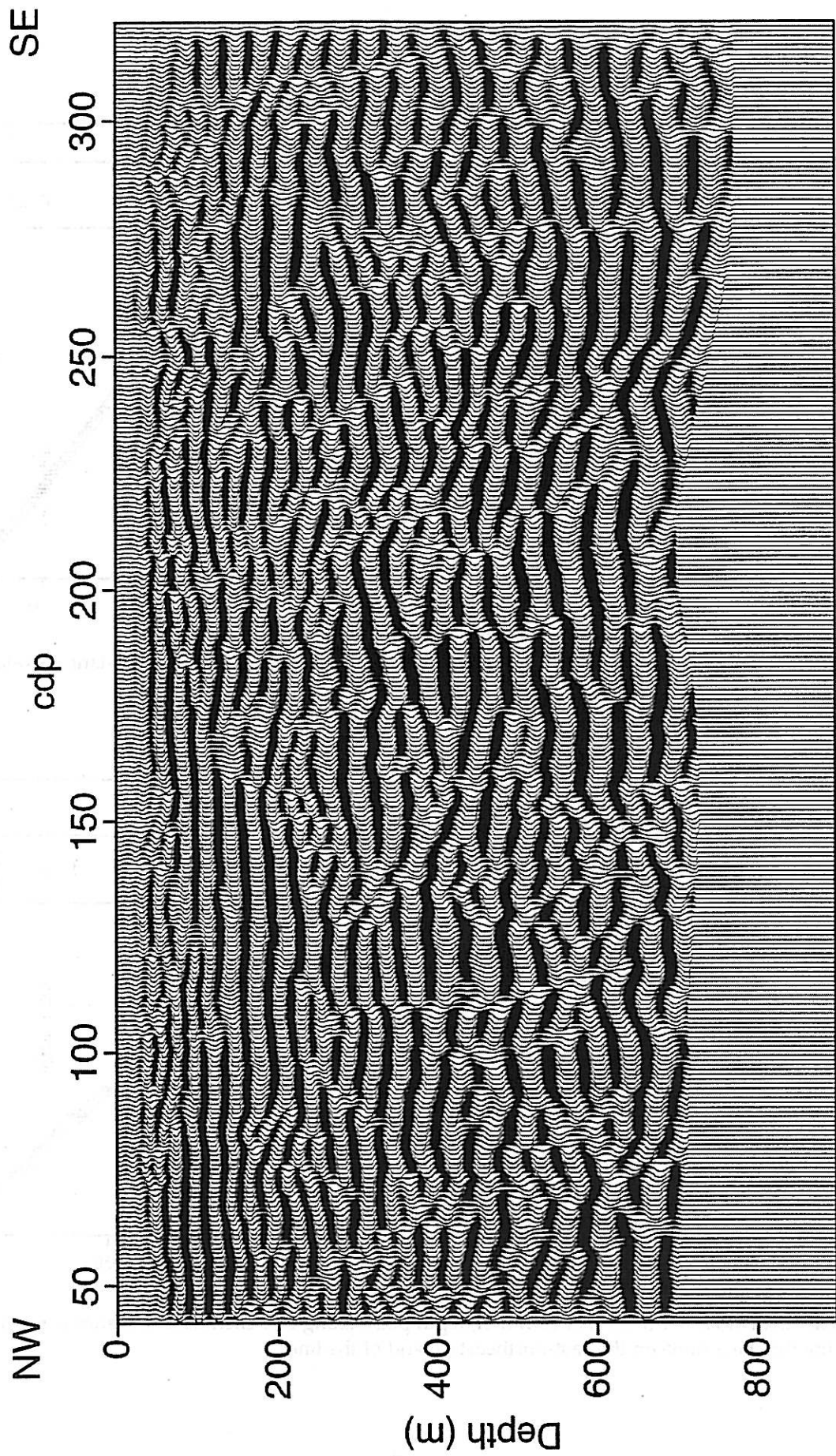


Figure 25. Stacked seismic section for Skunk North.

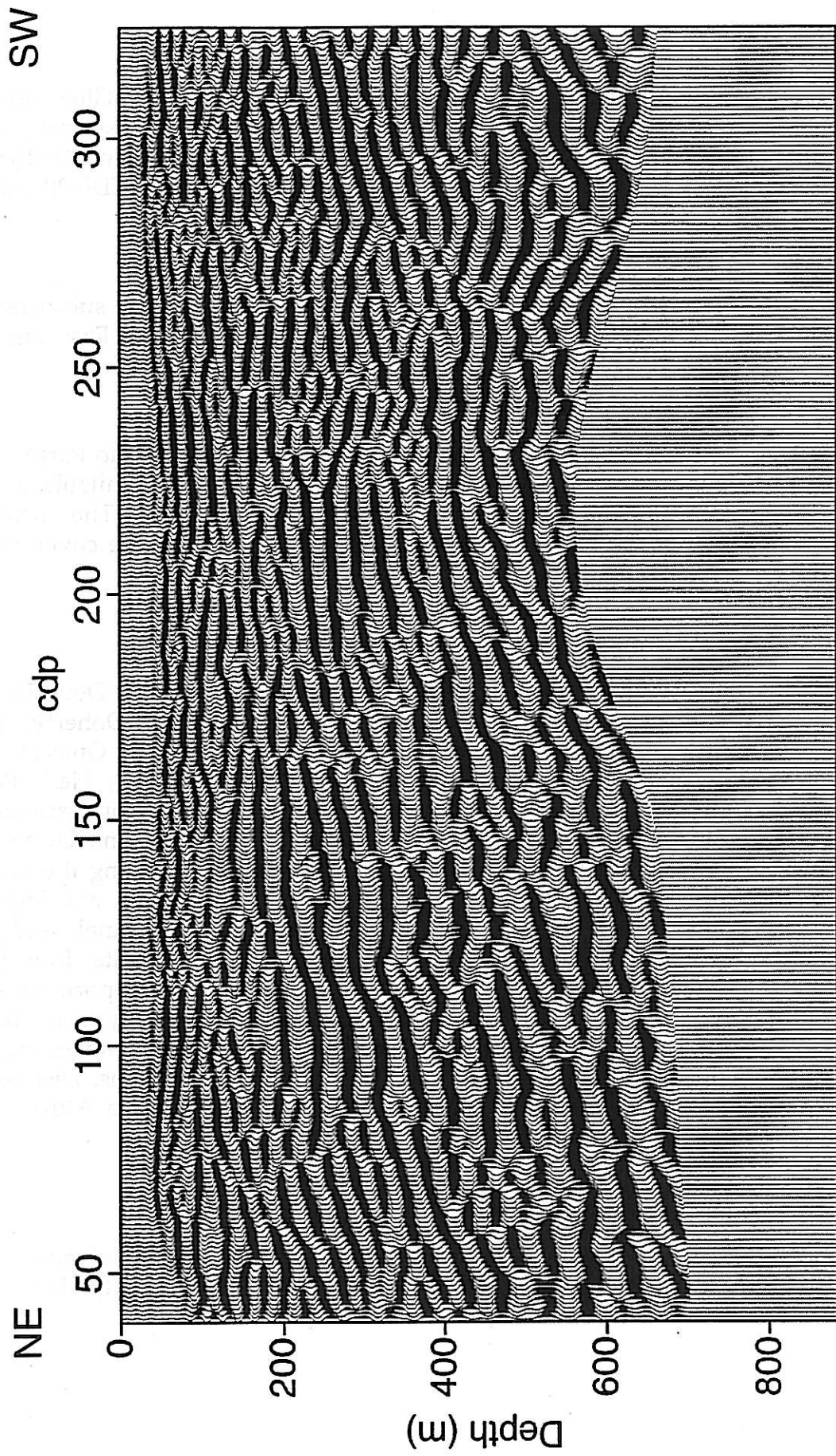


Figure 26. Stacked seismic section for Skunk East.

Fox Glen North

A stacked seismic image of the uppermost 600+ meters of Fox Glen North is shown in Figure 27. Numerous faults are inferred in the image, especially along the northwestern half of the line. Extensive shallow subsurface faulting is restricted mostly to the northwestern end of the profile (between CDP 30 and 70), but deeper faults are imaged below ~300 m along the entire section.

Fox Glen East

Appreciable faulting is inferred in both the shallow and deeper subsurface on the stacked seismic section of the uppermost 600 meters of Fox Glen East (Fig. 28).

DATA AVAILABILITY

The data presented in this report are archived at the USGS (Menlo Park) and at the IRIS-PASSCAL data center in SEG-Y format. The data are available as shot gathers with elevation and shot timing corrections applied. The principal investigator (R.D. Catchings) can be contacted at the address on the cover of this report for copies of the digital data.

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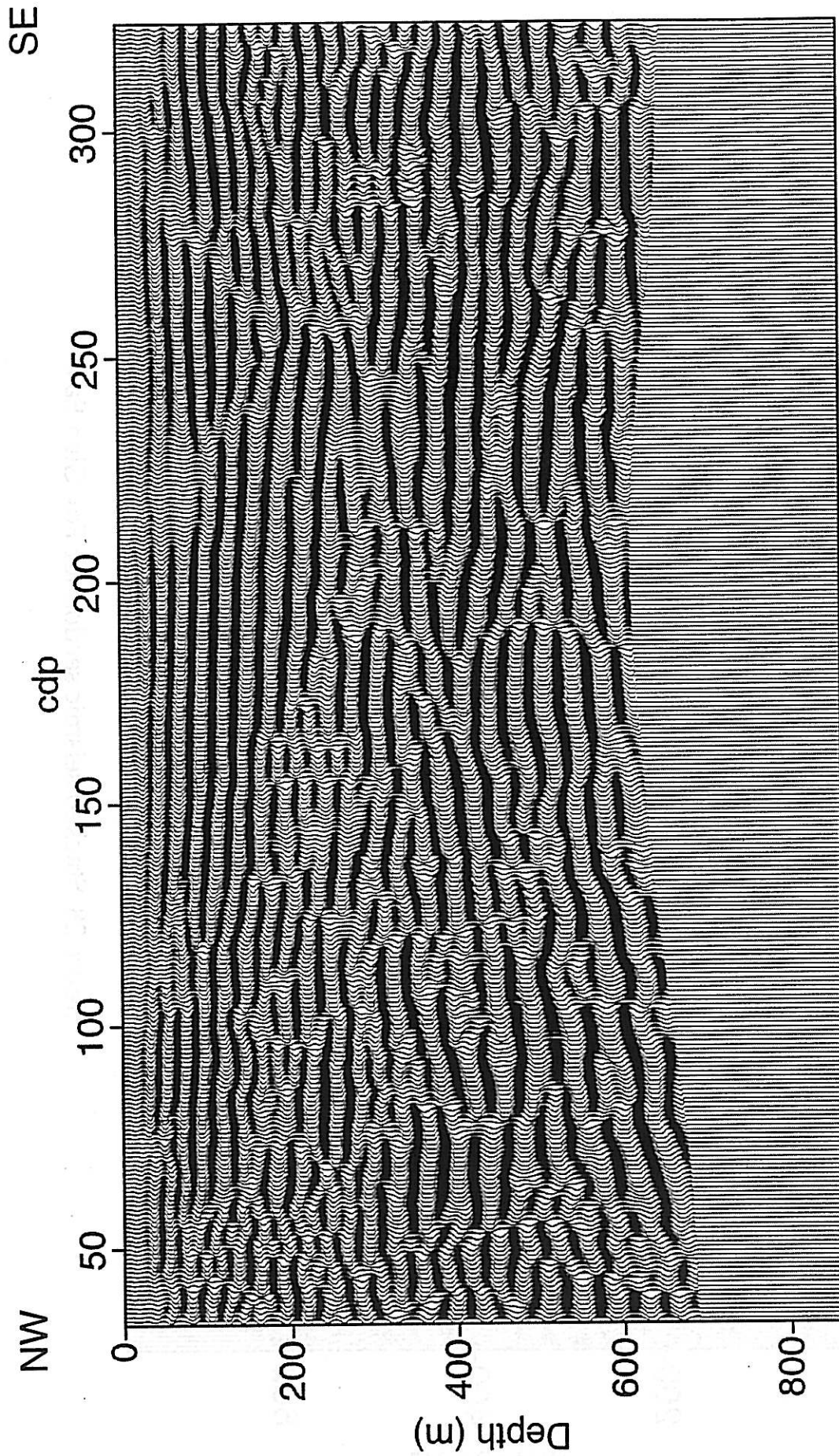


Figure 27. Stacked seismic section for Fox Glen North.

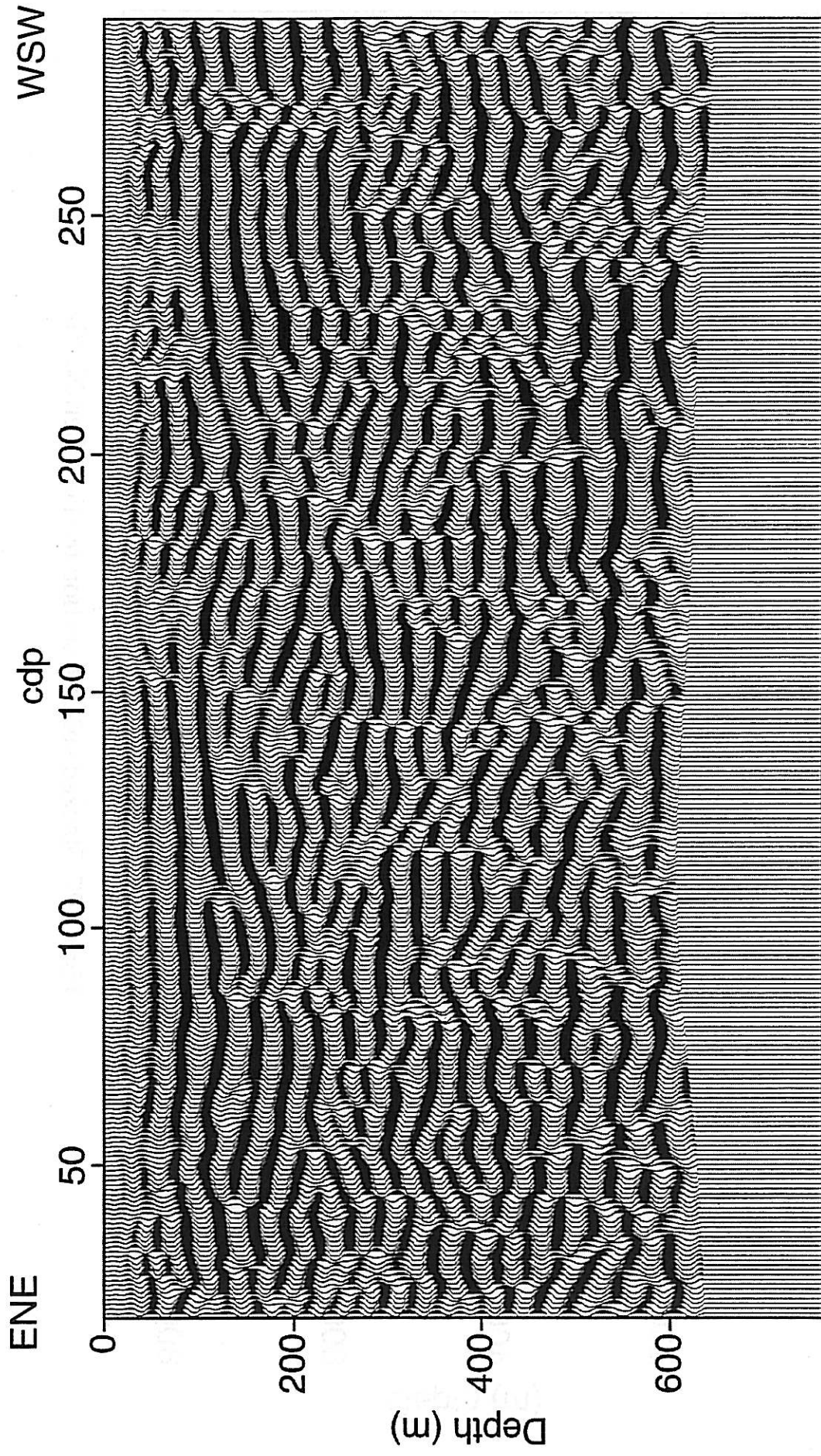


Figure 28. Stacked seismic section for Fox Glen East.

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Appendix A

Relative locations and elevations of receivers and shot points along Skunk North.
Distance is relative to the northwestern end of the line.

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	0.00	14.00		
	2.72	14.26		
	5.45	14.52		
	7.81	14.62		
	10.31	14.76		
	12.84	14.72		
	15.51	14.85		
	17.86	14.85		
	20.38	14.73		
	22.80	14.83		
	25.25	14.90		
	27.72	14.71		
	30.20	14.52		
	32.68	14.33		
	35.16	14.14		
	37.56	13.89		
	40.12	13.44		
	42.55	13.30		
	45.12	13.15		
	47.60	13.06		
	50.05	12.90		
	52.52	12.73		
	55.01	12.58		
	57.51	12.50		
	59.93	12.21		
	62.43	11.93		
	64.91	11.73		
	67.46	11.62		
	69.89	11.54		
	72.37	11.49		
	74.89	11.48		
	77.39	11.54		
	79.82	11.71		
	82.33	12.04		
	84.79	12.08		
	87.27	12.21		
	89.77	12.17		
	92.27	12.26		
	94.81	12.38		

Appendix A (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	97.27	12.38		
	99.79	12.18		
1	102.07	11.99	102.24	11.93
	104.69	11.84		
2	107.17	11.61	106.90	11.63
	109.63	11.37		
3	112.08	10.92	111.82	10.99
	114.60	10.51		
4	117.02	10.13	116.93	10.13
	119.51	9.89		
5	121.89	9.61	121.80	9.51
	124.38	9.50		
6	126.81	9.23	126.67	9.03
	129.25	8.90		
7	131.73	8.38	131.59	8.25
	134.12	7.83		
8	136.55	7.27	136.40	7.20
	139.04	6.88		
9	141.56	6.53	141.40	6.27
	144.01	6.19		
10	146.38	5.91	146.44	5.64
	148.91	5.47		
11	151.45	5.18	151.31	5.15
	153.73	4.98		
12	156.44	4.70	156.32	4.65
	158.74	4.32		
13	161.25	3.90	161.19	3.63
	163.63	3.25		
14	166.04	2.71	165.92	2.58
	168.57	2.27		
15	170.91	1.87	170.93	1.85
	173.43	1.64		
16	175.90	1.54	176.06	1.47
	178.40	1.35		
17	180.87	1.13	180.98	1.09
	183.39	0.91		
18	185.88	0.82	185.97	0.82
	188.37	0.75		
19	190.87	0.52	190.97	0.57

Appendix A (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	193.32	0.45		
20	195.82	0.32	195.98	0.26
	198.31	0.20		
21	200.83	0.17	201.00	0.22
	203.33	0.22		
22	205.81	0.25	205.91	0.25
	208.31	0.23		
23	210.81	0.15	210.95	0.17
	213.30	0.11		
24	215.82	0.09	215.96	0.10
	218.31	0.06		
25	220.85	0.04	220.84	0.01
	223.37	0.03		
26	225.83	0.04	225.89	0.09
	228.24	0.00		
27	230.81	0.07	230.81	0.07
	233.35	0.20		
28	235.83	0.14	236.01	0.16
	238.36	0.07		
29	240.80	0.14	240.82	0.12
	243.27	0.19		
30	245.78	0.13	245.75	0.20
	248.25	0.16		
31	250.78	0.16	250.78	0.23
	253.25	0.05		
32	255.71	0.02	255.69	-0.05
	258.21	0.11		
33	260.67	0.10	260.65	0.08
	263.21	0.08		
34	265.74	0.21	265.65	0.15
	268.20	0.34		
35	270.71	0.56	270.75	0.40
	273.22	0.74		
	275.72	0.86		
	278.17	1.10		
36	280.70	1.24	280.65	1.19
	283.18	1.40		
37	285.63	1.57	285.71	1.54
	288.14	1.89		

Appendix A (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
38	290.65	2.10	290.70	2.06
	293.11	2.32		
39	295.62	2.44	295.60	2.33
	298.13	2.56		
40	300.55	2.68	300.55	2.55
	303.08	2.86		
41	305.61	3.00	305.46	2.97
	308.06	3.21		
42	310.58	3.35	310.55	3.30
	313.06	3.49		
	315.76	3.63		
	317.86	3.77		
43	320.38	3.98	320.44	3.79
	322.97	4.09		
44	325.47	4.04	325.78	3.89
	327.94	3.97		
45	330.50	4.31	330.62	4.14
	333.07	4.35		
	335.49	4.41		
	337.97	4.38		
46	340.53	4.29	340.48	4.12
	342.96	4.20		
47	345.48	4.30	345.63	4.12
	347.76	4.23		
	350.40	4.24		
	352.90	4.18		
	355.41	4.24		
	357.93	4.31		
	360.45	4.29		
	362.94	4.32		
	365.40	4.36		
	367.90	4.40		
	370.45	4.45		
	372.92	4.50		
375.44	4.49			
377.94	4.51			
380.46	4.51			
382.90	4.63			
385.40	4.66			

Appendix A (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	387.92	4.65		
	390.41	4.69		
	392.89	4.71		
	395.37	4.73		
	397.89	4.83		
	400.38	4.87		
	402.86	4.92		
	405.38	4.91		
	407.81	4.94		
	410.38	4.98		
	412.88	5.05		
	415.37	5.09		
	417.89	5.15		
	420.38	5.23		
	422.88	5.37		
	425.38	5.43		
	427.91	5.47		
	430.40	5.49		
	432.87	5.70		
	435.38	5.58		
	437.85	5.65		
	440.35	5.79		
	442.84	5.92		
	445.34	6.06		

Appendix B

Relative locations and elevations of receivers and shot points along Skunk East.
Distance is relative to the northeastern end of the line.

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	0.00	1.68		
	2.56	1.79		
	5.02	1.98		
	7.53	2.16		
	10.07	2.40		
	12.48	2.42		
	14.96	2.58		
	17.48	2.69		
	19.93	2.82		
	22.44	2.96		
	24.99	3.13		
	27.42	3.22		
	29.97	3.36		
	32.57	3.48		
	35.00	3.62		
	37.52	3.71		
	39.98	3.82		
	42.43	4.00		
	44.87	4.16		
	47.35	4.25		
	49.86	4.47		
	52.37	4.59		
	54.85	4.78		
	57.24	5.00		
	59.92	5.62		
	62.18	6.51		
	64.68	7.49		
	67.07	8.32		
	69.36	9.05		
	71.86	9.67		
	74.27	10.31		
	76.68	10.81		
	79.17	11.11		
	81.70	11.16		
	84.34	11.28		
	86.74	11.03		
	89.11	10.86		
	91.68	10.85		
1	93.80	10.75	93.77	10.70

Appendix B (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	96.24	10.72		
2	98.76	10.57	98.55	10.62
	101.28	10.49		
3	103.76	10.42	103.56	10.47
	106.24	10.32		
4	108.72	10.19	108.55	10.23
	111.22	10.02		
5	113.85	9.92	113.54	9.92
	116.20	9.77		
6	118.58	9.69	118.44	9.61
	121.18	9.42		
7	123.67	9.05	123.49	9.05
	126.03	8.66		
8	128.51	8.25	128.40	8.23
	130.99	7.79		
9	133.57	7.56	133.24	7.50
	135.99	7.42		
10	138.52	7.26	138.24	7.30
	141.01	7.12		
11	143.28	7.04	143.24	6.99
	145.97	6.80		
12	148.39	6.59	148.22	6.56
	151.38	6.33		
13	153.47	6.21	153.10	6.23
	155.91	6.06		
14	158.46	5.82	158.21	5.89
	160.79	5.57		
15	163.32	5.37	163.25	5.39
	166.02	5.21		
16	168.32	5.01	168.12	5.03
	170.86	4.77		
17	173.32	4.60	173.14	4.58
	175.79	4.39		
18	178.32	4.07	177.98	4.27
	180.80	3.71		
19	183.32	3.41	183.03	3.56
	185.75	3.18		
20	188.22	2.85	188.01	2.92
	190.67	2.53		

Appendix B (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
21	193.17	2.13	192.87	2.16
	195.68	1.61		
22	198.09	1.17	197.89	1.38
	200.66	0.86		
23	203.20	0.54	202.94	0.64
	205.70	0.00		
24	208.23	0.12	207.85	0.12
	210.71	0.66		
25	213.20	0.68	212.89	0.65
	215.71	0.65		
26	218.23	0.69	217.84	0.69
	220.72	0.62		
27	223.27	0.70	222.89	0.74
	225.74	0.90		
	228.26	0.76		
	230.70	0.67		
28	233.14	0.58	232.86	1.04
	235.74	0.80		
29	237.79	1.08	237.85	1.17
	240.27	1.27		
30	243.23	1.50	242.89	1.60
	245.70	1.80		
31	248.19	1.95	247.75	2.00
	250.67	2.18		
32	253.19	2.35	252.62	2.44
	255.66	2.60		
33	258.13	2.80	257.73	2.80
	260.65	3.00		
34	263.19	3.19	262.71	3.24
	265.61	3.44		
35	268.17	3.64	267.65	3.67
	270.57	3.86		
36	273.05	4.14	272.59	4.13
	275.54	4.44		
37	278.05	4.65	277.62	4.66
	280.58	4.88		
38	283.03	5.16	282.59	5.17
	285.48	5.43		
39	287.88	5.72	287.52	5.60

Appendix B (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	290.39	5.99		
40	292.87	6.36	292.68	6.31
	295.19	6.67		
41	297.89	7.19	297.48	7.03
	300.43	7.63		
42	302.79	7.99	302.47	7.98
	305.31	8.49		
43	307.71	8.82	307.11	8.59
	310.14	9.26		
44	312.68	9.76	312.09	9.48
	315.12	10.37		
45	317.57	10.84	317.11	10.48
	319.98	11.42		
46	322.37	12.12	321.92	11.86
	324.83	12.68		
47	327.30	13.15	326.68	12.91
	329.80	13.58		
48	332.24	14.02	331.76	13.84
	334.73	14.40		
49	337.13	14.81	336.65	14.58
	339.62	15.26		
50	341.91	15.74	341.49	15.61
	344.45	16.47		
51	346.87	17.29	346.48	17.08
	349.27	17.87		
52	351.60	18.52	350.89	18.29
	354.16	19.16		
	356.58	19.60		
	359.01	19.99		
	361.50	20.42		
	363.83	20.86		
	366.31	21.39		
	368.67	21.94		
	371.26	22.56		
	373.60	23.26		
	376.09	23.54		
	378.54	23.91		
	381.03	24.11		
	383.65	24.16		

Appendix B (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	386.04	24.17		
	388.50	24.22		
	391.03	24.04		
	393.48	24.10		
	395.12	24.02		
	397.64	24.06		
	400.07	24.07		
	402.59	24.05		
	405.12	23.93		
	407.50	23.76		
	410.16	23.60		
	412.68	23.52		
	415.11	23.64		
	417.59	23.30		
	420.05	22.90		
	422.57	22.42		
	424.95	21.94		
	427.58	21.68		
	429.96	21.06		
	432.55	20.56		
	434.89	20.04		
	437.55	19.68		
	440.02	19.44		
	442.49	19.23		

Appendix C

Relative locations and elevations of receivers and shot points along Fox Glen North.
Distance is relative to the northwestern end of the line.

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	0.00	20.49		
	2.41	20.02		
	4.82	19.50		
	7.30	19.04		
	9.79	18.55		
	12.32	18.16		
	14.65	17.75		
	17.10	17.31		
	19.57	16.96		
	22.07	16.56		
	24.55	16.18		
	27.02	15.85		
	29.48	15.58		
	31.94	15.36		
	34.44	15.09		
	36.95	14.80		
	39.40	14.35		
	41.84	13.99		
	44.30	13.52		
	46.77	13.12		
	49.29	12.78		
	51.68	12.48		
	54.30	12.03		
	56.71	11.69		
	59.18	11.44		
	61.54	10.39		
	63.99	10.35		
	66.54	10.06		
	68.95	9.35		
	71.33	8.81		
	73.83	8.32		
	76.28	7.88		
1	78.56	7.12	78.63	7.11
	81.04	6.45		
2	83.36	5.78	83.57	5.76
	85.79	5.14		
3	88.20	4.49	88.33	4.51
	90.68	3.91		
4	93.13	3.40	93.03	3.37

Appendix C (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	95.63	3.28		
5	98.08	2.99	97.99	2.95
	100.58	2.88		
6	103.09	2.85	102.96	2.86
	105.60	2.91		
7	108.07	2.95	107.99	2.86
	110.57	3.07		
8	113.09	3.16	112.99	3.03
	115.58	3.22		
9	118.08	3.35	117.98	3.34
	120.55	3.33		
10	123.03	3.40	123.00	3.45
	125.55	3.58		
11	128.03	3.61	127.89	3.62
	130.52	3.75		
12	133.03	3.74	133.10	3.73
	135.54	3.77		
13	138.02	3.76	137.92	3.72
	140.53	3.72		
14	143.03	3.71	143.00	3.68
	145.51	3.65		
15	148.02	3.63	147.97	3.52
	150.52	3.59		
16	153.00	3.58	152.97	3.52
	155.52	3.53		
17	157.97	3.49	157.97	3.44
	160.46	3.44		
18	163.01	3.43	162.79	3.37
	165.43	3.43		
19	167.99	3.41	167.86	3.39
	170.50	3.44		
20	172.96	3.43	172.87	3.39
	175.49	3.44		
21	178.00	3.48	177.90	3.46
	180.46	3.52		
22	182.96	3.56	182.88	3.50
	185.47	3.56		
	187.98	3.55		
	190.50	3.60		

Appendix C (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
23	193.06	3.60	192.97	3.60
	195.50	3.58		
24	197.94	3.55	197.92	3.51
	200.42	3.50		
25	202.91	3.45	202.93	3.38
	205.42	3.39		
	207.95	3.34		
	210.46	3.27		
26	213.00	3.23	212.96	3.17
	215.48	3.18		
27	217.93	3.16	217.82	3.15
	220.44	3.11		
28	223.04	3.14	222.87	3.11
	225.45	3.13		
29	227.88	3.09	227.90	3.10
	230.43	3.10		
30	232.95	3.08	232.93	3.01
	235.40	3.03		
31	237.94	3.01	237.86	2.96
	240.44	2.97		
32	242.96	2.90	242.95	2.82
	245.46	2.81		
33	247.94	2.66	247.86	2.70
	250.45	2.78		
34	252.91	2.71	252.87	2.64
	255.45	2.62		
35	257.82	2.62	257.73	2.62
	260.46	2.57		
36	262.90	2.54	262.92	2.56
	265.45	2.54		
37	267.92	2.63	267.94	2.67
	270.34	2.58		
38	272.90	2.55	272.77	2.60
	275.33	2.64		
39	277.82	2.69	277.86	2.55
	280.41	2.63		
40	282.89	2.68	282.86	2.67
	285.43	2.67		
41	287.89	2.69	287.85	2.68

Appendix C (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	290.37	2.72		
42	292.85	2.70	292.76	2.70
	295.32	2.70		
43	297.84	2.74	297.88	2.70
	300.27	2.75		
44	302.86	2.78	303.02	2.78
	305.36	2.79		
45	308.02	2.80	307.96	2.88
	310.33	2.78		
46	312.86	2.82	312.98	2.84
	315.35	2.85		
47	317.85	2.73	317.87	2.70
	320.32	2.66		
48	322.86	2.65	322.94	2.67
	325.29	2.61		
49	327.79	2.60	327.83	2.61
	330.37	2.59		
50	332.81	2.55	332.85	2.57
	335.24	2.48		
51	337.80	2.49	337.93	2.54
	340.30	2.42		
52	342.56	2.37	342.82	2.54
	345.30	2.32		
53	347.87	2.44	347.71	2.53
	350.29	2.53		
54	352.70	2.44	352.84	2.52
	355.30	2.37		
	357.79	2.27		
	360.27	2.18		
	362.77	2.33		
	366.00	1.33		
	367.64	0.52		
	370.15	0.00		
	372.72	0.43		
	375.28	1.50		
	377.62	1.89		
	380.25	1.54		
	382.66	1.06		
	385.24	0.50		

Appendix C (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	387.80	1.16		
	390.19	1.78		
	392.53	2.70		
	395.08	2.64		
	397.47	3.30		
	399.96	3.92		
	402.28	4.66		
	404.13	5.28		
	406.96	6.40		
	409.29	7.72		
	411.52	7.58		
	413.42	9.10		
	415.97	10.82		
	418.41	11.49		
	420.81	12.11		
	423.26	12.62		
	425.69	13.24		
	428.11	14.05		
	430.41	14.72		
	432.67	15.41		
	435.16	16.02		
	437.67	16.51		
	440.36	17.18		
	442.51	17.41		

Appendix D

Relative locations and elevations of receivers and shot points along Fox Glen East.
Distance is relative to the east-northeastern end of the line.

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	0.00	13.70		
	2.47	13.56		
	4.88	13.36		
	7.14	13.18		
	9.70	13.08		
	12.23	13.46		
	14.72	13.43		
	17.07	12.94		
	19.43	12.39		
	21.87	11.50		
	24.23	11.21		
	26.80	10.58		
	29.21	10.17		
	31.45	9.45		
	33.94	8.56		
	36.23	7.79		
	38.52	6.84		
1	40.82	6.02	40.73	6.00
	43.24	5.14		
2	45.69	4.47	45.44	4.53
	48.14	3.96		
3	50.60	3.63	50.34	3.75
	53.09	3.29		
4	55.61	3.08	55.22	3.11
	58.07	2.78		
5	60.55	2.52	60.23	2.62
	63.05	2.28		
6	65.48	1.85	65.19	1.96
	67.96	1.38		
7	70.34	0.69	70.13	0.83
	72.78	0.18		
8	75.23	0.19	75.09	0.26
	77.62	0.92		
9	80.10	1.39	79.82	1.49
	82.53	1.61		
10	85.03	2.01	84.82	2.07
	87.55	2.46		
11	90.00	1.64	89.73	1.67
	92.47	1.32		

Appendix D (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
12	94.99	1.30	94.70	1.33
	97.48	1.30		
13	99.97	1.28	99.87	1.35
	102.51	1.21		
14	104.99	1.20	104.67	1.28
	107.51	1.19		
15	110.01	1.19	109.76	1.22
	112.49	1.24		
16	115.00	1.29	114.68	1.32
	117.51	1.37		
17	120.00	1.38	119.71	1.40
	122.50	1.44		
18	124.99	1.44	124.73	1.50
	127.56	1.43		
19	129.98	1.42	129.85	1.44
	132.51	1.45		
20	134.96	1.43	134.76	1.46
	137.49	1.35		
21	140.03	1.37	139.61	1.35
	142.46	1.32		
22	145.02	0.96	144.81	1.26
	147.47	0.90		
23	149.93	0.53	149.67	0.59
	152.41	0.27		
24	154.95	0.10	154.65	0.08
	157.40	0.00		
25	159.95	0.29	159.67	-0.02
	162.45	0.00		
26	164.94	0.25	164.58	0.25
	167.36	0.56		
27	169.86	0.96	169.70	0.94
	172.32	1.40		
28	174.76	1.74	174.54	1.70
	177.29	1.99		
29	179.76	2.16	179.42	1.54
	182.27	2.32		
30	184.76	2.37	184.41	2.38
	187.25	2.33		
31	189.74	2.11	189.36	2.17

Appendix D (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
	192.26	1.54		
	194.72	1.27		
	197.21	1.18		
	199.72	1.28		
	202.11	1.35		
32	204.60	1.34	204.53	1.37
	207.13	1.40		
33	209.71	1.45	209.54	1.45
	212.12	1.49		
34	214.47	1.66	214.52	1.50
	217.26	1.85		
35	219.56	1.93	219.41	1.82
	222.10	2.31		
36	224.59	2.38	224.42	2.30
	227.09	2.37		
37	229.56	2.27	229.42	2.16
	232.08	2.13		
38	234.57	2.05	234.50	2.05
	237.06	1.98		
39	239.57	1.86	239.47	1.83
	242.04	1.78		
	244.58	1.78		
	247.08	2.00		
40	249.58	2.15	249.40	2.22
	252.07	2.18		
41	254.56	2.18	254.33	2.15
	257.08	2.22		
42	259.56	2.21	259.30	2.22
	262.05	2.19		
43	264.59	2.13	264.33	2.09
	267.04	2.02		
	269.50	1.74		
	271.99	1.59		
44	274.50	1.60	274.25	1.65
	277.01	1.65		
45	279.54	1.72	279.29	1.79
	282.02	1.77		
46	284.50	1.82	284.19	1.85
	287.01	1.79		

Appendix D (cont.)

Shot Number	Receiver Dist. (m)	Receiver Elev. (m)	Shot Dist. (m)	Shot Elev. (m)
47	289.51	1.66	289.24	2.26
	291.89	1.66		
48	294.37	1.72	294.32	1.73
	296.90	1.81		
49	299.33	1.80	299.36	1.77
	301.89	1.81		
50	304.36	1.81	304.13	1.79
	306.87	2.05		
51	309.31	2.17	309.18	2.23
	311.86	2.22		
52	314.32	2.42	314.16	2.47
	316.79	2.87		
	319.20	3.31		
	321.64	3.78		
53	324.09	4.30	324.02	4.25
	326.58	5.00		
54	328.97	5.68	328.84	5.62
	331.42	6.23		
55	333.92	6.72	333.73	6.77
	336.27	7.17		
56	338.72	7.71	338.60	7.69
	341.24	8.01		
57	343.63	8.43	343.72	8.46
	346.12	8.82		
58	348.62	9.08	348.74	9.06
	351.12	9.33		
59	353.58	9.54	353.64	9.56
	356.14	9.74		
60	358.63	9.97	358.57	9.93
	361.09	10.27		
61	363.56	10.57	363.48	10.58
	366.03	11.00		
	368.45	11.33		