New Jersey Geological Survey
Technical Memorandum 88-5

SEISMIC REFRACTION AND ELECTRICAL RESISTIVITY SURVEYS, WEST MILFORD TOWNSHIP, PASSAIC COUNTY, NEW JERSEY

Department of Environmental Protection
Division of Water Resources

1989

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by
Jeffrey S. Waldner, Thomas C. Bambrick, and John C. Groenewold

New Jersey Department of Environmental Protection
Division of Water Resources
Geological Survey
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Jeffrey S. Waldner, Thomas C. Bambrick, and John C. Groenewold

INTRODUCTION

A geophysical investigation using seismic refraction profiles and vertical electrical resistivity soundings was conducted at two sites in the West Milford area, West Milford Township, Passaic County, New Jersey. These were in areas considered most favorable for a municipal well and are designated as the Cooley Brook and the Wallisch property sites (figs. 1a, 1b). The purpose of the geophysical investigation was to aid in determining the thickness and composition of the glacial overburden aquifer at the two sites.

The evaluation was requested as a continuation of the Carl's Diner spill investigation by William Kramer (New Jersey Geological Survey, written commun., 1987). Geophysical field work for the project was completed during April-June, 1987.

Acknowledgments

The authors gratefully acknowlege the assistance and contributions of David W. Hall, Donald Jagel, David L. Pasicznyk, and Stewart K. Sandberg. We would also like to thank Gregory C. Herman, Scott D. Stanford, and Ronald W. Witte for their geologic information and aid in formulating an integrated interpretation.

a.

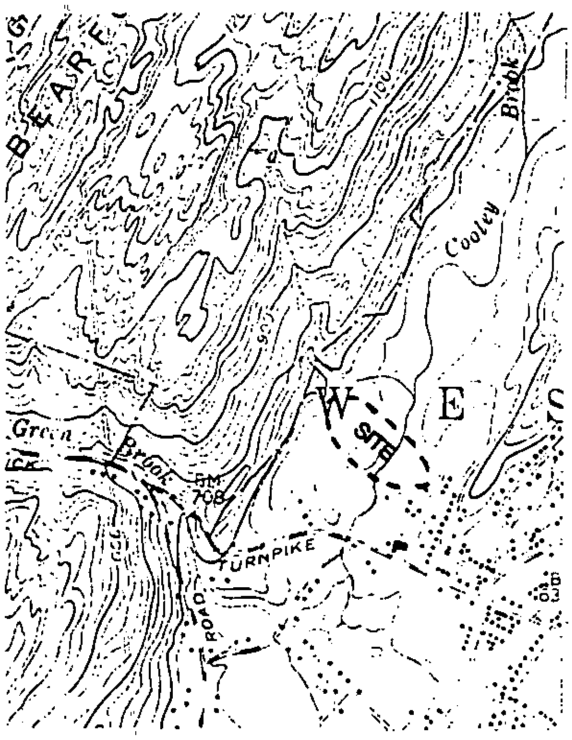
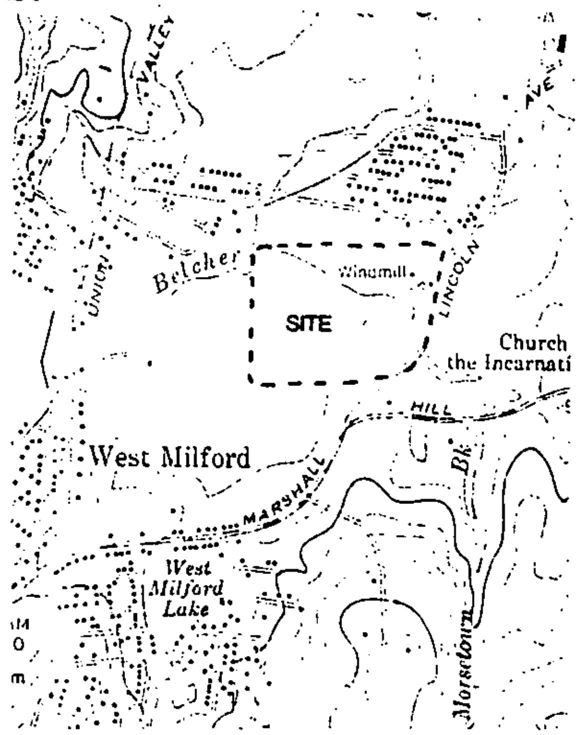


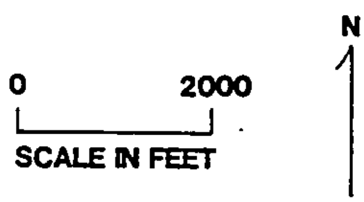
Figure 1a. Cooley Brook site.

b.



1b. Wallisch Property site.

Contour interval 20 ft. Base from U.S. Geological Survey Greenwood Lake quadrangle, 1954.



GEOPHYSICAL METHODS USED IN THE INVESTIGATION

SEISMIC REFRACTION

The seismic refraction method is used by the geophysicist to determine geologic structure by measuring the behavior of acoustic waves transmitted into the subsurface (fig. 2a). Seismic energy is usually generated by a controlled explosion or impact source located on the surface or in a borehole. When the acoustic wave arrives at a boundary between two different velocity media, part of the wave's energy is refracted (transmitted into the lower medium at a change in direction in agreement with Snell's Law). Where velocity increases with depth, as at both the Cooley Brook and Wallisch Property sites, the refracted wave travels along the media interface and seismic energy leaves the interface, upwards, at the same angle at which it initially traveled. The times of the refracted energy arrivals at the ground surface are measured using geophones placed at measured intervals from the seismic source.

ELECTRICAL RESISTIVITY

Vertical electrical sounding is a method of measuring changes in the apparent electrical resistivity of a layered earth section with depth (fig. 2b). The geophysicist uses the resistivities of the media to infer the lithology of the section.

Two symmetrically spaced current electrodes introduce a direct, low frequency (less than 1 hertz) current into the ground. Non-polarizing electrodes (the potentials) placed near the center of the array measure the potential difference from the impressed current. As the spacing of the current electrodes is increased, the current flow lines penetrate deeper into the layered earth section. The apparent resistivity is calculated using the ratio of impressed current to the voltage measured at the potentials and a geometric function of the electrode separations.

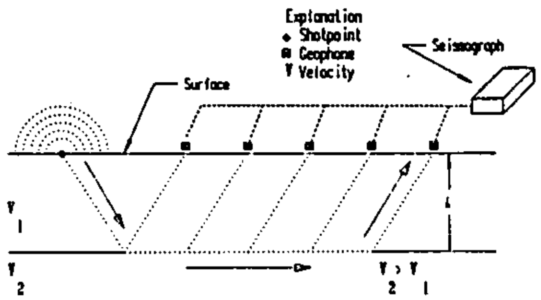


Figure 2 a) Seismic refraction energy raypath of a two layer case (modified from Dietrich, 1978, AGI data sheet 59.1).

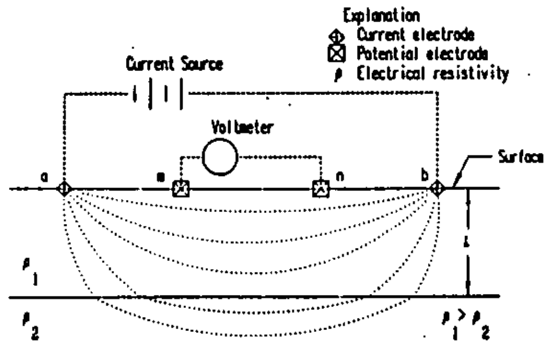


Figure 2b) Schlumberger electrical resistivity array geometry showing lines of current flow between electrodes for a two layer case (from Dobrin, 1976, fig. 17-7, p. 578).

SITE DESCRIPTION AND GEOPHYSICAL MEASUREMENT LOCATIONS

COOLEY BROOK SITE

The Cooley Brook site (fig. 1a) is located on the township ballfield property northwest of the Queen of Peace Catholic Church. The elevation was estimated from the Greenwood Lake topographic quadrangle.

Two seismic traverses and two electrical resistivity soundings were conducted (fig. 3). Seismic refraction traverse CD-5 crossed the ballfield area in a south-north orientation. Traverse, CD-6, oriented perpendicular to the trend of a buried valley shown by Stanford (New Jersey Geological Survey, written communication, 1987) intersected CD-5 and extended across Cooley Brook.

Resistivity sounding CDVES 3 was oriented parallel to the trend of the buried valley and

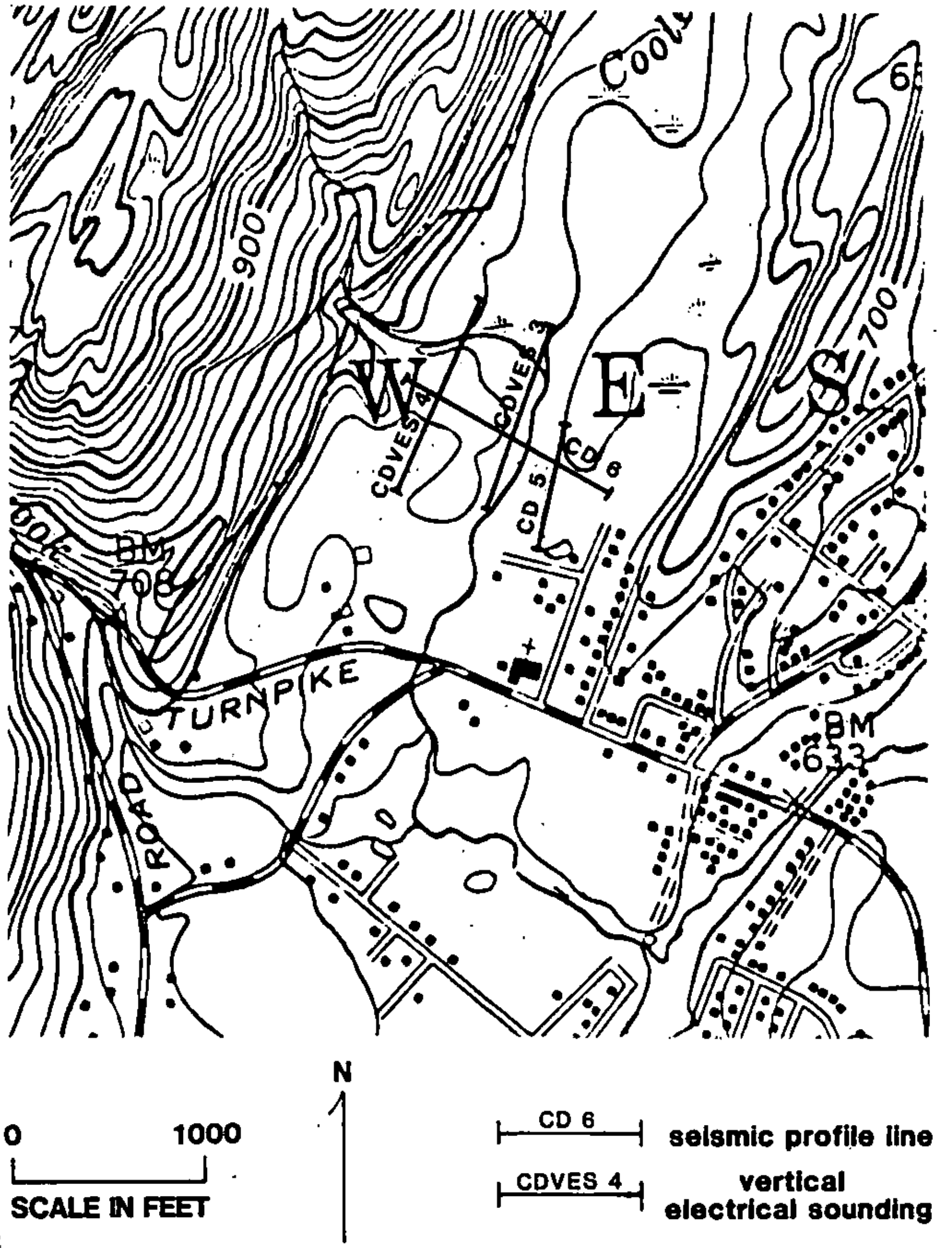


Figure 3. Geophysical survey locations at the Cooley Brook site.

was centered at geophone station 23 of spread 1 on seismic traverse CD-6 (fig. 3). The second resistivity sounding, CDVES 4, was also oriented parallel to the buried valley trend with the center located on seismic traverse CD-6 at geophone station 22 of spread 2.

Latitude-longitude coordinates for the traverse midpoints are:

CD-5 41° 09' 30" 74° 21' 18"

CD-6 41° 09' 50" 74° 21' 25"

WALLISCH PROPERTY SITE

The site (fig. 1b) is on the Wallisch farm at 65 Lincoln Avenue, approximately 5300 feet southeast of the Brown's Point site (a prior wellsite investigated under the Carl's Diner spill fund project which proved non-productive) and 6600 feet south of the Cooley Brook site. The area surveyed was north of Morseton Brook and east of Belcher Creek. The elevation was estimated from the Greenwood Lake topographic quadrangle.

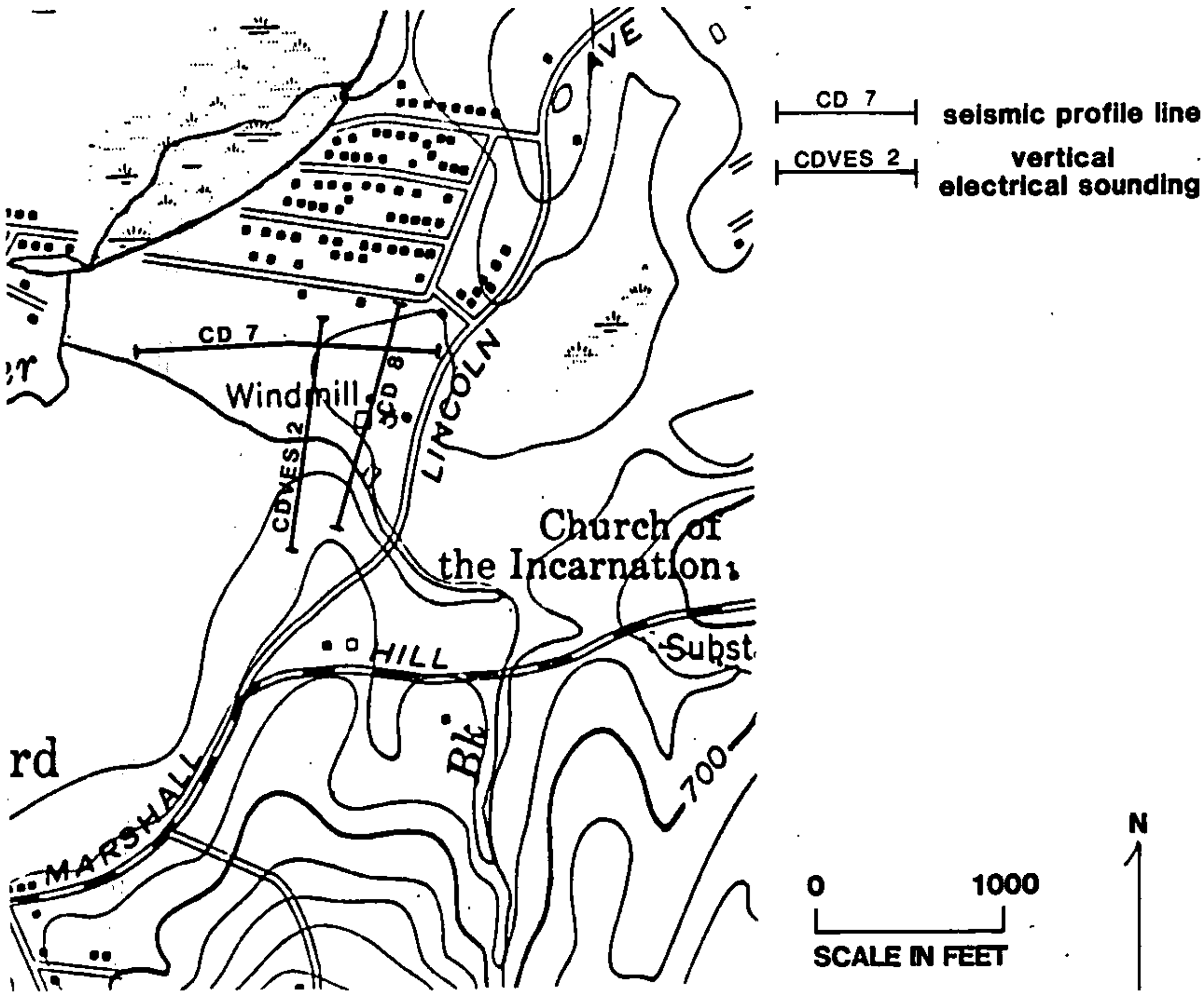


Figure 4. Geophysical survey locations at the Wallisch Property site.

The investigation included two intersecting seismic traverses (CD-8 and CD-7) and one resistivity sounding (CDVES 2). Profile CD-7 traversed open farm fields, roughly parallel to a buried gas pipeline, and ended at the intersection of the tributaries (fig. 4). Profile CD-8 intersected CD-7 at the midpoints of the first geophone spread of both traverses. The electrical resistivity sounding, CDVES 2, was centered 820 feet south of geophone station 8, spread 2 on seismic traverse CD-7 (fig. 4).

Latitude-longitude coordinates for the traverse midpoints are:

CD-7 41° 08' 26" 74° 21' 25"

CD-8 41° 08' 23" 74° 21' 22"

SURVEY DESIGN AND FIELD OPERATIONS

SEISMIC REFRACTION

The seismograph used in this study was a 24-channel Bison Instruments GeoPro 8024 non-saturating, signal enhancement seismograph. Analog filters used throughout the survey were 7- hertz Bessel high-pass and 200-hertz Butterworth or 375-hertz ChebyShev low-pass analog filters. A digital tape recorder (Bruel & Kjaer type 7400) stored data for later processing. A single geophone (Terra Cable ADR-711 accelerometer) per seismic trace was used to acquire the data.

The seismic sources which proved most effective in the survey were an EG&G Dynasource, a vacuum-activated weight drop source and an 8-gauge Buffalo gun (which detonates a shotgun shell into a 3- to 4-foot-deep, fluid-filled borehole). Half-foot increments marked along the length of the Buffalo gun showed depth of the shot below the ground surface.

Each seismic line consisted of one to three geophone spreads, with 24 geophone stations per spread. Shotpoints were 120 feet apart (or slightly offset to permit access) and the geophone station interval was 20 feet. Split traverses using one to seven shotpoints per geophone spread gave maximum redundancy of data and allowed the high resolution of the seismic interpretation. Locations of the shotpoints used for each spread were as follows: 130 and 10 feet from geophone station 1, at midpoints between geophone stations 6 and 7, 12 and 13, 18 and 19, and reverse shotpoints 10 and 130 feet from geophone station 24. Geophone spreads were 20 feet apart (geophone station 1 of spread 2 was 20 feet from geophone station 24 of spread 1), thus enabling the forward and reverse offset shotpoint locations to be reoccupied for adjoining spreads, as shown in figure 5. Shotpoints along the seismic lines were surveyed for elevation control relative to datum.

ELECTRICAL RESISTIVITY

The resistivity receiver used in this study was a Bison Instruments 2390. The data were collected at 10 current electrode separations per decade, spaced at logarithmic intervals. The potential electrodes used were non-polarizable copper-copper sulfate porous pots and the current electrodes were steel stakes.

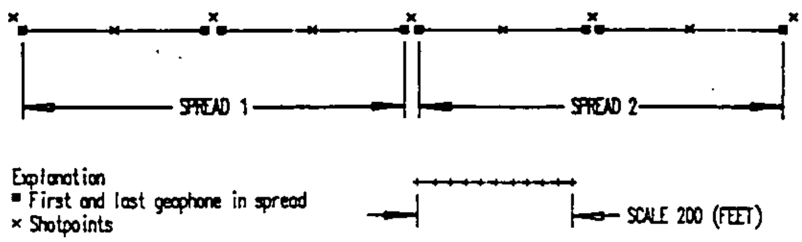


Figure 5. Seismic refraction field array showing shotpoint and geophone locations.

GEOPHYSICAL DATA REDUCTION AND INTERPRETATION

SEISMIC REFRACTION - DATA REDUCTION

Arrival times for the seismic refraction events (appendix A) were determined directly from the seismograph. The data were then processed using SIPT, a seismic refraction inverse modeling computer program (Scott and others, 1972; Scott, 1977; Haeni and others, 1987). This program uses the delay-time method and a ray- tracing modeling technique. Each traverse was re-evaluated according to its line-tie fit and reprocessed using an averaged velocity for the saturated overburden and bedrock.

SEISMIC REFRACTION - INTERPRETATION

Cooley Brook Site

Seismic velocities for the overburden material ranged between 1,300 ft/s and 1,900 ft/s for unsaturated material and 4,600 ft/s and 6,300 ft/s for saturated sediments. The bedrock velocity was between 13,000 ft/s and 13,600 ft/s. Profiles showing acoustic basement topography, overburden thickness, water-table, and ground surface were constructed from the seismic interpretation plots (figs. 6 and 7).

The bedrock profiles for both CD-5 and CD-6 are undulatory and correlate well with mapped bedrock contours (fig. 8). Stratigraphic interpretation (G. Herman, New Jersey Geological Survey, written commun., 1987) and seismic velocities suggest that the bedrock is the Cornwall Formation of Devonian age (figs. 9 and 10).

Barnett (1976), using the now superseded name Marcellus Formation, describes the Cornwall as a very dark gray, slightly silty shale. Local exposures show open fractures roughly one millimeter in width oriented cross-strike (G. Herman, New Jersey Geological Survey, written commun., 1987).

Wallisch Property Site

Profiles showing acoustic basement topography, overburden thickness, and ground surface were constructed from the seismic interpretation plots (figs. 11 and 12). Average seismic velocities for the overburden material are 1,800 ft/s for unsaturated material and 5,900 ft/s for saturated sediments. The average bedrock velocity was 16,600 ft/s for both profiles.

The seismic bedrock profile for both CD-7 and CD-8 compares well with mapped bedrock contours (fig. 13). Stratigraphic interpretation (G. Herman, New Jersey Geological Survey, written commun., 1987) and seismic velocity analysis suggest that the bedrock is Precambrian gneiss or granite in fault contact with the Green Pond conglomerate (figs. 11, 14).

ELECTRICAL RESISTIVITY - DATA REDUCTION

The true resistivities of the layered earth sections (appendix B) were determined using the inverse modeling program RESINV (J. Groenewold, New Jersey Geological Survey, written communication, 1987). Some of the layer thicknesses were constrained using information derived from the seismic refraction data.

ELECTRICAL RESISTIVITY - INTERPRETATION

Cooley Brook Site

The modeling results for CDVES 3 are presented in figure 16a. The first layer has a resistivity of 1332 ohm-meters and is 1.3 feet (0.4 meters) thick; this layer represents the unsaturated soil horizon. The next layer has a resistivity of 3759 ohm-meters and is 9.2 feet (2.8 meters) thick; this layer is the unsaturated alluvium. The modeled third layer has a resistivity of 544 ohm-meters and a thickness of 203.8 feet (63.5 meters) and does not correlate directly with the seismic horizons. The seismic interpretation places the interface between the saturated alluvium and the shale bedrock within the modeled resitivity third layer. As the boundary between the saturated alluvium and the shale could not be resolved, it is evident that there is little resistivity contrast between them.

The modeling results for CDVES4 are presented in figure 15b. The first layer is a saturated soil having a resistivity of 534 ohm-meters and a thickness of 1.0 feet (0.3 meters). The second layer has a resistivity of 5132 ohm-meters (typical for unsaturated alluvium) and is 15.4 feet (4.7 meters) thick. The third layer has a resistivity of 553 ohm-meters, which again represents a combined layer consisting of the saturated alluvium and shale bedrock.

Wallisch Property Site

The modeling results for CDVES 2 are presented in figure 16. The first layer consists of the unsaturated soil horizon, with a resistivity of 666 ohm-meters and a thickness of 2.5 feet (0.8 meters). The next two layers are interpreted as alluvium, with the second layer being the unsaturated zone represented by a resistivity of 196 ohm-meters and a thickness of 5.9 feet (1.8 meters). The third layer is saturated alluvium, having a resistivity of 63 ohm-meters and a thickness of 22.3 feet (6.8 meters). The resistivities of the alluvium layers are quite

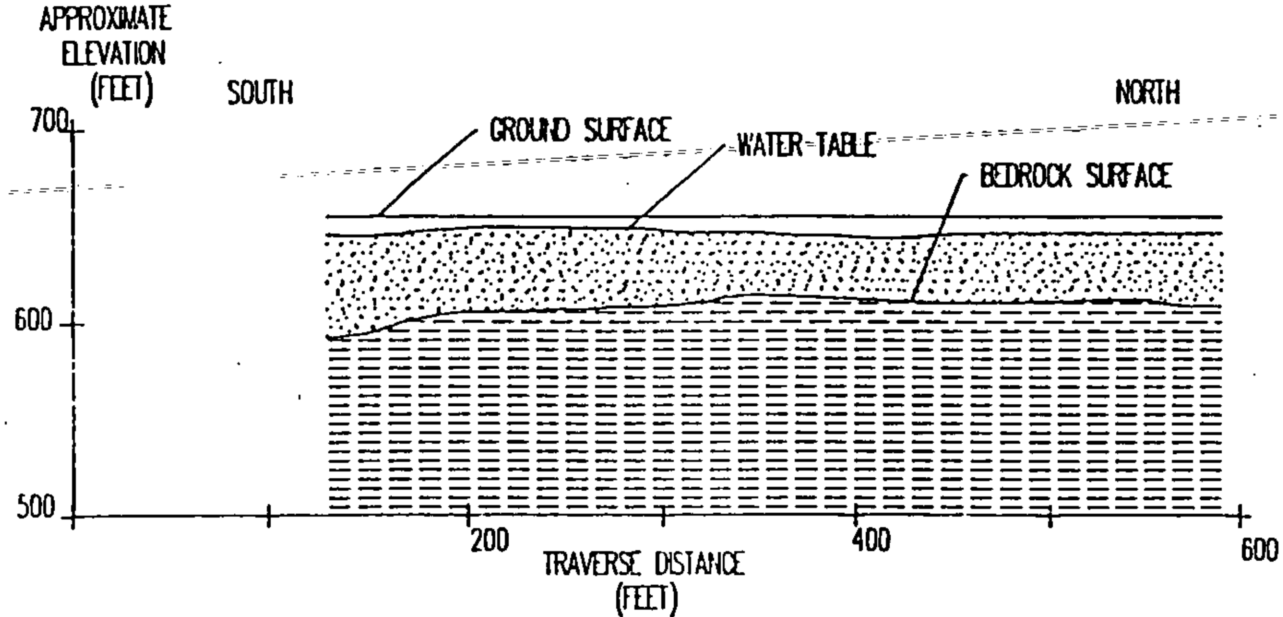


Figure 6. Interpreted seismic profile, traverse CD 5, Cooley Brook site.

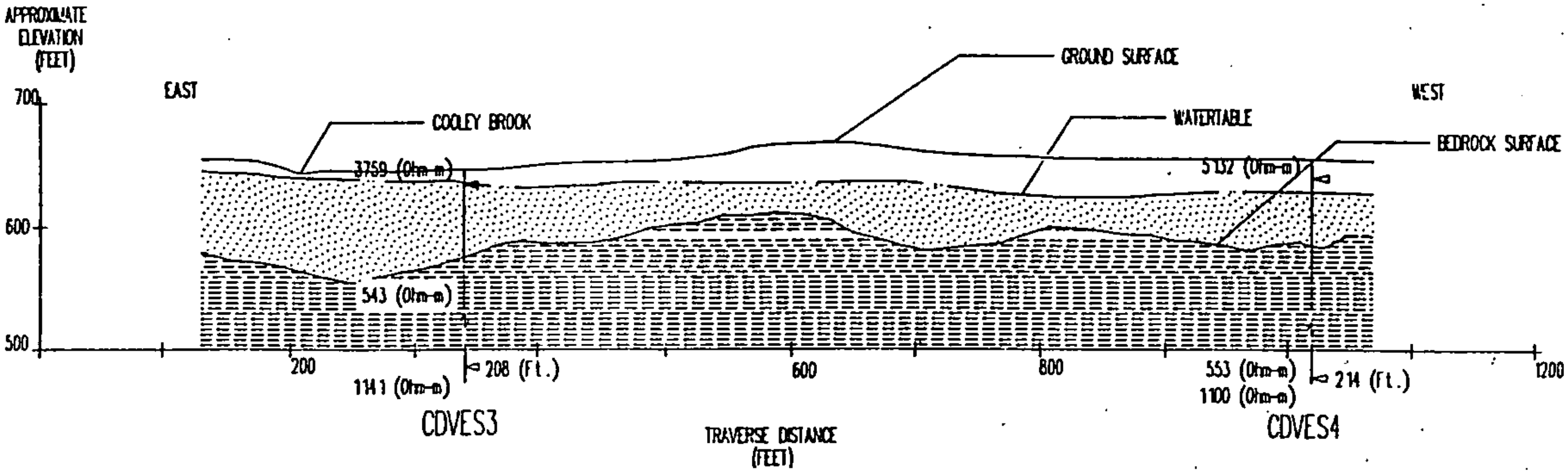


Figure 7. Interpreted seismic profile, traverse CD 6, Cooley Brook site, showing the locations of resistivity soundings CDVES 3 and CDVES 4.

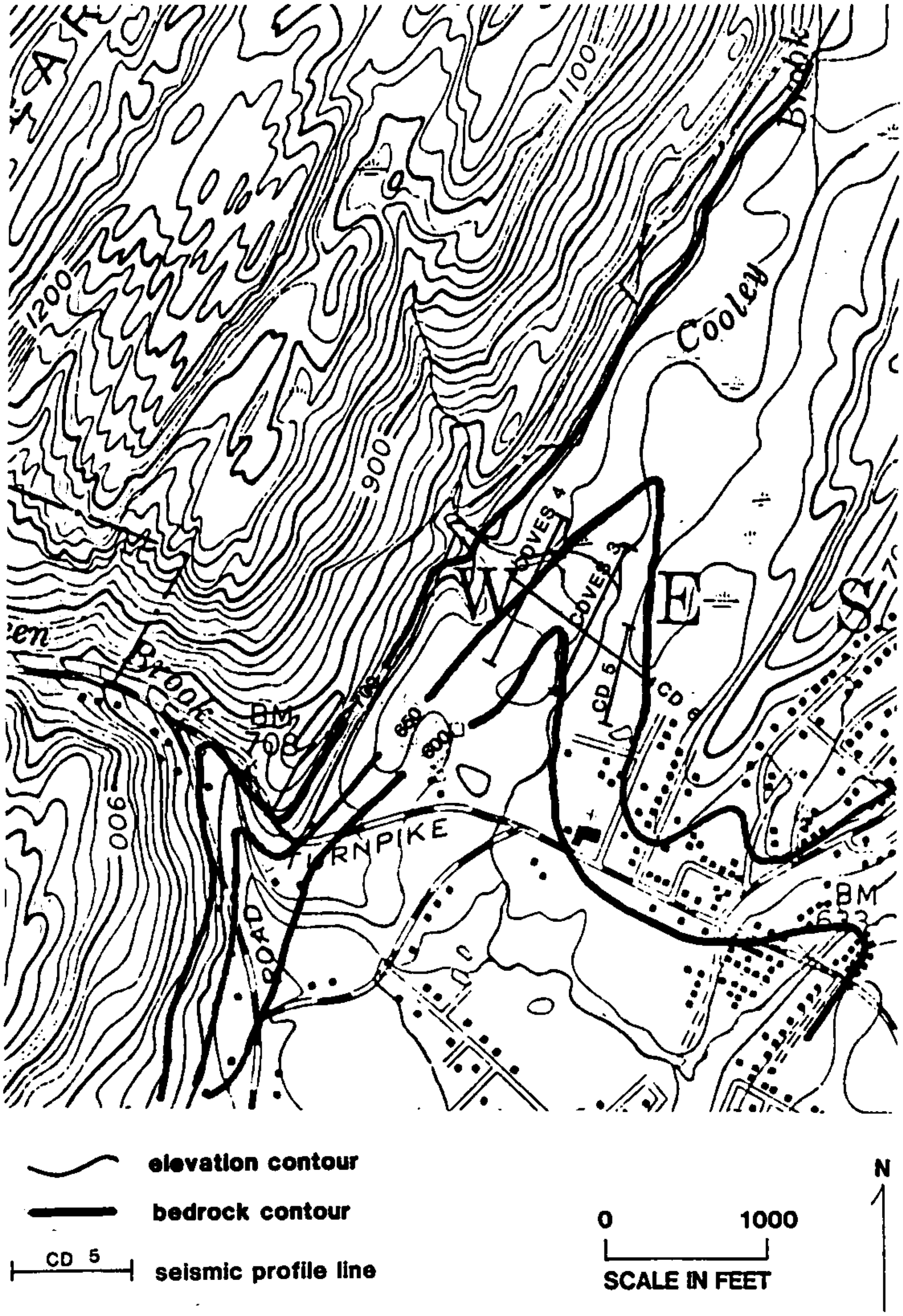


Figure 8. Bedrock contour map of the Cooley Brook site (from Stanford, unpub).

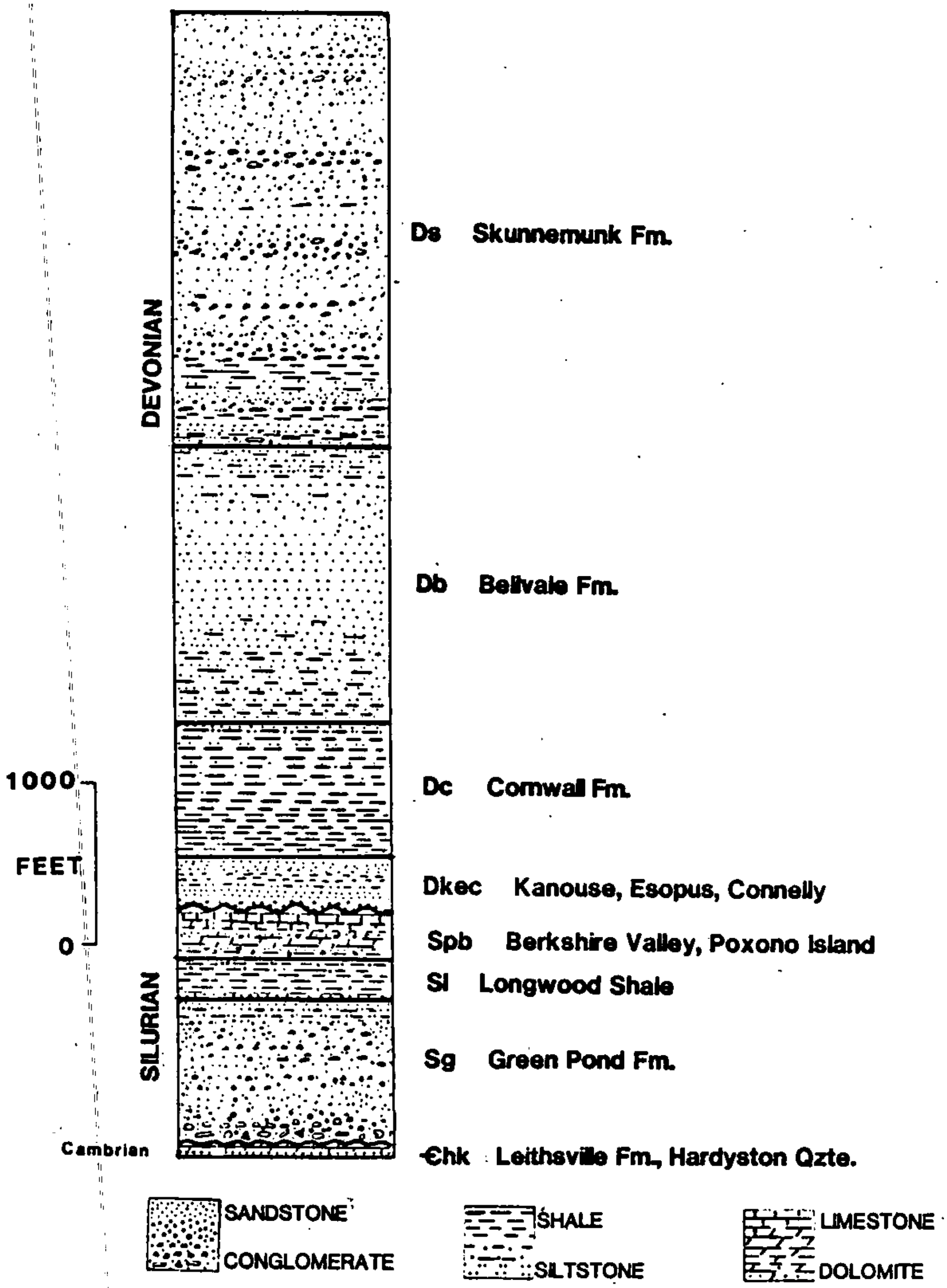


Figure 9. Cambrian-Devonian stratigraphic column, West Milford area (modified from Herman and Mitchell, in press).

Figure 10. Cooley Brook site geophysical survey locations. Geology from Herman and Mitchell (in press).

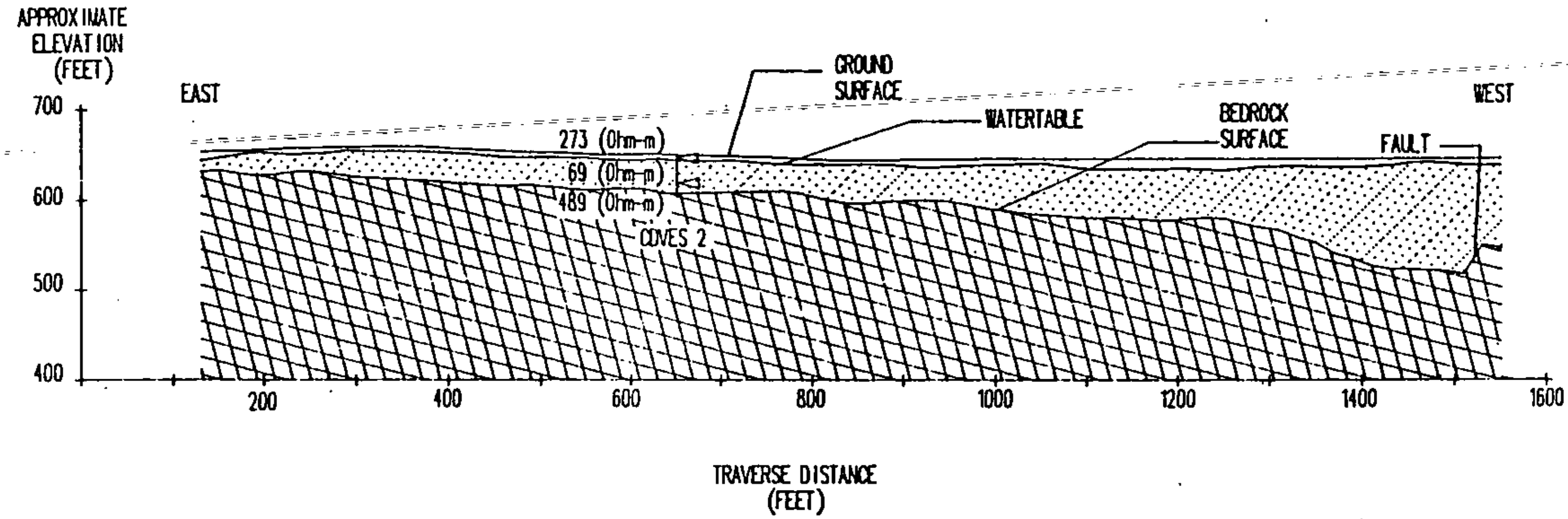


Figure 11. Interpreted seismic profile CD 7, Wallisch Property site, showing the location of resistivity sounding CDVES 2.

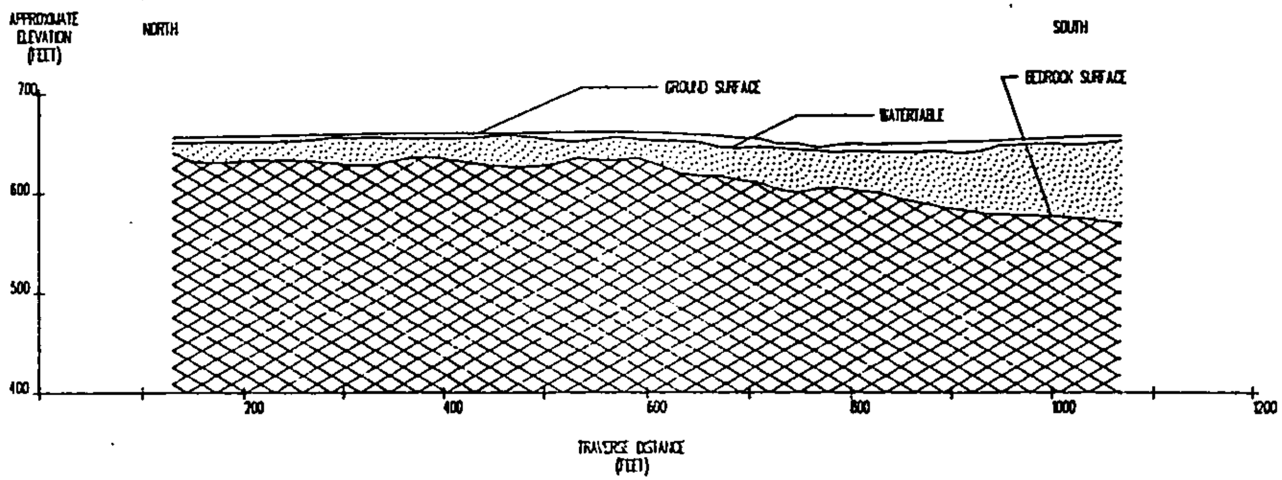


Figure 12. Interpreted seismic profile CD 8 at Wallisch Property site.

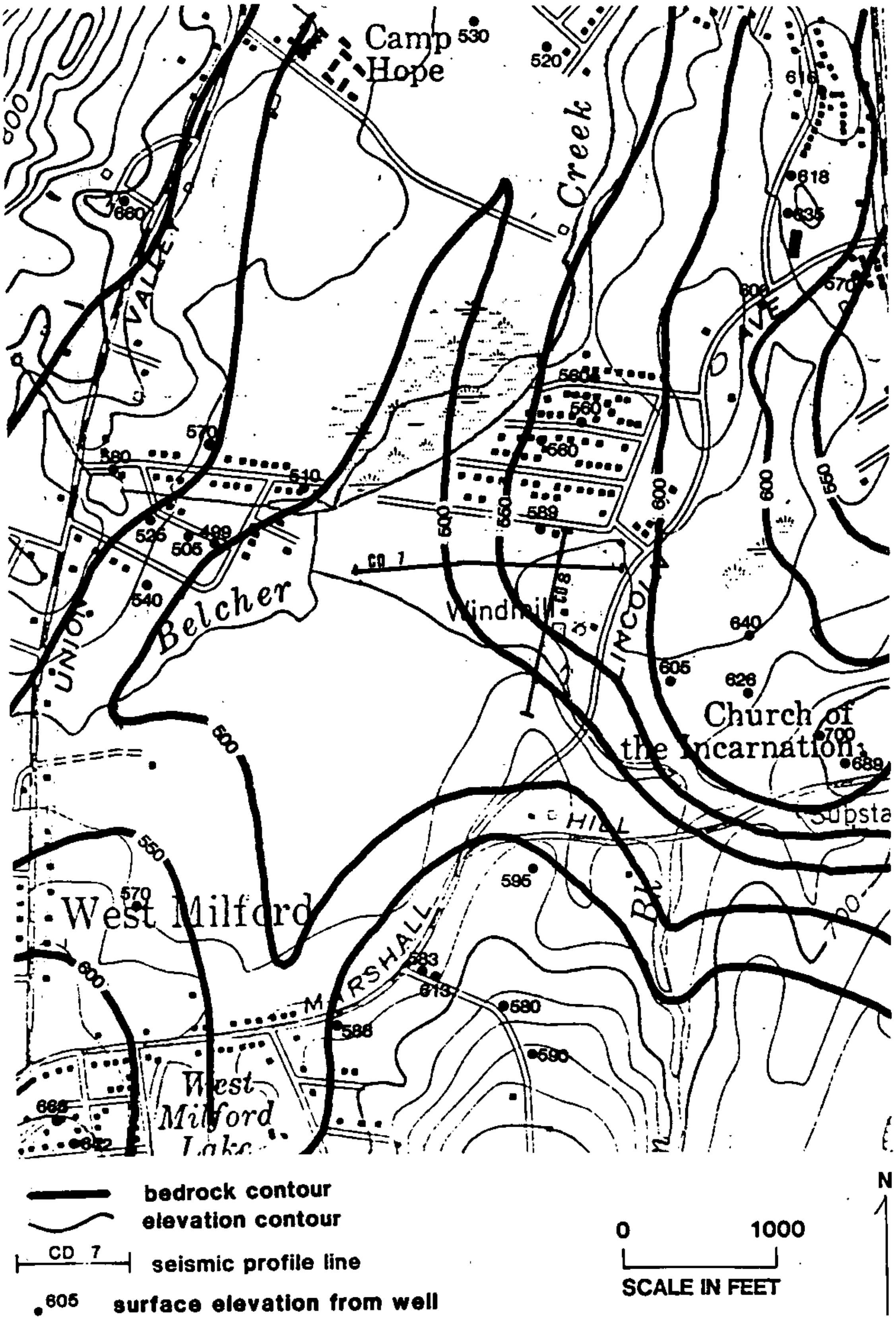


Figure 13. Bedrock contour map of the Wallisch Property site (modified from Stanford, unpub.).

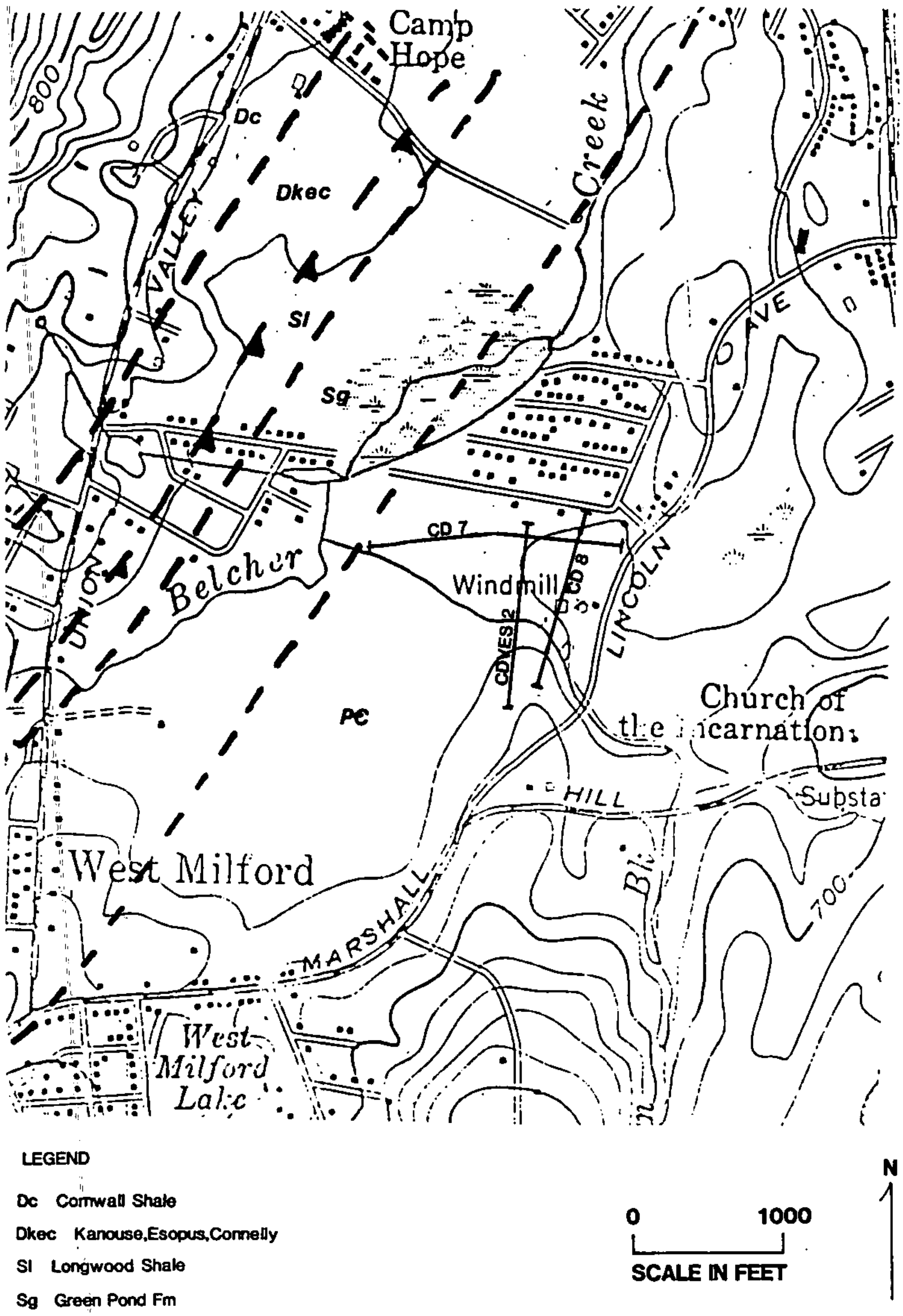


Figure 14. Wallisch Property site geophysical survey locations and geologic interpretation (modified from Herman and Mitchell, in press).

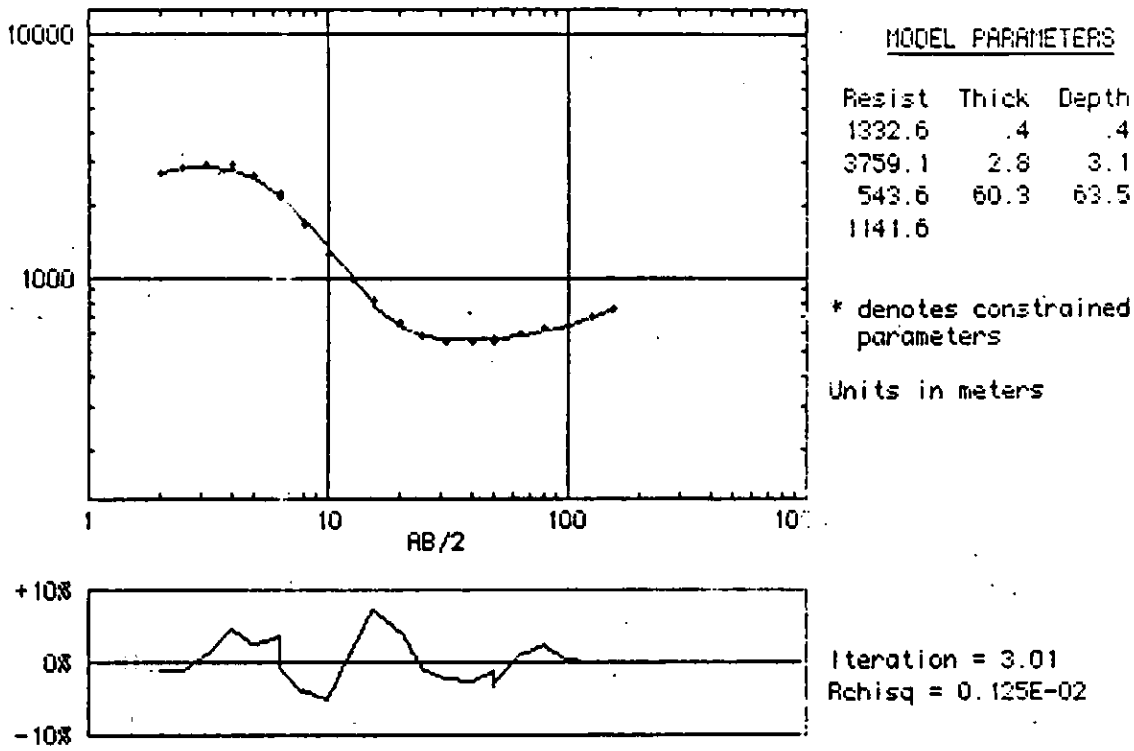


Figure 15a. Resistivity modeling plot for sounding CDVES 3, Cooley Brook site.

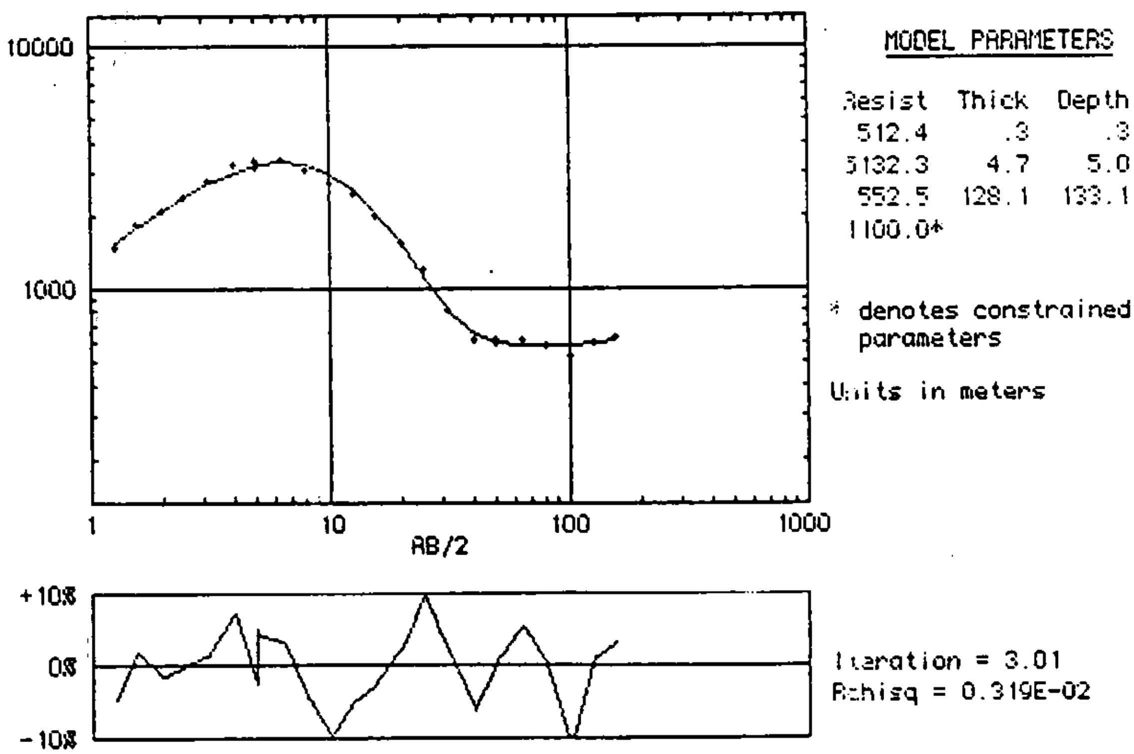


Figure 15b. Resistivity modeling plot for sounding CDVES 4, Cooley Brook site.

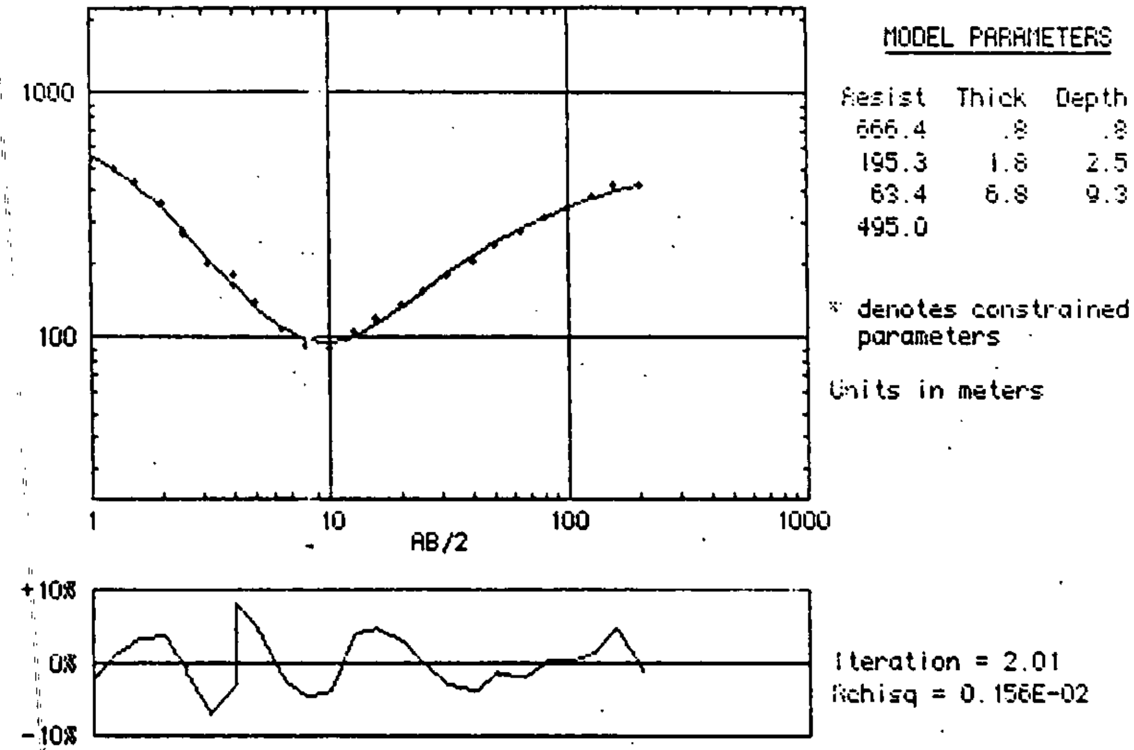


Figure 16. Resistivity modeling plot for sounding CDVES 2, Wallisch Property site.

low, which suggests a clayey composition. The resistivity below the resolved third layer is 495 ohm-meters, which is less than typical for Precambrian bedrock. This bedrock resistivity is likely the result of fracturing and clay alteration within the fractures.

INTEGRATED INTERPRETATION AND RECOMMENDATIONS

At both sites, geological and geophysical evidence indicates that ground water may be available. Both sites have areas where 1) glacial overburden ranges between 50 and 100 feet thick, 2) ground-water may be available from the bedrock (from fractures in the Cornwall Formation at the Cooley Brook site, from the fault zone at the Wallisch property site), and 3) a surface-water body is in close proximity.

The glacial overburden has been interpreted to be deltaic sequences overlying lake-bottom sediments at the Cooley Brook site and lake bottom sediments at the Wallisch property site (R. Witte, New Jersey Geological Survey, written commun., 1987) Supporting this, the resistivity interpretation also suggests that the overburden material has a greater clay content at the Wallisch Property site. While the fine-grained, lake-bottom sediments are marginal for ground-water production, the bedrock structure, particularly at the Wallisch property site, may allow a productive zone.

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APPENDIX A

Seismic Refraction Traverses
Arrival Times and Refraction Traveltime Curves

ARRIVAL TIMES SEISMIC LINE CD-5 SPREAD # 1
COOLEY BROOK SITE

Arrival Times in Milliseconds (ms)

Shot Location

Geophone Station	Shot 1 (130'F)	Shot 2 (10'F)	Shot 3 (6&7)	Shot 4 (10'R)	Shot 5 (130'R)	Shot 6 (250'R)
1	38.1	8.8	36.5	49.3	----	56.9
2	45.3	20.4	34.5	49.3	56.1	55.7
3	46.5	24.5	26.9	44.1	52.9	51.7
4	47.3	26.5	22.5	39.7	49.7	50.1
5	47.3	30.5	18.0	37.3	48.9	48.9
6	48.9	34.5	9.4	34.9	47.3	46.9
7	50.5	38.5	9.4	32.5	46.1	46.1
8	51.3	----	20.4	----	44.1	42.9
9	53.7	45.3	24.9	27.3	43.3	43.7
10	54.9	47.3	30.1	22.5	40.9	41.7
11	55.3	48.1	33.3	18.8	28.1	38.9
12	56.1	48.9	38.1	8.4	----	37.3

ARRIVAL TIMES SEISMIC LINE CD-5 SPREAD # 2
COOLEY BROOK SITE

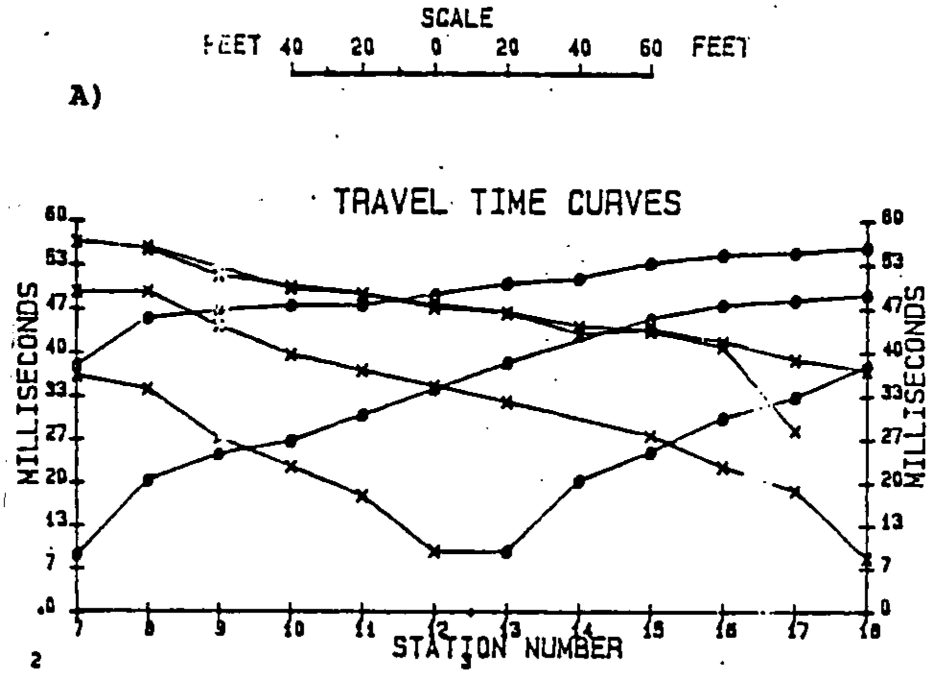
Arrival Times in Milliseconds (ms)

Shot Location

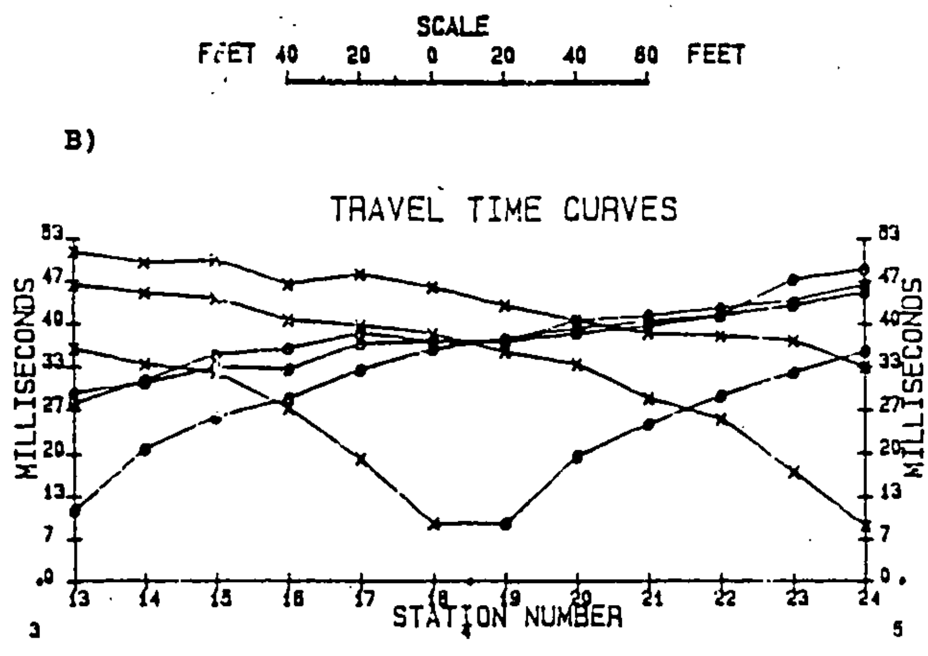
Geophone Station	Shot 1 (250'F)	Shot 2 (130'F)	Shot 3 (10'F)	Shot 4 (6&7)	Shot 5 (10'R)	Shot 6 (80'R)
1	29.3	27.7	11.2	36.1	46.1	51.3
2	30.9	31.3	20.8	33.7	44.9	49.7
3	33.3	35.3	25.6	32.5	44.1	50.1
4	32.9	36.1	28.5	26.9	40.5	46.1
5	36.9	38.5	32.9	19.2	39.7	47.7
6	37.3	37.3	36.1	9.2	38.5	45.7
7	37.3	37.3	37.7	9.2	35.7	42.9
8	38.5	40.5	39.3	19.6	33.7	40.5
9	39.7	41.3	40.5	24.5	28.5	38.5
10	41.3	42.5	41.3	28.9	25.3	38.1
11	46.9	43.7	42.9	32.5	17.2	37.3
12	48.5	46.1	44.9	35.7	8.8	33.3

F= Forward Shot Direction
R= Reverse Shot Direction
- Arrival Times could not be determined

A)



B)



REFRACTION TRAVELTIME CURVES
COOLEY BROOK SITE CD-5

A) CD-5 SPREAD 1
B) CD-5 SPREAD 2

ARRIVAL TIMES SEISMIC LINE CD-6 SPREAD # 1
COOLEY BROOK SITE

Arrival Times in Milliseconds (ms)

Shot Location

Geophone Station	Shot 1 (130'F)	Shot 2 (10'F)	Shot 3 (6&7)	Shot 4 (12&13)	Shot 5 (18&19)
1	41.4	5.2	27.8	---	65.4
2	43.4	11.8	23.0	---	63.8
3	45.8	16.2	19.0	---	61.8
4	----	20.2	14.6	---	60.2
5	43.4	23.4	7.0	---	59.0
6	----	25.8	1.4	25.0	57.4
7	----	33.4	1.4	23.0	54.6
8	53.8	39.8	8.2	19.4	52.6
9	----	43.0	12.2	16.2	50.2
10	55.8	47.4	16.6	13.0	47.8
11	----	50.6	20.2	9.4	44.2
12	57.8	53.8	----	5.0	41.0
13	59.4	54.2	33.0	5.0	38.6
14	61.4	56.6	37.4	10.6	32.2
15	64.2	59.4	39.8	17.0	26.6
16	65.8	61.0	41.8	22.0	20.2
17	67.8	63.0	44.0	27.0	12.0
18	69.8	64.0	45.8	33.0	3.4
19	----	63.0	47.8	36.0	3.4
20	72.6	67.6	50.2	39.4	11.0
21	74.6	69.0	53.0	42.4	17.8
22	77.0	71.4	55.8	44.2	24.2
23	79.8	73.8	58.2	46.6	31.8
24	82.2	76.2	61.0	49.0	37.0

F= Forward Shot Direction
R= Reverse Shot Direction
\- Arrival Times could not be determined

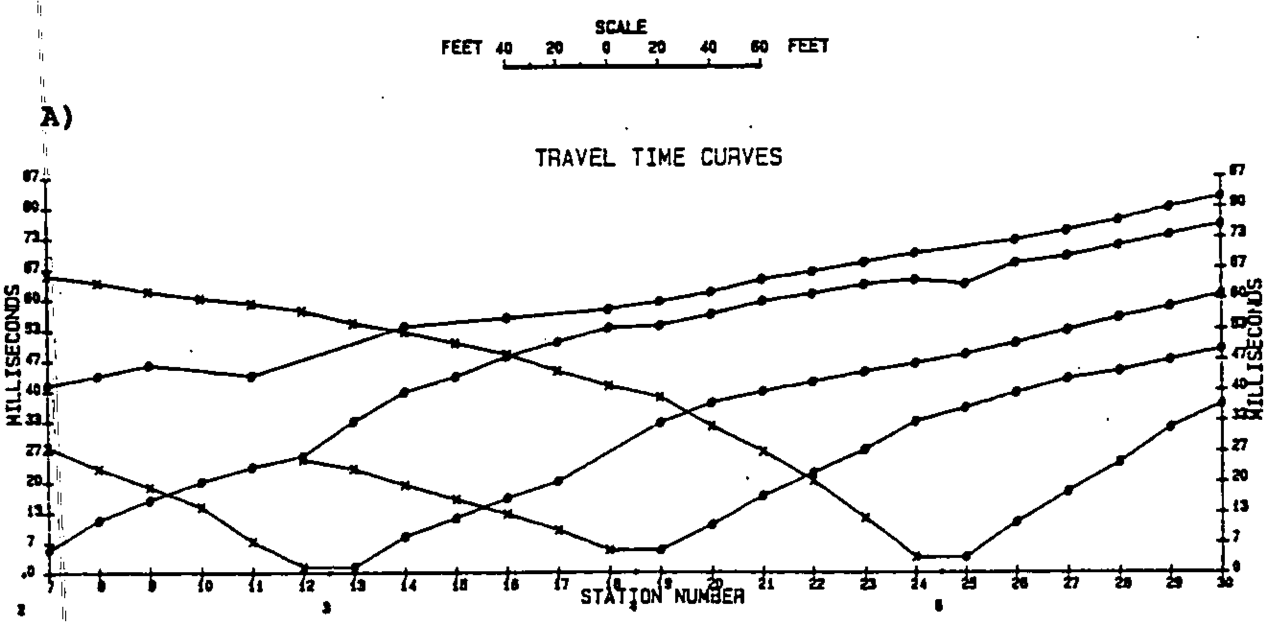
ARRIVAL TIMES SEISMIC LINE CD-6 SPREAD # 2
COOLEY BROOK SITE

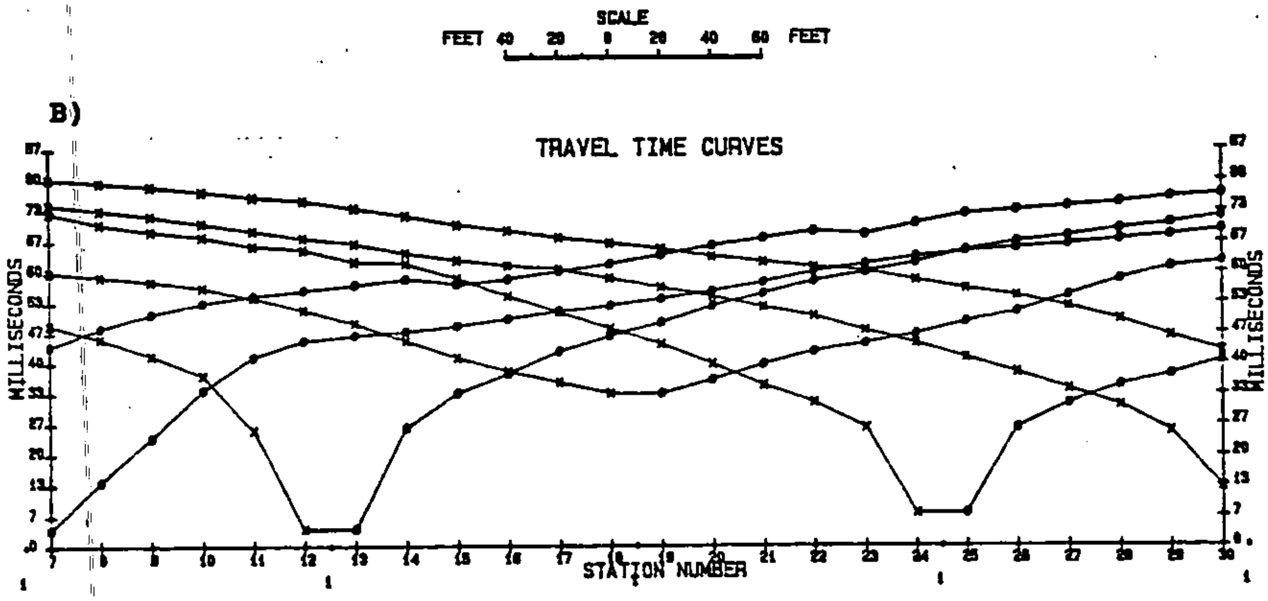
Arrival Times in Milliseconds (ms)

Shot Location

Geophone Station	Shot 1 (130'F)	Shot 2 (10'F)	Shot 3 (6&7)	Shot 4 (12&13)	Shot 5 (18&19)	Shot 6 (10'R)	Shot 7 (130'R)
1	43.8	3.8	48.5	60.1	72.9	74.6	80.2
2	47.8	14.2	45.5	59.1	70.5	73.4	79.4
3	51.0	23.8	41.7	58.1	68.9	72.2	78.6
4	53.4	34.2	37.3	56.7	67.7	70.6	77.4
5	55.0	41.4	25.3	54.5	65.7	69.0	76.2
6	56.2	45.0	3.9	51.7	64.9	67.4	75.4
7	57.4	46.2	3.9	48.7	62.3	66.2	73.8
8	58.6	47.0	25.9	44.9	61.9	64.2	72.2
9	57.4	48.2	33.5	41.1	58.7	62.6	70.2
10	58.6	49.8	37.7	38.1	54.7	61.4	69.0
11	60.2	51.4	42.5	35.7	51.1	60.6	67.4
12	61.8	52.6	45.9	33.3	47.5	58.6	66.2
13	63.8	54.2	48.9	33.3	44.1	56.6	65.0
14	65.8	55.8	52.5	36.3	39.7	54.6	63.4
15	67.4	57.8	55.3	39.7	35.1	52.2	62.2
16	69.0	60.2	58.1	42.5	31.3	50.2	61.0
17	68.2	61.8	60.1	44.3	25.7	47.0	60.2
18	70.6	63.4	62.1	46.3	7.3	44.2	58.2
19	72.6	64.6	64.7	48.9	7.3	41.0	56.2
20	73.4	66.6	65.3	51.1	25.7	37.8	54.6
21	74.2	67.8	66.1	54.7	31.3	34.2	52.2
22	75.0	69.4	67.1	58.3	35.1	30.6	49.4
23	76.2	70.6	68.1	61.1	37.5	25.0	45.8
24	77.0	72.2	69.3	62.3	40.7	13.0	42.6

F= Forward Shot Direction
R= Reverse Shot Direction
- Arrival Times could not be determined





REFRACTION TRAVELTIME CURVES
COOLEY BROOK SITE CD-6

A) CD-6 SPREAD 1
B) CD-6 SPREAD 2

ARRIVAL TIMES SEISMIC LINE CD-7 SPREAD # 1
WALLISCH PROPERTY SITE

Arrival Times in Milliseconds (ms)

Shot Location

Geophone Station	Shot 1 (131'F)	Shot 2 (10'F)	Shot 3 (6&7)	Shot 4 (12&13)	Shot 5 (18&19)	Shot 6 (10'R)	Shot 7 (130'R)
1	22.2	7.9	19.9	25.2	36.5	42.8	53.4
2	23.0	13.7	17.0	24.2	34.6	40.0	51.8
3	23.8	15.5	15.9	23.1	33.0	39.0	50.6
4	24.2	16.7	14.5	22.0	32.1	38.2	49.8
5	26.2	17.7	12.8	21.1	31.4	38.0	48.6
6	27.0	18.1	8.1	20.7	----	37.2	47.8
7	27.8	19.9	7.3	19.3	30.7	35.8	46.2
8	28.6	21.1	13.4	18.0	29.0	34.8	45.0
9	29.8	22.5	15.3	17.3	28.2	34.1	44.2
10	31.0	24.1	17.8	16.4	27.1	33.1	43.0
11	32.6	25.1	19.0	12.3	26.1	32.3	42.1
12	34.6	26.5	20.6	6.3	25.0	31.7	41.0
13	35.8	28.1	22.7	6.8	24.2	31.0	39.8
14	37.0	29.7	23.8	12.9	22.4	30.3	38.6
15	38.6	30.7	24.8	16.0	19.7	28.5	37.0
16	40.6	32.7	26.8	19.0	16.9	27.5	35.4
17	42.2	33.9	28.0	21.7	14.1	26.9	34.2
18	43.4	34.8	30.2	23.0	7.3	24.5	33.0
19	44.6	35.8	31.6	23.5	7.3	23.3	32.6
20	45.8	36.6	32.0	24.2	13.9	20.9	31.8
21	46.6	37.6	33.2	26.2	16.5	18.5	30.6
22	47.8	39.0	33.8	27.2	18.8	15.5	29.4
23	48.6	40.4	34.9	28.6	21.3	12.7	28.2
24	49.8	41.2	36.0	29.7	23.2	7.3	26.6

F= Forward Shot Direction
R= Reverse Shot Direction
- Arrival Times could not be determined

ARRIVAL TIMES SEISMIC LINE CD-7 SPREAD # 2
WALLISCH PROPERTY SITE

Arrival Times in Milliseconds (ms)

	Shot Location						
Geophone Station	Shot 1 (130'F)	Shot 2 (10'F)	Shot 3 (6&7)	Shot 4 (12&13)	Shot 5 (18&19)	Shot 6 (10'R)	Shot 7 (130'R)
1	26.5	6.7	25.4	31.5	40.9	51.6	63.0
2	27.7	11.3	21.4	30.5	39.1	49.6	62.2
3	29.9	14.9	18.8	29.1	37.5	48.4	60.6
4	31.5	18.3	15.9	28.2	36.4	47.0	59.4
5	32.7	20.7	12.4	25.8	35.5	45.0	58.2
6	33.9	23.5	5.9	24.2	34.5	43.6	56.2
7	34.5	26.5	9.6	23.0	32.8	42.6	55.8
8	35.0	27.5	12.6	20.3	31.6	42.0	54.5
9	36.5	28.5	15.7	17.0	30.2	41.0	53.8
10	37.2	29.3	18.5	13.8	29.3	----	53.0
11	39.2	30.3	22.7	10.6	28.7	40.6	51.0
12	41.0	32.2	24.9	7.8	27.7	39.0	50.2
13	41.8	33.2	25.7	5.6	24.4	38.0	49.4
14	42.2	34.6	26.5	9.4	20.1	37.0	48.6
15	44.0	35.0	27.9	13.3	17.2	36.1	47.8
16	45.4	37.6	29.6	18.4	14.6	35.3	46.5
17	47.0	38.4	31.1	21.6	9.9	33.5	45.8
18	48.0	39.2	32.3	23.1	4.3	29.5	44.2
19	49.8	41.8	34.3	26.9	5.8	27.1	43.4
20	50.6	43.2	36.7	28.9	10.1	24.3	42.6
21	52.6	45.8	39.0	31.2	14.6	20.3	41.4
22	53.8	46.6	40.1	32.2	17.4	15.1	37.8
23	54.8	47.4	41.0	33.3	20.2	10.5	33.4
24	56.2	49.8	42.1	34.6	23.9	6.9	31.4

F= Forward Shot Direction
R= Reverse Shot Direction
- Arrival Times could not be determined

ARRIVAL TIMES SEISMIC LINE CD-7 SPREAD # 3
WALLISCH PROPERTY SITE

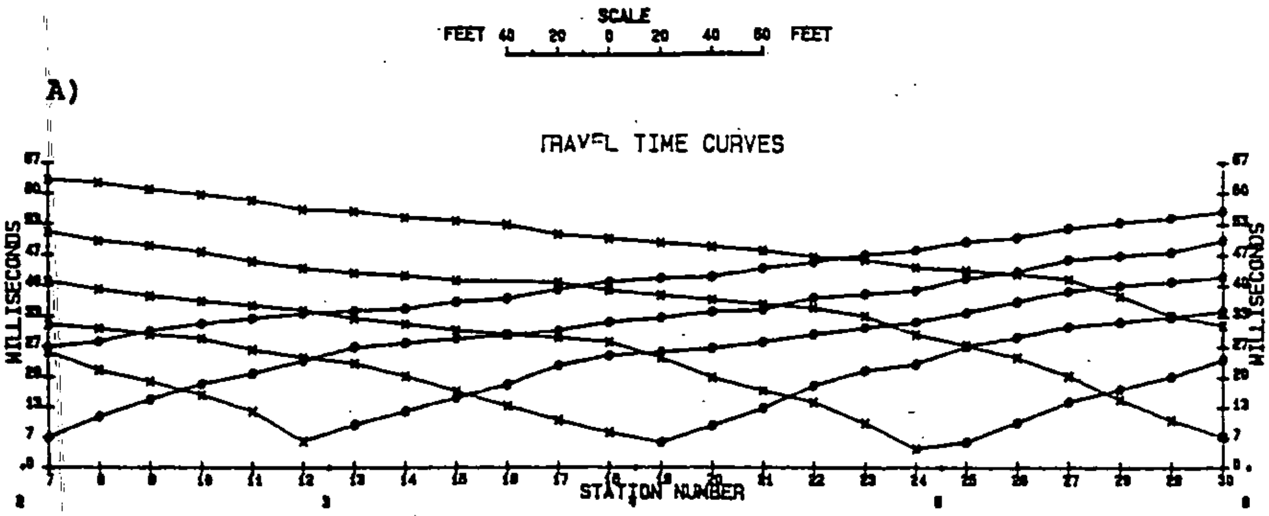
Arrival Times in Milliseconds (ms)

Shot Location

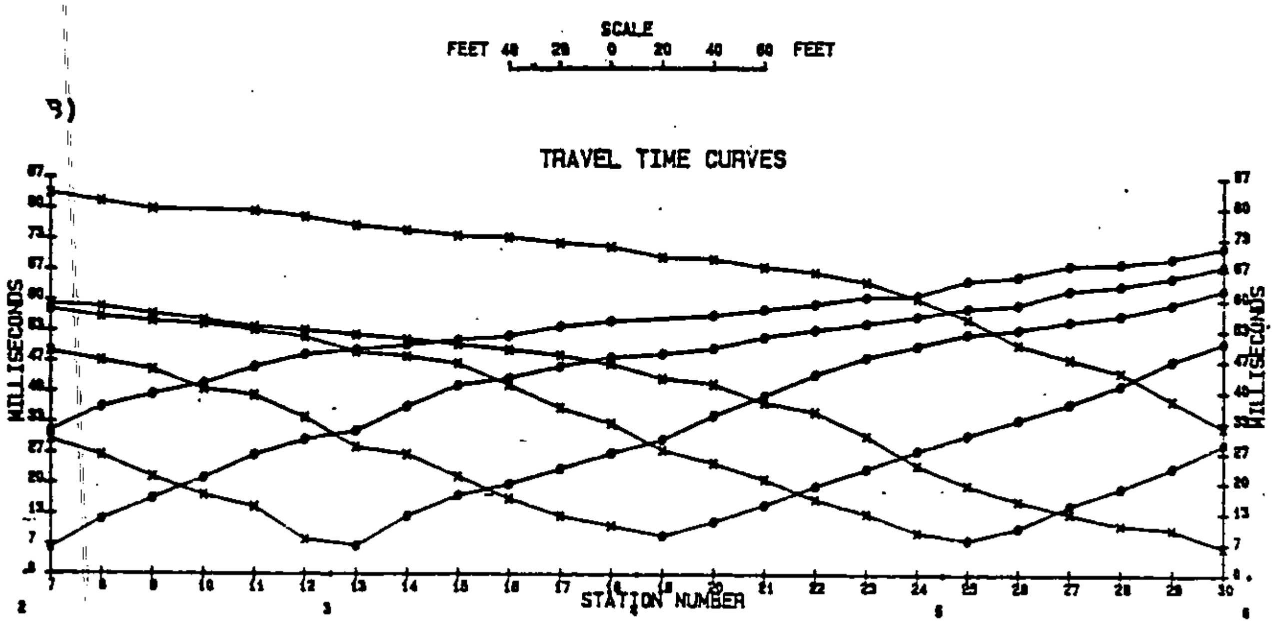
Geophone Station	Shot 1 (130'F)	Shot 2 (10'F)	Shot 3 (6&7)	Shot 4 (12&13)	Shot 5 (18&19)	Shot 6 (10'R)	Shot 7 (130'R)
1	31.4	5.7	29.5	48.8	58.0	59.0	83.2
2	36.6	12.1	26.1	46.8	56.4	58.6	81.6
3	39.4	16.7	21.3	44.8	55.4	57.0	80.0
4	41.8	21.1	17.3	40.4	54.8	55.8	----
5	45.4	26.1	14.7	39.0	53.5	54.2	79.6
6	48.2	29.5	7.5	34.2	52.0	53.4	78.4
7	49.2	31.3	6.1	27.7	48.6	52.4	76.4
8	50.2	36.6	12.7	26.1	47.6	51.4	75.2
9	51.4	41.2	17.3	21.3	46.0	50.2	74.0
10	52.2	42.8	19.7	16.5	41.2	49.0	73.6
11	54.2	45.4	23.1	12.7	36.2	47.8	72.4
12	55.4	47.4	26.5	10.5	32.9	45.8	71.6
13	----	48.2	29.5	8.3	27.1	42.6	69.2
14	56.6	49.4	34.8	11.5	24.3	41.4	68.8
15	57.8	51.8	39.0	15.1	20.7	37.4	67.0
16	59.0	53.4	43.6	19.3	16.3	35.4	65.8
17	60.6	54.8	47.3	23.1	13.1	30.2	63.8
18	61.0	56.4	50.0	27.1	9.1	23.8	60.2
19	64.2	58.2	52.6	30.5	7.5	19.4	55.8
20	65.2	59.0	53.6	34.0	10.1	16.0	50.2
21	67.6	62.2	55.4	37.6	15.1	13.2	47.0
22	68.0	63.2	56.8	41.6	18.9	10.7	44.2
23	69.2	65.0	59.2	46.8	23.5	9.8	38.2
24	71.6	67.6	62.4	50.8	28.7	6.0	32.2

F= Forward Shot Direction
R= Reverse Shot Direction
\- Arrival Times could not be detrermined

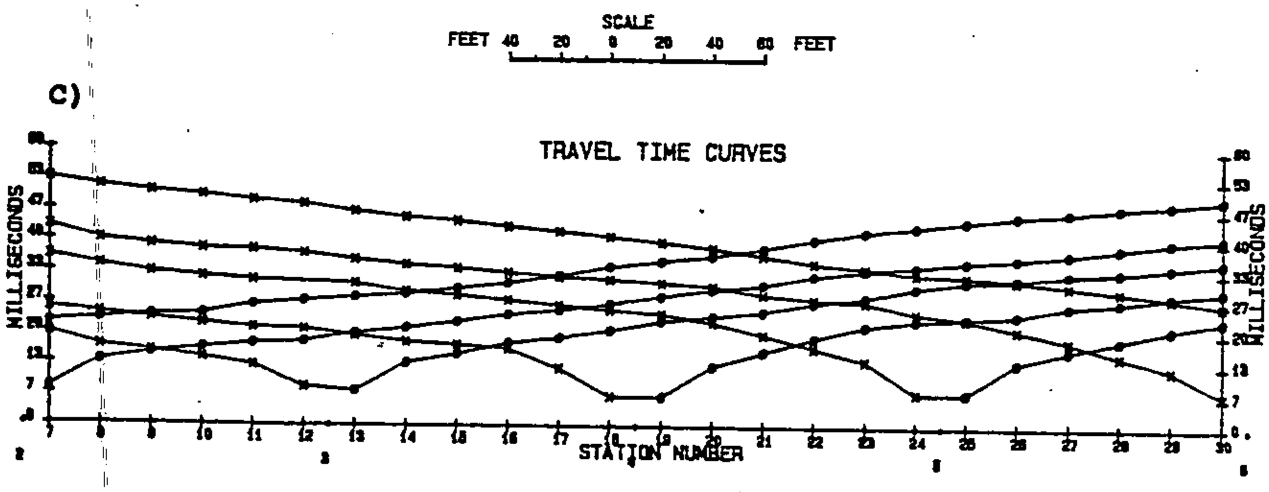
A)



B)



C)



REFRACTION TRAVELTIME CURVES
WALLISH PROPERTY SITE CD-7

A) CD-7 SPREAD 1
B) CD-7 SPREAD 2
C) CD-7 SPREAD 3

ARRIVAL TIMES SEISMIC LINE CD-8 SPREAD # 1
WALLISCH PROPERTY SITE

Arrival Times in Milliseconds (ms)

Shot Location

Geophone Station	Shot 1 (130'F)	Shot 2 (10'F)	Shot 3 (6&7)	Shot 4 (12&13)	Shot 5 (18&19)	Shot 6 (10'R)	Shot 7 (140'R)
1	17.0	4.1	20.7	28.1	35.4	42.0	51.8
2	18.6	10.1	19.6	27.5	36.0	41.6	51.0
3	19.8	13.7	17.8	26.5	34.8	40.2	50.0
4	21.0	15.7	15.6	24.7	33.7	39.2	49.0
5	22.6	16.7	12.3	22.8	31.8	37.4	47.4
6	23.4	18.1	6.8	21.4	30.4	36.2	46.0
7	24.6	20.5	6.6	20.8	29.5	35.5	45.4
8	25.8	21.3	12.1	19.1	28.0	34.5	44.2
9	27.4	22.5	14.9	16.1	26.0	33.5	42.8
10	29.0	23.9	18.4	15.4	25.8	31.3	43.2
11	31.0	26.2	20.4	11.9	23.8	30.1	40.8
12	32.2	26.6	21.7	5.6	21.6	29.1	38.8
13	33.0	----	22.6	5.6	20.3	28.1	37.2
14	33.8	----	23.3	11.4	18.7	27.3	----
15	34.6	27.4	24.5	----	17.9	26.9	----
16	36.2	28.6	25.7	14.9	16.1	----	36.0
17	37.0	29.6	27.7	17.8	10.9	----	35.1
18	38.6	31.8	29.6	20.4	4.8	25.3	35.1
19	39.4	33.4	31.2	22.2	4.8	23.5	34.7
20	40.6	34.8	32.3	23.3	11.4	22.3	33.7
21	42.2	36.4	33.6	24.4	17.8	20.5	31.5
22	43.4	37.2	34.5	25.3	20.7	17.3	29.9
23	44.6	37.8	35.3	26.3	21.5	11.9	28.3
24	45.4	39.0	36.4	27.6	23.4	6.1	27.7

F = Forward Shot Direction
R = Reverse Shot Direction
- Arrival Times could not be determined

ARRIVAL TIMES SEISMIC LINE CD-8 SPREAD # 2
WALLISCH PROPERTY SITE

Arrival Times in Milliseconds (ms)

Geophone Station	Shot Location Shot 1 (130'F)	Shot 2 (10'F)	Shot 3 (6&7)	Shot 4 (12&13)	Shot 5 (18&19)	Shot 6 (10'R)	Shot 7 (130'R)
1	24.7	6.1	27.6	32.0	45.0	52.4	63.4
2	26.5	12.7	26.4	30.4	44.0	51.8	62.2
3	27.7	16.9	25.1	29.8	42.2	50.4	61.2
4	29.3	20.9	22.9	28.6	41.0	49.6	60.2
5	30.9	23.1	18.9	27.8	40.2	48.8	58.8
6	32.3	24.1	13.5	25.1	38.0	47.4	57.4
7	33.1	25.1	11.3	24.5	36.6	45.6	55.2
8	----	26.0	10.7	22.7	33.6	43.4	53.8
9	34.5	24.9	14.1	18.5	30.4	39.6	49.4
10	35.5	27.8	19.9	20.5	33.2	43.0	52.6
11	36.7	30.0	23.5	15.3	32.0	42.2	52.6
12	38.1	32.4	24.7	7.7	31.6	41.4	51.6
13	39.3	33.2	25.8	7.5	31.0	40.4	53.0
14	41.1	35.6	28.0	15.3	28.8	39.4	51.4
15	42.3	37.4	31.2	20.1	29.4	39.8	53.4
16	43.7	41.0	35.4	25.8	19.1	35.8	53.8
17	44.3	40.2	36.0	28.2	13.3	33.4	51.6
18	45.5	43.4	39.0	32.0	8.7	32.2	51.0
19	47.1	44.0	39.8	33.0	6.9	25.6	49.0
20	48.1	45.0	40.6	34.0	12.7	22.5	47.2
21	49.3	46.2	42.2	35.2	15.9	19.5	44.4
22	50.7	47.8	45.0	37.8	20.3	17.5	43.4
23	51.7	49.8	46.0	39.2	24.1	13.1	40.4
24	52.9	51.0	47.2	41.4	27.0	5.9	32.2

F = Forward Shot Direction
R = Reverse Shot Direction
\- Arrival Times could not be determined

APPENDIX B

Electrical Resistivity Soundings
Observed and Calculated Apparent Resistivities

CDVES2
COOLEY BROOK SITE

Observed and Calculated Apparent Resistivities

mn (m)	ab/2 (m)	Observed Apparent Resistivity (ohm-m)	Calculated Apparent Resistivity (ohm-m)
0.600	1.000	0.5398E+03	0.5185E+03
0.600	1.260	0.4987E+03	0.4820E+03
0.600	1.580	0.4347E+03	0.4294E+03
0.600	2.000	0.3542E+03	0.3584E+03
0.600	2.500	0.2709E+03	0.2840E+03
0.600	2.500	0.2725E+03	0.2840E+03
0.600	2.500	0.2696E+03	0.2840E+03
0.600	3.160	0.2005E+03	0.2119E+03
0.600	4.000	0.1633E+03	0.1570E+03
2.000	4.000	0.1831E+03	0.1702E+03
2.000	5.000	0.1417E+03	0.1300E+03
2.000	6.310	0.1094E+03	0.1085E+03
2.000	8.000	0.9441E+02	0.9959E+02
2.000	10.000	0.9237E+02	0.9846E+02
2.000	12.600	0.1061E+03	0.1037E+03
2.000	15.800	0.1206E+03	0.1152E+03
2.000	20.000	0.1390E+03	0.1337E+03
2.000	25.000	0.1580E+03	0.1562E+03
2.000	31.600	0.1802E+03	0.1837E+03
2.000	40.000	0.2090E+03	0.2145E+03
2.000	50.000	0.2442E+03	0.2458E+03
8.000	50.000	0.2437E+03	0.2451E+03
8.000	63.100	0.2753E+03	0.2793E+03
8.000	80.000	0.3154E+03	0.3144E+03
8.000	100.000	0.3466E+03	0.3465E+03
8.000	126.000	0.3812E+03	0.3776E+03
8.000	158.000	0.4213E+03	0.4051E+03
8.000	200.000	0.4208E+03	0.4299E+03

ab/2 = 1/2 distance between current electrodes
mn = distance between potentials

CDVES3
COOLEY BROOK SITE

Observed and Calculated Apparent Resistivities

mn (m)	ab/2 (m)	Observed Apparent Resistivity (ohm-m)	Calculated Apparent Resistivity (ohm-m)
0.600	2.000	0.2723E+04	0.2765E+04
0.600	2.500	0.2832E+04	0.2860E+04
0.600	3.160	0.2927E+04	0.2887E+04
0.600	4.000	0.2941E+04	0.2795E+04
0.600	5.000	0.2648E+04	0.2571E+04
0.600	6.310	0.2288E+04	0.2203E+04
2.000	6.310	0.2195E+04	0.2231E+04
2.000	6.310	0.2189E+04	0.2231E+04
2.000	8.000	0.1687E+04	0.1768E+04
2.000	8.000	0.1692E+04	0.1768E+04
2.000	10.000	0.1275E+04	0.1337E+04
2.000	12.600	0.1006E+04	0.9825E+03
2.000	15.800	0.8280E+03	0.7603E+03
2.000	20.000	0.6731E+03	0.6418E+03
2.000	25.000	0.5881E+03	0.5943E+03
2.000	31.600	0.5629E+03	0.5759E+03
2.000	40.000	0.5576E+03	0.5724E+03
2.000	50.000	0.5692E+03	0.5783E+03
8.000	50.000	0.5580E+03	0.5782E+03
8.000	63.100	0.5952E+03	0.5938E+03
8.000	80.000	0.6293E+03	0.6208E+03
8.000	100.000	0.6540E+03	0.6563E+03
8.000	126.000	0.7038E+03	0.7009E+03
8.000	158.000	0.7603E+03	0.7483E+03

ab/2 = 1/2 distance between current electrodes
mn = distance between potentials

CDVES4
WALLISCH PROPERTY SITE

Observed and Calculated Apparent Resistivities

mn (m)	ab/2 (m)	Observed Apparent Resistivity (ohm-m)	Calculated Apparent Resistivity (ohm-m)
0.600	1.260	0.1457E+04	0.1523E+04
0.600	1.580	0.1827E+04	0.1803E+04
0.600	2.000	0.2070E+04	0.2114E+04
0.600	2.500	0.2396E+04	0.2418E+04
0.600	3.160	0.2736E+04	0.2727E+04
0.600	4.000	0.3207E+04	0.3003E+04
0.600	5.000	0.3104E+04	0.3197E+04
2.000	5.000	0.3355E+04	0.3163E+04
2.000	5.000	0.3331E+04	0.3163E+04
2.000	6.310	0.3402E+04	0.3271E+04
2.000	8.000	0.3083E+04	0.3205E+04
2.000	10.000	0.2706E+04	0.2958E+04
2.000	12.600	0.2429E+04	0.2532E+04
2.000	12.600	0.2429E+04	0.2532E+04
2.000	15.800	0.1976E+04	0.2020E+04
2.000	20.000	0.1534E+04	0.1504E+04
2.000	25.000	0.1202E+04	0.1125E+04
2.000	31.600	0.8180E+03	0.8801E+03
2.000	40.000	0.6179E+03	0.7627E+03
2.000	50.000	0.6006E+03	0.7190E+03
8.000	50.000	0.6028E+03	0.7201E+03
8.000	63.100	0.6167E+03	0.7021E+03
8.000	80.000	0.5791E+03	0.6946E+03
8.000	100.000	0.5215E+03	0.6910E+03
8.000	126.000	0.5967E+03	0.6888E+03
8.000	158.000	0.6290E+03	0.6876E+03

ab/2 = 1/2 distance between current electrodes
mn = distance between potentials

Seismic Refraction and Electrical Resistivity Surveys, West Milford Township, Passaic County, New Jersey
(New Jersey Geological Survey Technical Memorandum 88-5)