Missouri S&T

# Center for Transportation Infrastructure and Safety


# Louisville Southern Indiana Ohio River Bridges Project, Kentucky East End Approach Tunnel

by

Neil Anderson

A National University Transportation Center
at Missouri University of Science and Technology

## *Disclaimer*

## Technical Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| NUTC R202 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| Louisville Southern Indiana Ohio River Bridges Project, Kentucky East End Approach Tunnel | July 2010 |
| | 6. Performing Organization Code |
| 7. Author/s<br>Neil Anderson | 8. Performing Organization Report No.<br>00017730 |
| 9. Performing Organization Name and Address<br>Center for Transportation Infrastructure and Safety/NUTC program<br>Missouri University of Science and Technology<br>220 Engineering Research Lab<br>Rolla, MO 65409 | 10. Work Unit No. (TRAIS)<br>11. Contract or Grant No.<br>DTRT06-G-0014 |
| 12. Sponsoring Organization Name and Address<br>U.S. Department of Transportation<br>Research and Innovative Technology Administration<br>1200 New Jersey Avenue, SE<br>Washington, DC 20590 | 13. Type of Report and Period Covered<br>Final<br>14. Sponsoring Agency Code |

15. Supplementary Notes


16. Abstract

Missouri S&T proposes to acquire electrical resistivity and refraction tomography at the KDOT tunnel site, Louisville, Kentucky. These geophysical data will be processed, analyzed and interpreted with the objective of mapping and characterizing soil and bedrock at this construction site. The main project deliverables will be a suite of maps and geologic cross-sections depicting variations in soil thicknesses and lithology and rock quality. Maps showing the locations and orientations of solution-widened joints and other potential engineering hazards will also be presented.


| 17. Key Words | 18. Distribution Statement |
|---|---|
| Non-destructive imaging, non-invasive imaging, technology transfer, education, echo sounding, sub-bottom profiling | No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161. |

| 19. Security Classification (of this report) | 20. Security Classification (of this page) | 21. No. Of Pages | 22. Price |
|---|---|---|---|
| unclassified | unclassified | 30 | |

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# Louisville Southern Indiana Ohio River Bridges Project, Kentucky East End Approach Tunnel

Prepared by:

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Department of Geological Sciences and Engineering
Missouri University of Science and Technology

## EXECUTIVE SUMMARY

Six independent geophysical data sets were acquired along predetermined traverses at the Drumanard Estate Site, Louisville, Kentucky.

- conventional seismic refraction
- gravity
- self-potential
- ground-penetrating radar
- electrical resistivity
- multi-channel surface wave

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## 1. SCOPE OF WORK

Six independent geophysical data sets were acquired along a total of nine traverses immediately adjacent to the Drumanard Estate Site, Louisville, Kentucky (Figures 1 and 2) as part of a pilot program designed to field-test subsurface imaging technologies. The following six geophysical methods were employed and evaluated:

- electrical resistivity
- multi-channel surface wave (MASW)
- conventional seismic refraction
- ground-penetrating radar (GPR)
- self-potential (SP)
- gravity

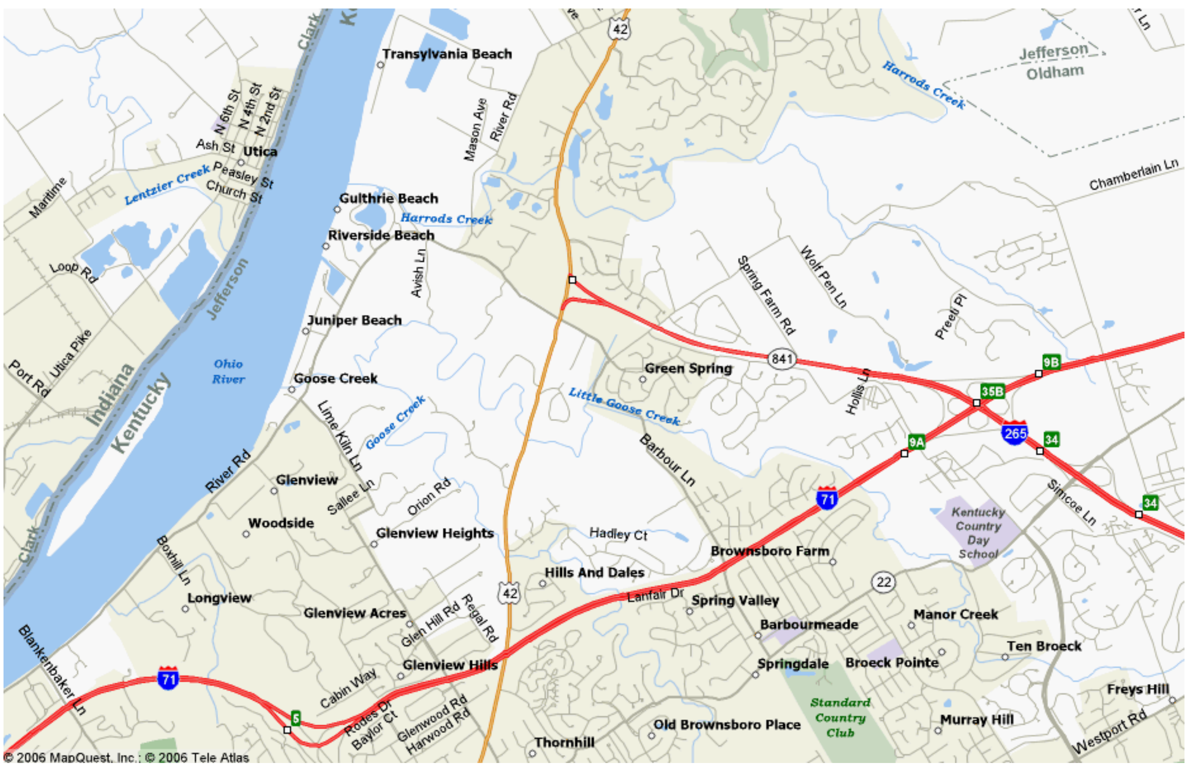



*Figure 1: The Drumanard Estate Site is located at the intersection of Highway 841 and Route 42.*

The primary objective of this pilot study was to determine which of these six imaging methods should be used in the planned follow-up detailed geophysical investigation of the Drumanard Estate Site (Figure 2).

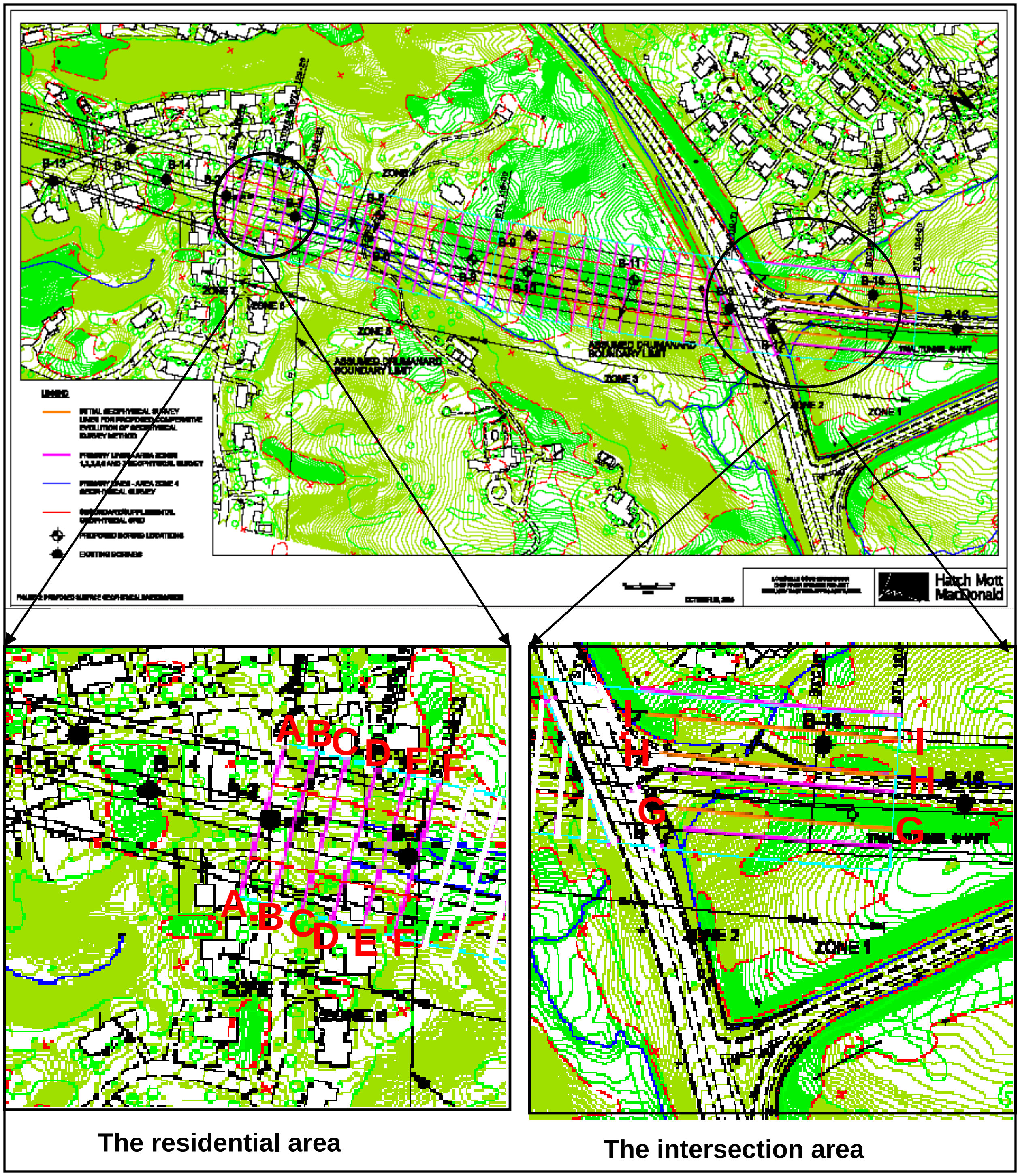



*Figure 2: Six independent geophysical data sets were acquired immediately adjacent to the Drumanard Estate Site (Residential Area and Intersection Area) as part of a pilot program designed to evaluate the utility of available geophysical technologies. The nine geophysical traverses are designated by the letters A-I, inclusive.*

## 2. DATA ACQUISITION AND PROCESSING

Six independent geophysical data sets were acquired along nine flagged traverses (A-I, inclusive) immediately adjacent to the Drumanard Estate Site, Louisville, Kentucky (Figures 1 and 2) as part of a pilot program designed to evaluate the utility of geophysical imaging technologies. The following methods were field-tested and evaluated.

- electrical resistivity
- multi-channel surface wave (MASW)
- conventional seismic refraction
- ground-penetrating radar (GPR)
- self-potential (SP)
- gravity

The acquired geophysical data were processed, interpreted and evaluated. Evaluations of each of the field-tested technologies are presented sequentially in this section (Section 2) of the Report. The processed data themselves are presented in Appendix A.

**Electrical Resistivity Data**: The electrical resistivity data were acquired using a SuperSting R8 resistivity unit equipped with 40 electrodes (Figure 3). An electrode spacing of 10 feet was used to acquire all resistivity data (Figures A1–A9), with the exception of traverse I. For comparative purposes, two resistivity profiles were acquired along traverse I; Electrical resistivity profile I was acquired using a 10 ft electrode spacing, whereas electrical profile I-2 was acquired using a 5 ft electrode spacing (Figure 4).

***Figure 3: Electrical resistivity data were acquired using a SuperSting R8 resistivity unit equipped with 40 electrodes.***

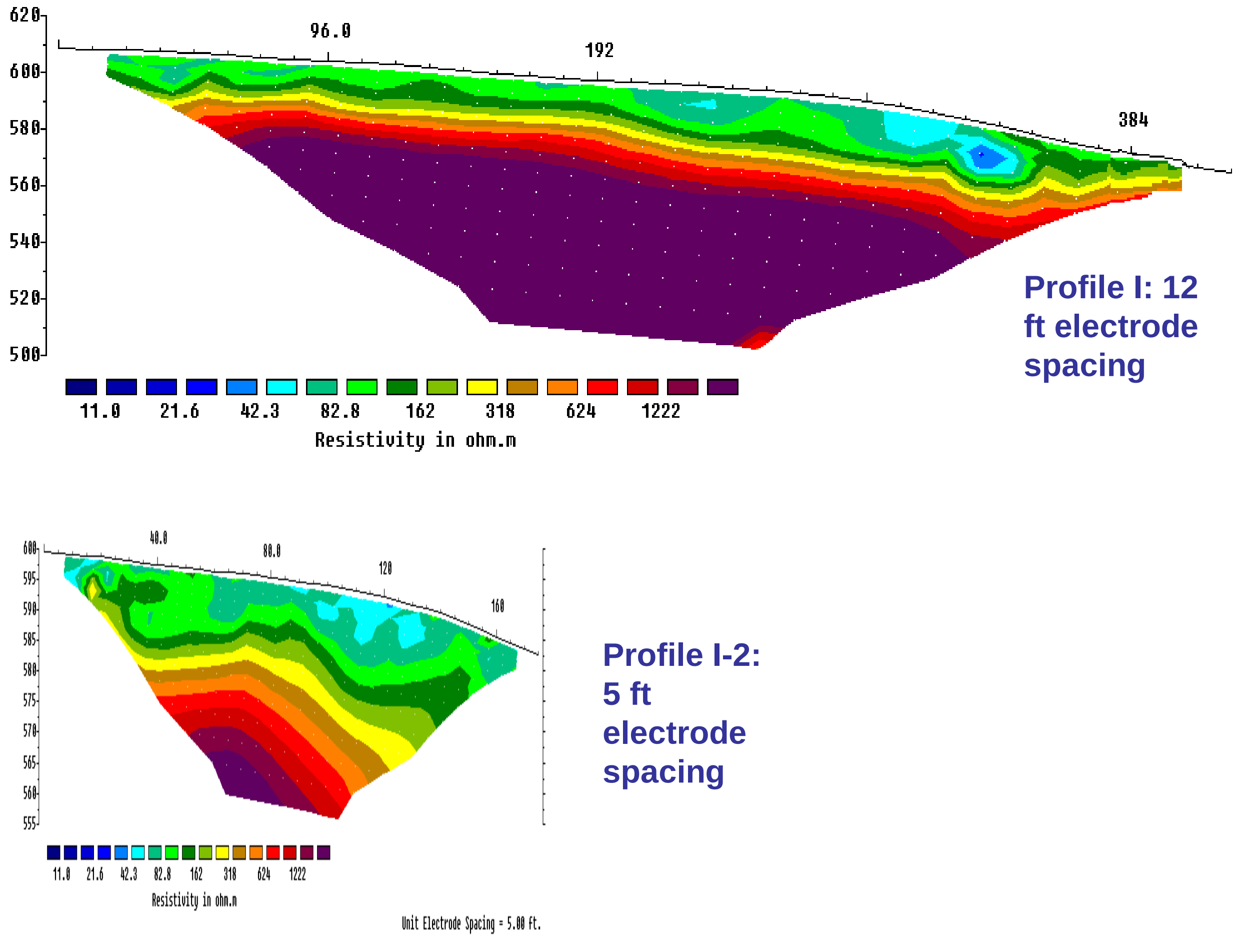



***Figure 4: Electrical Resistivity profile I was acquired using a 10 ft electrode spacing; electrical resistivity profile I-2 was acquired using a 5 ft electrode spacing.***

The acquired resistivity data were processed using the commercially available software package RES2DINV.

Two example resistivity profiles are presented in Figure 4. Profile I was acquired using a 12 ft electrode spacing; profile 1-2 was acquired along a segment of traverse I, using a 5 ft electrode spacing. The bedrock surface is readily mapped across both of these profiles (approximately coincident with 318 ohm-m contour). As illustrated in Figure 4, the I-2 profile (with 5 ft electrode spacing) provides markedly superior resolution.

Unfortunately, the bedrock surface is not as well-defined on many of the other resistivity profiles (see resistivity profile B; Figure 5). In our opinion, the complexity of resistivity profile B, and many of the resistivity images acquired at the test site, is indicative of the complexity of the bedrock surface, which appears to be intensely weathered and fractured, and in-filled with soil, in places.

Based on our evaluation of the acquired test data, we recommend that electrical resistivity data be acquired on the Drumanard Estate site. However, because of the apparent complexity of the bedrock surface, we recommend that data be acquired using an electrode spacing of 5 ft and penetration depths on the order of 50 ft.

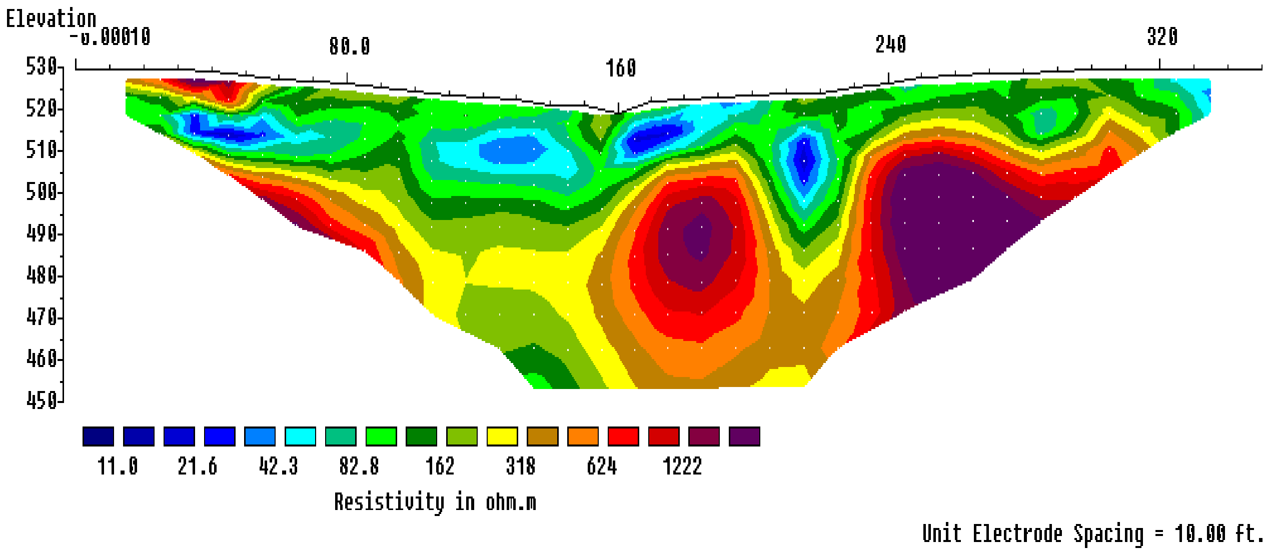
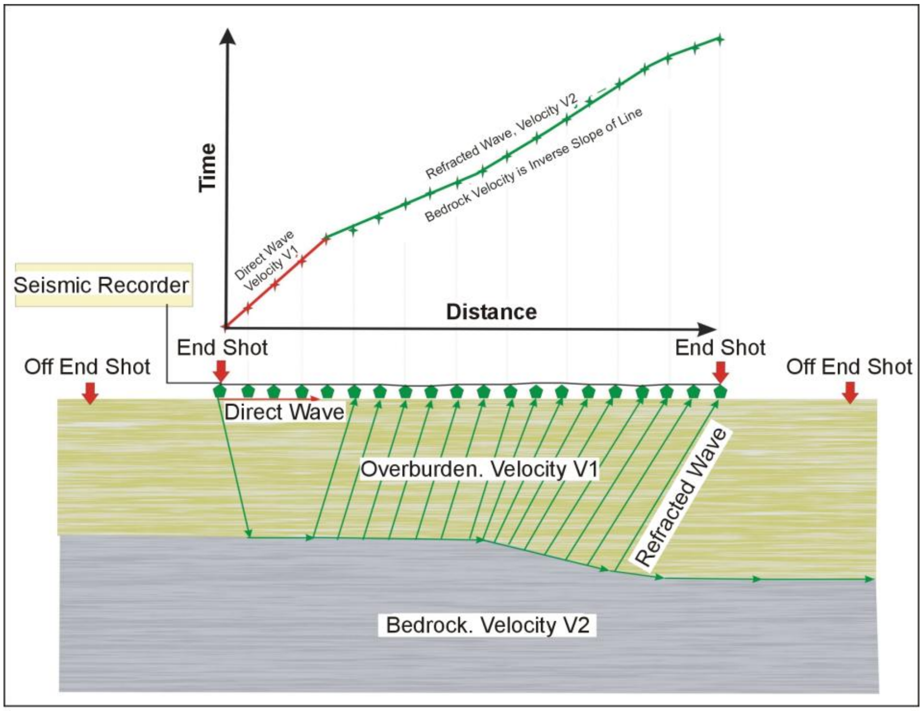



***Figure 5: Electrical Resistivity profile B.***

**Multi-channel Surface Wave Data (MASW)**: MASW data were acquired using a

SuperSting R8 resistivity unit equipped with 40 electrodes (Figure 3). An electrode spacing of 10 feet was used to acquire all resistivity data (Figures A1–A9), with the exception of traverse I. For comparative purposes, two resistivity profiles were acquired along traverse I; Electrical resistivity profile I was acquired using a 10 ft electrode spacing, whereas electrical profile I-2 was acquired using a 5 ft electrode spacing (Figure 4).

different slopes) on the travel time curve (Figure 8). The slopes of the travel time segments can be used to calculate the acoustic velocity of each layer. The extrapolated intercept times can be used to estimate the depth of each lithologic contact.




(a) Instrument layout, refracted waves, and time-distance plot.

(b) Seismograph data recorder. (Geometrics Inc.)

***Figure 8: Seismic Refraction: field set up and data recorder.***

The seismic refraction method works well at shallow depths (<100 ft) and in areas where the acoustic velocities of successive layers increases significantly (such as soil to bedrock). The refraction technique does not work as well for depths greater than 100 ft, especially in "acoustically noisy" areas where the subsurface is not characterized by layers with significant velocity increases. Under such conditions, it is very difficult to generate interpretable data because the refractions from deeper horizons are relatively low amplitude and are commonly masked by background noise.

***Figure 9: Example of a seismic refraction interpretation.***

***Figure 11: Example seismic reflection record. Reflections are characterized by hyperbolic travel time curves, the curvature of which can be used to calculate layer velocities.***

## 7. REFERENCES

FHWA, 2005, Application of Geophysical Methods to Highway Related Problems: http://www.cflhd.gov/agm/index.htm

Herrmann, R. B., Julia-Casas, J., Rix, G., Akinci, A., Bodin, P., and Ammon, C.J., 2005, Shear-wave velocity estimates for deep soils of the Mississippi embayment from the inversion of teleseismic receiver functions: http://www.eas.slu.edu/People/RBHerrmann/EMBAYRFTN.0113/

Kociu, S., Luna, R., Anderson, N., Zheng, W and Hoffman, D., 2003, Non-linear soil response to strong ground motion: Determinations based on SASW velocity profiles: Geophysics 2003, http://www.dot.state.fl.us/statematerialsoffice/geotechnical/conference/geophysics.htm

UNR, 2005, Refraction Microtremor (ReMi) for Shear Velocity : The Most Efficient Shallow Shear-Velocity Estimates: http://seismo.unr.edu/remi/

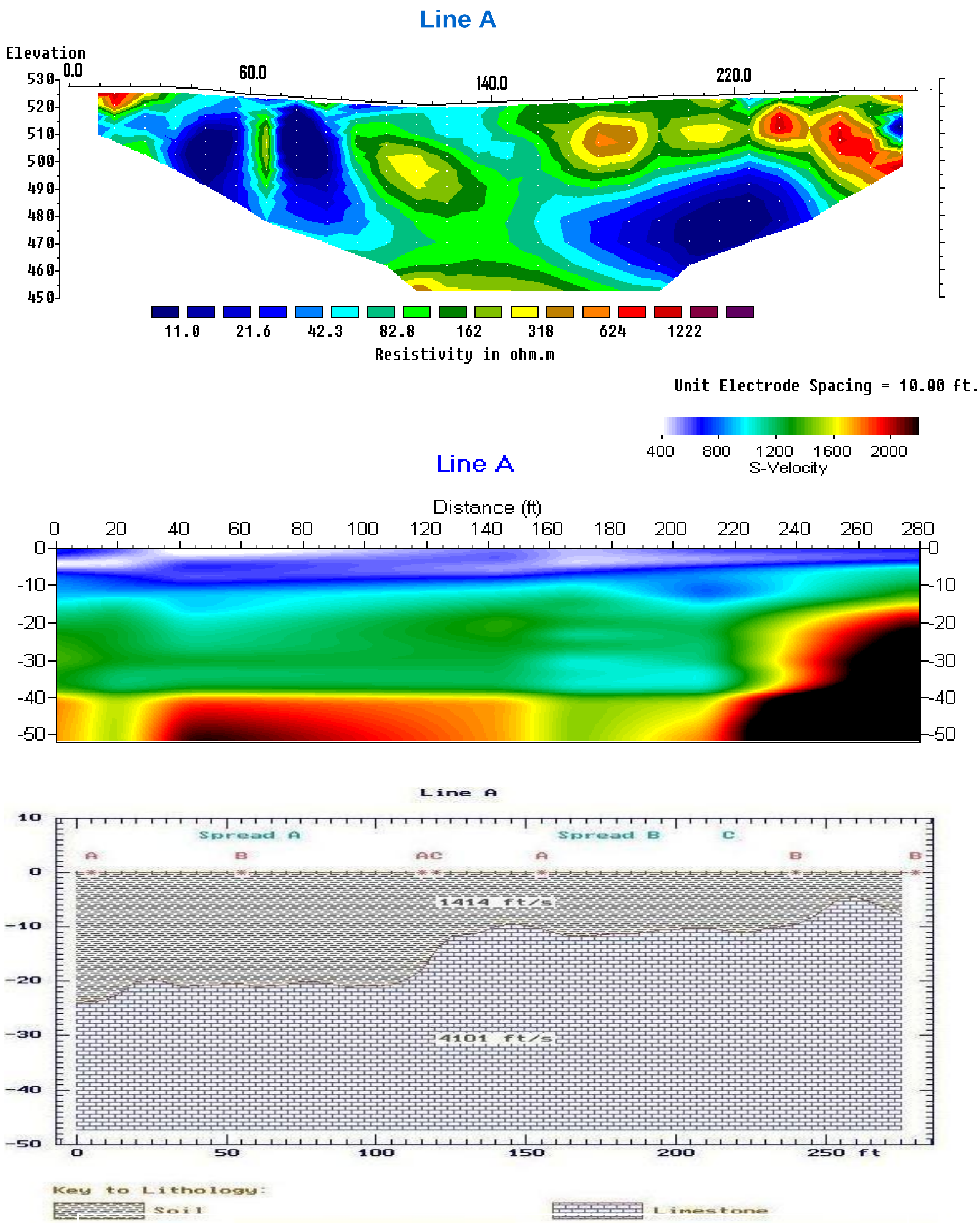



***Figure A1:Caption A: electrical resistivty profile A; Caption B: MASW profile A; Caption C: conventional seismic refraction profile A.***

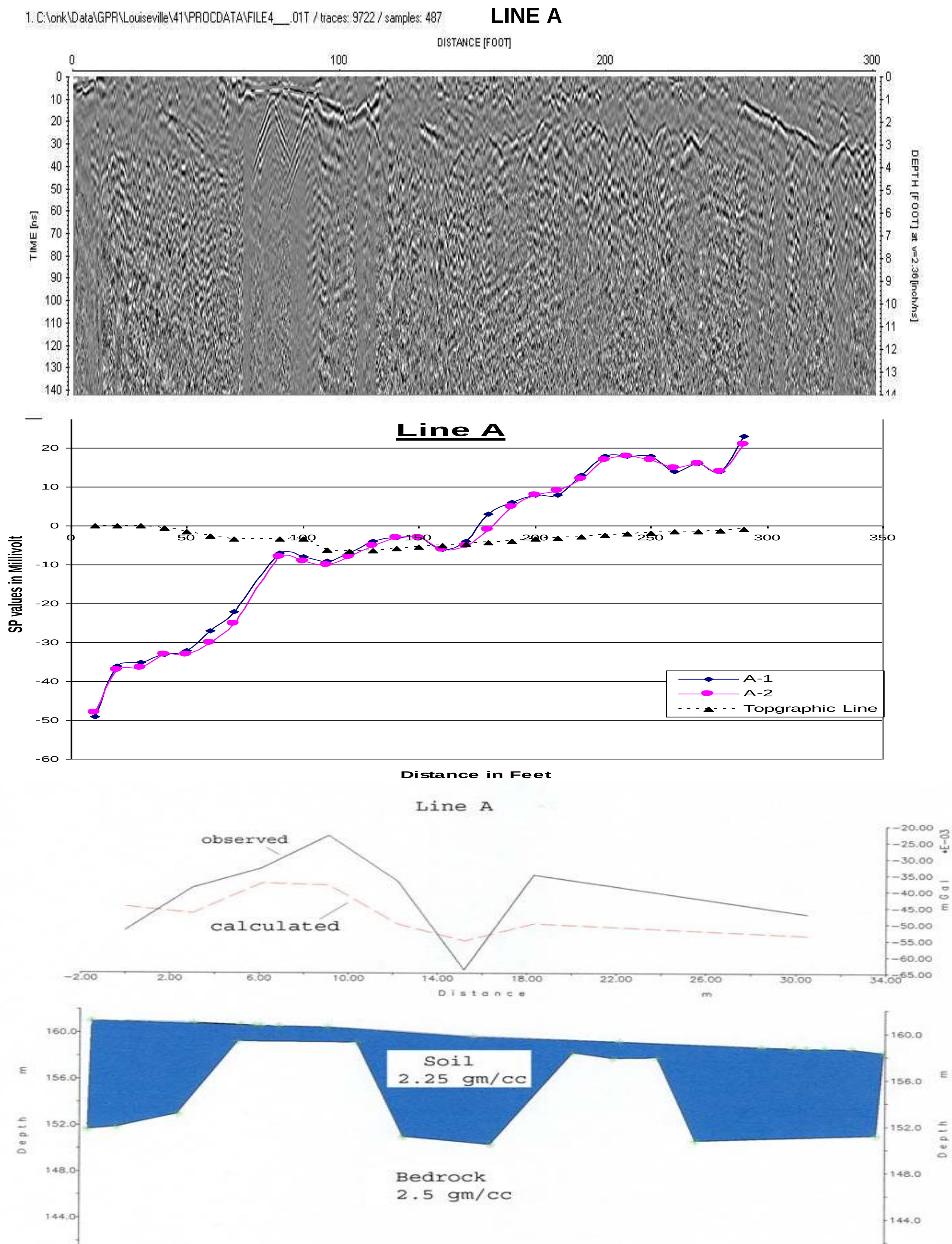
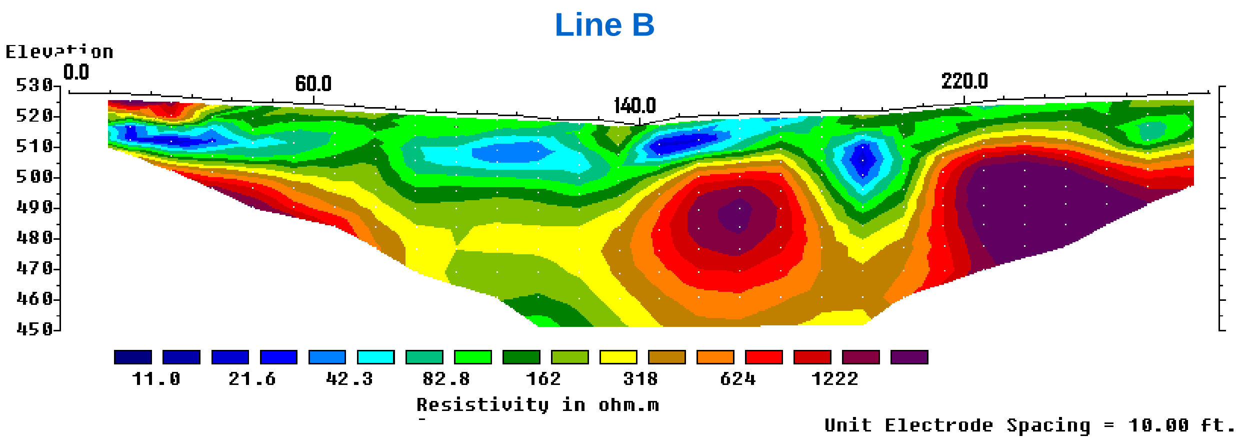



*Figure A1 (continued):Caption D: GPR  profile A; Caption B: SP profile A; Caption C: gravity profile A.*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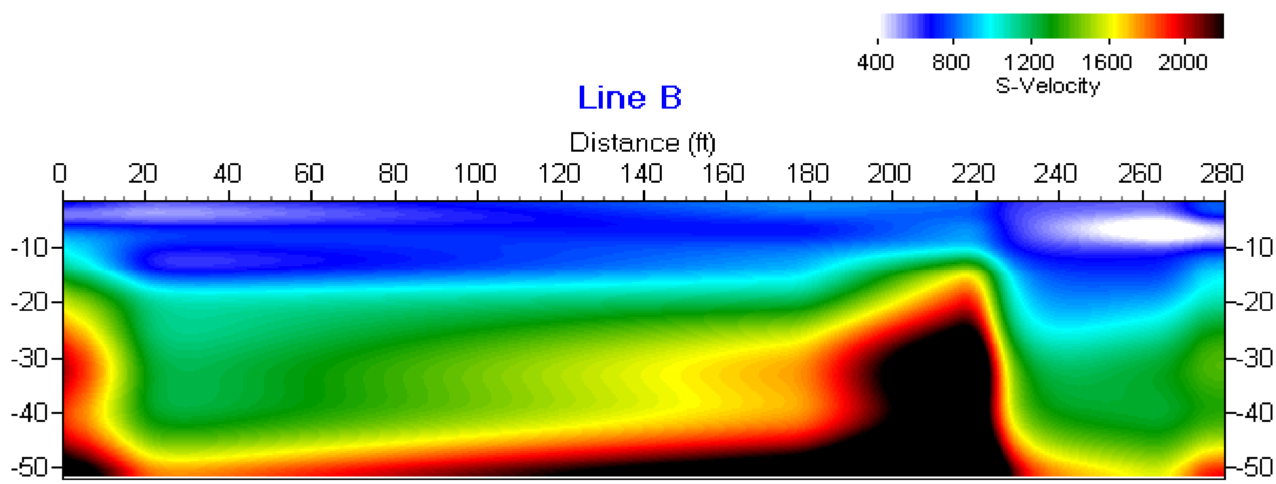
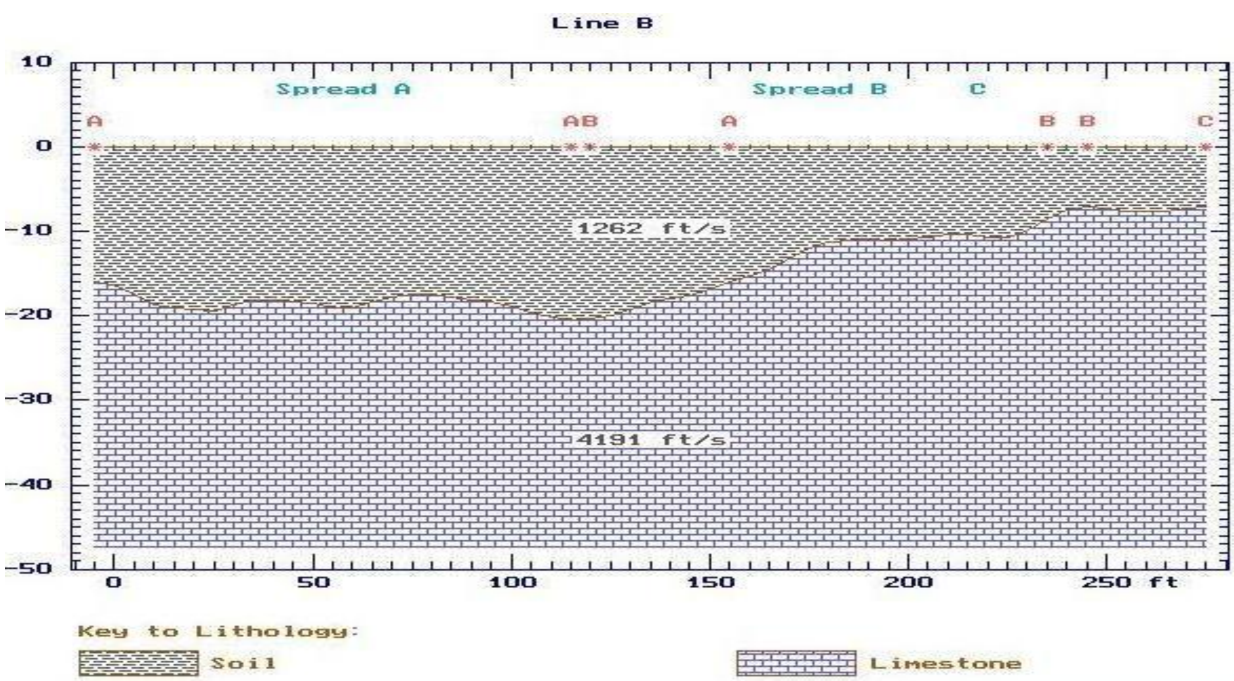
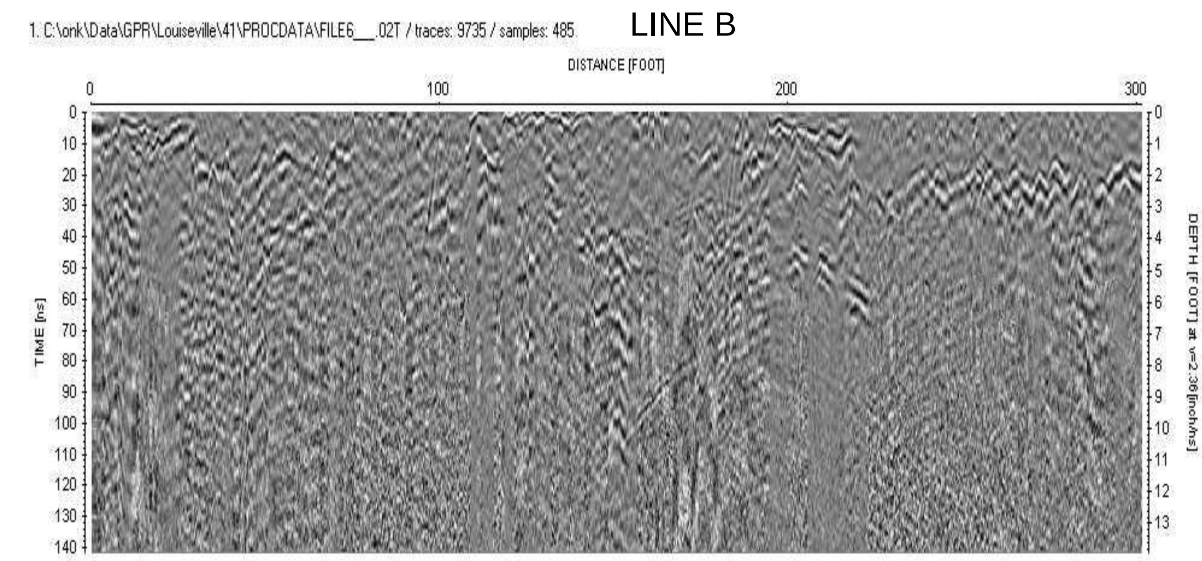
Elevation
0.0
60.0
140.0
220.0
530
520
510
500
490
480
470
460
450
11.0
21.6
42.3
82.8
162
318
624
1222
Resistivity in ohm.m
Unit Electrode Spacing = 10.00 ft.


400
800
1200
1600
2000
S-Velocity
Line B
Distance (ft)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
-10
-20
-30
-40
-50


Line B
Spread A
Spread B
C
1262 ft/s
4191 ft/s
10
0
-10
-20
-30
-40
-50
0
50
100
150
200
250 ft
Key to Lithology:
Soil
Limestone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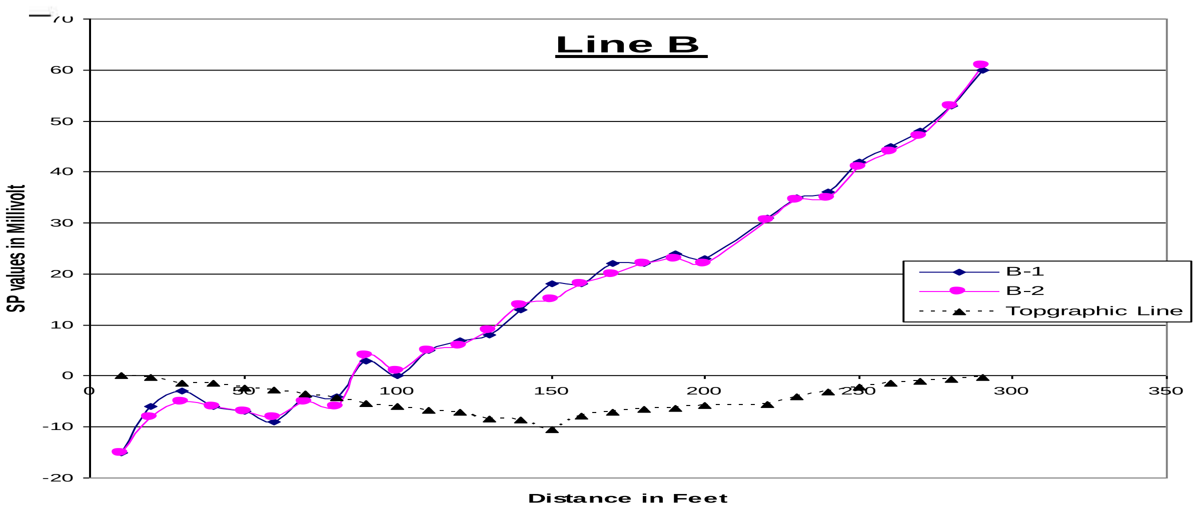
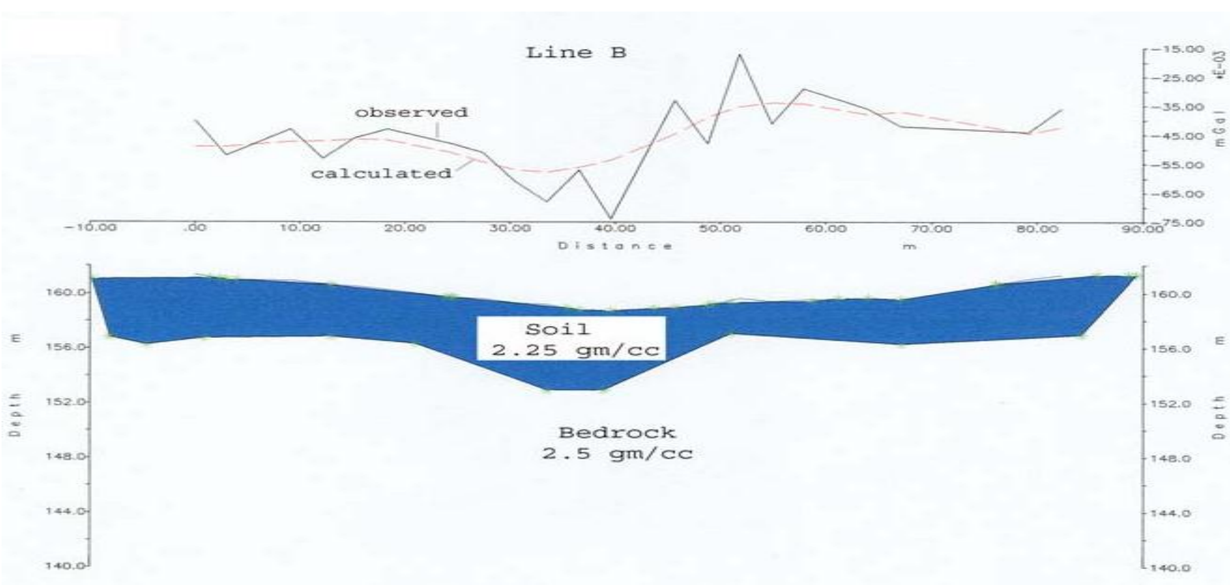
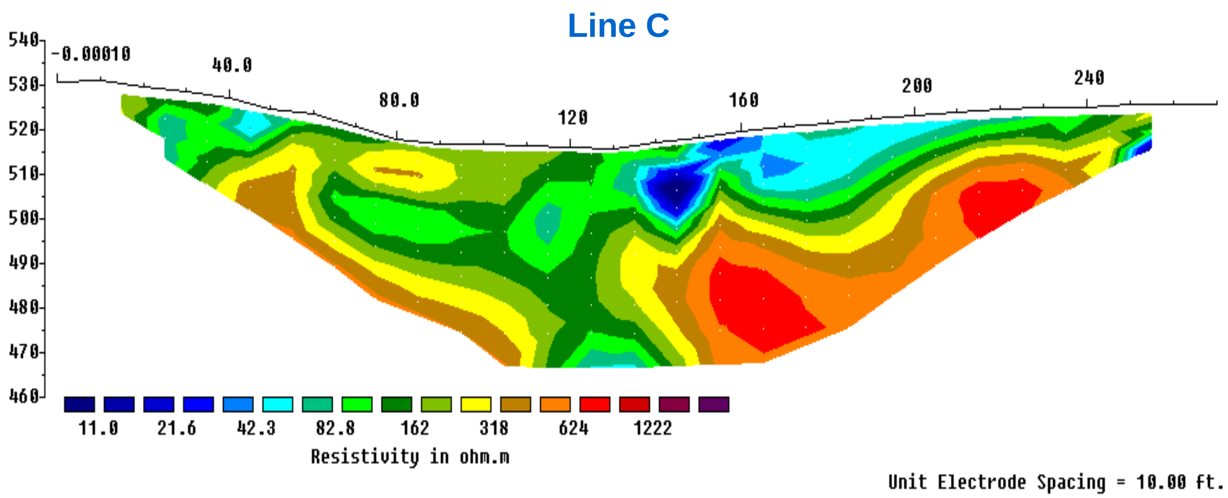
DEPTH [FOOT] at v=2.36[inch/ns]


Line B
SP values in Millivolt
Distance in Feet
B-1
B-2
Topgraphic Line


Line B
observed
calculated
Distance
m
mGal
Soil
2.25 gm/cc
Bedrock
2.5 gm/cc
Depth


Line C
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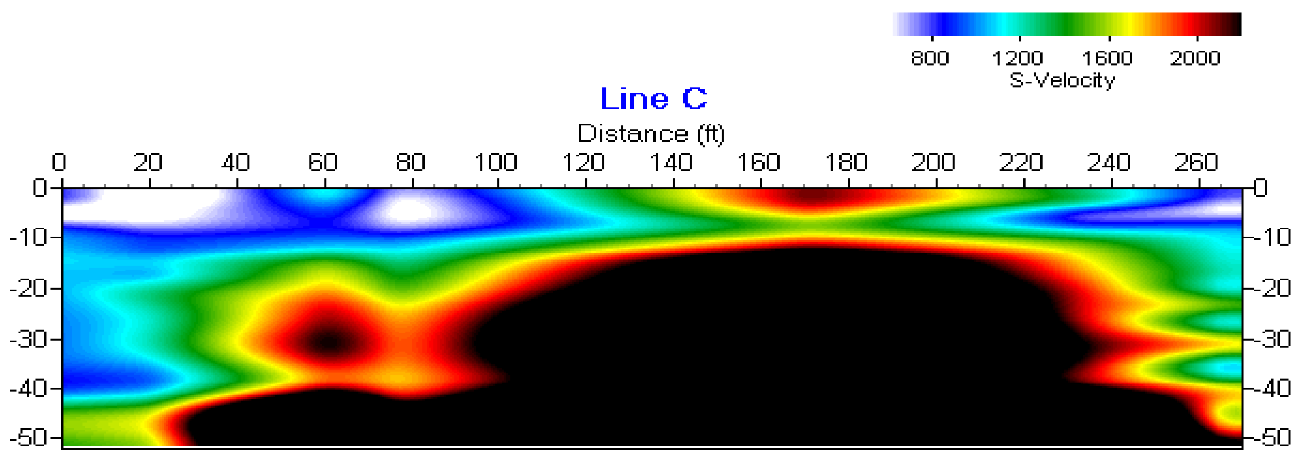
40.0
80.0
120
160
200
240
540
530
520
510
500
490
480
470
460
11.0 21.6 42.3 82.8 162 318 624 1222
Resistivity in ohm.m
Unit Electrode Spacing = 10.00 ft.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S-Velocity
Line C
Distance (ft)
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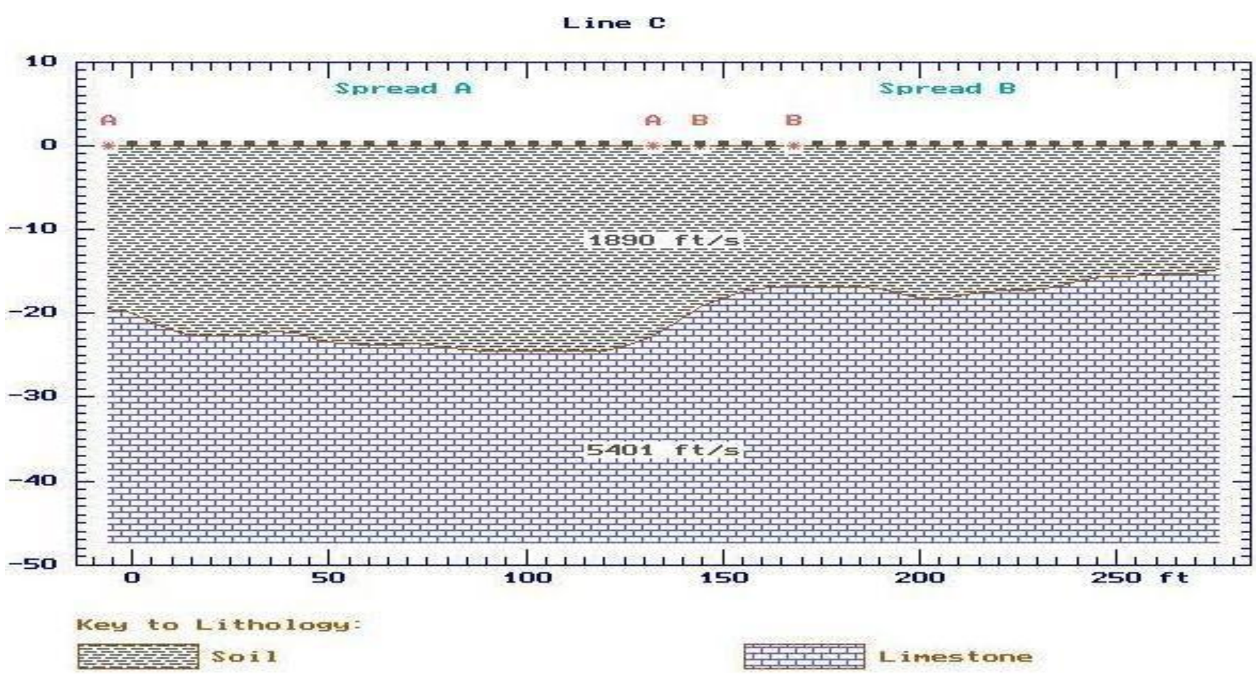
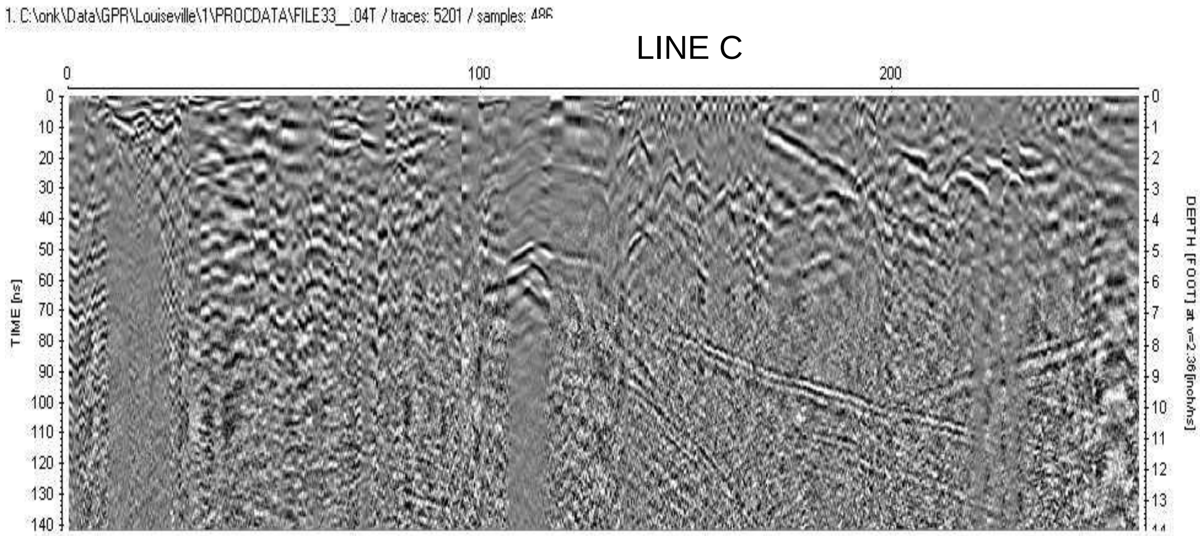
0
-10
-20
-30
-40
-50


Line C
Spread A
Spread B
A
A B
B
1890 ft/s
5401 ft/s
10
0
-10
-20
-30
-40
-50
0 50 100 150 200 250 ft
Key to Lithology:
Soil
Limestone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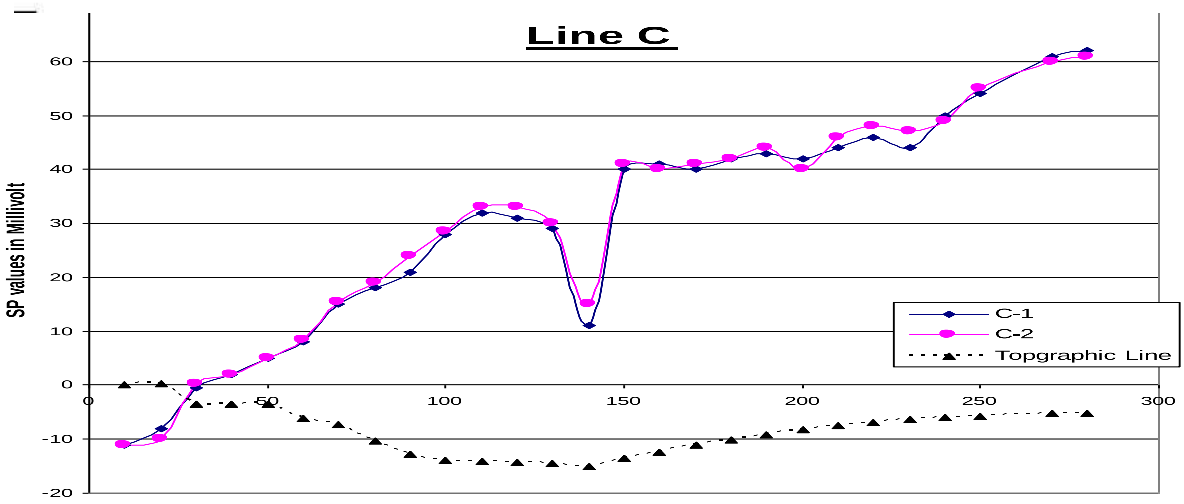
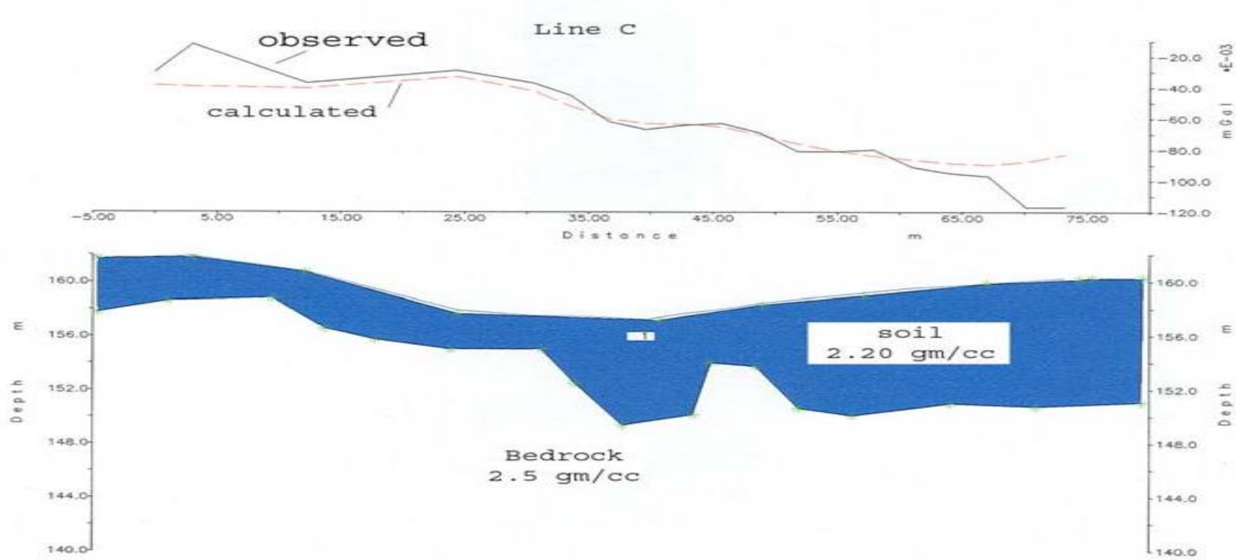
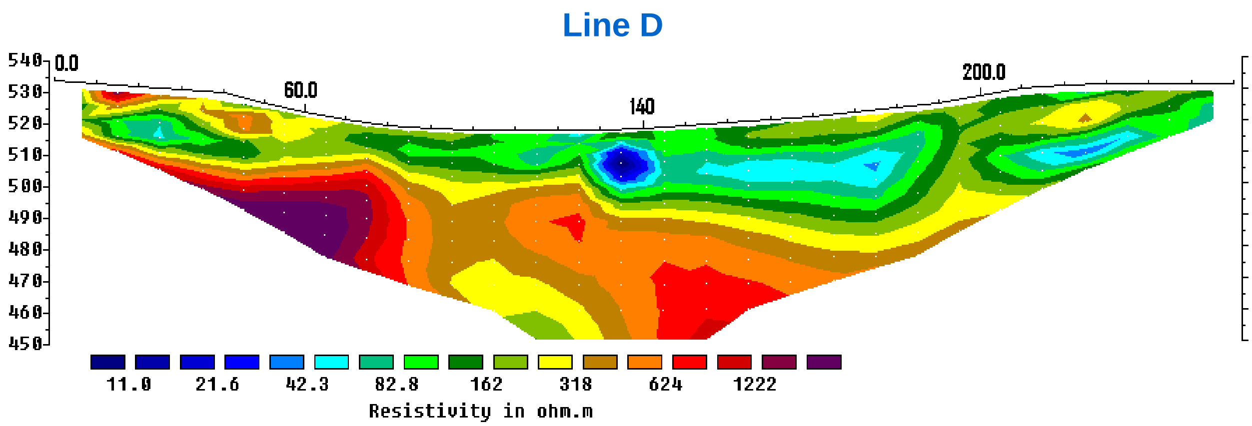
LINE C
TIME [ns]
DEPTH [FOOT] at v=2.36[inch/ns]


Line C
SP values in Millivolt
C-1
C-2
Topgraphic Line


Line C
observed
calculated
Distance
m
mGal
Depth
soil
2.20 gm/cc
Bedrock
2.5 gm/cc


Line D
0.0
60.0
140
200.0
540
530
520
510
500
490
480
470
460
450
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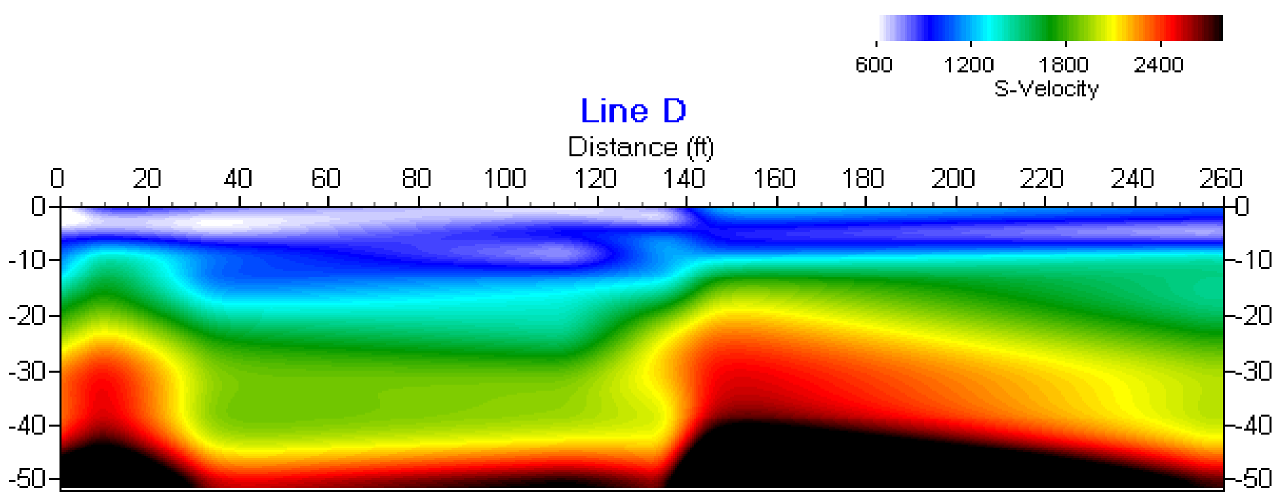
21.6
42.3
82.8
162
318
624
1222
Resistivity in ohm.m
Unit Electrode Spacing = 10.00 ft.


600
1200
1800
2400
S-Velocity
Line D
Distance (ft)
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40
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80
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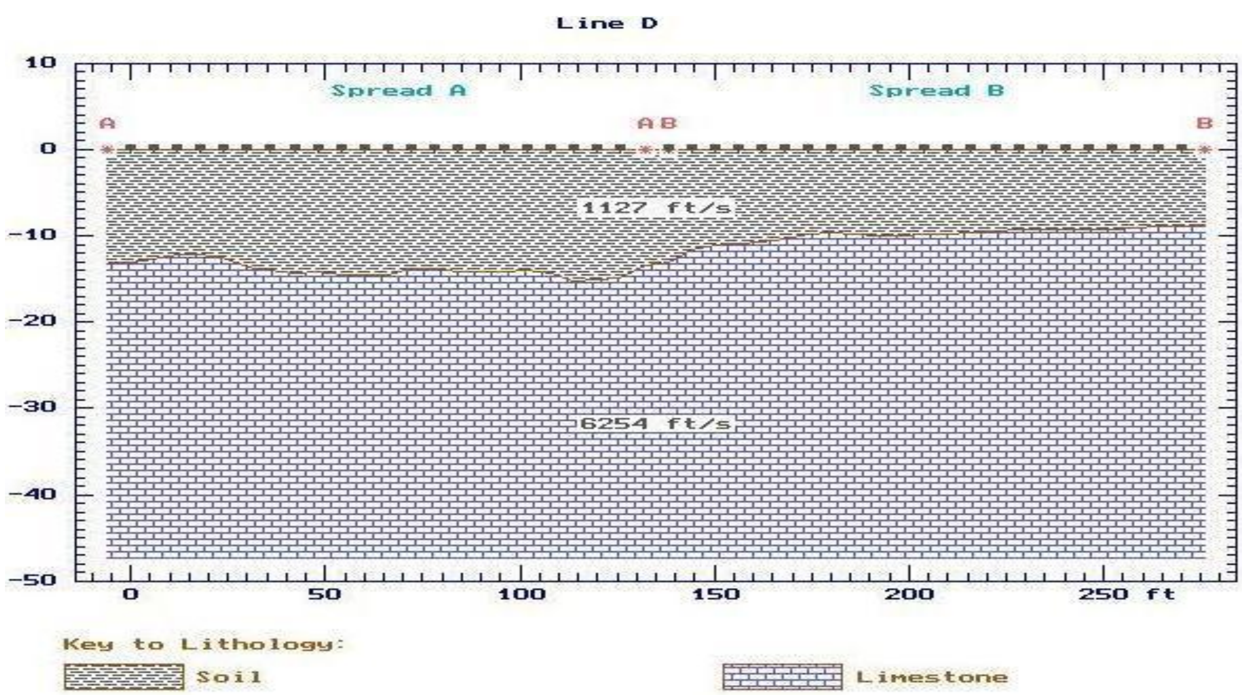
-30
-40
-50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Spread A
Spread B
A
A B
B
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6254 ft/s
10
0
-10
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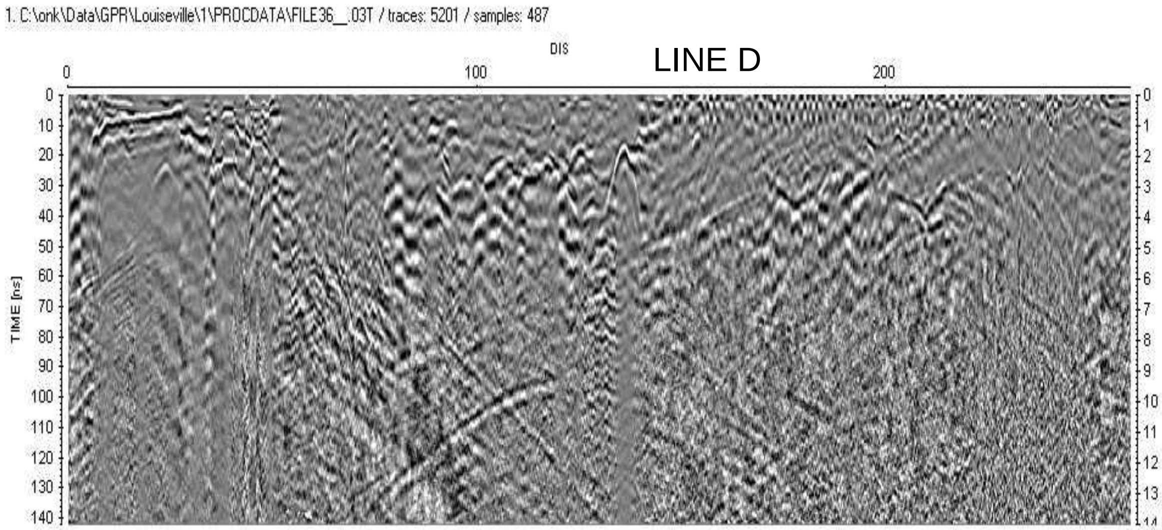
200
250 ft
Key to Lithology:
Soil
Limestone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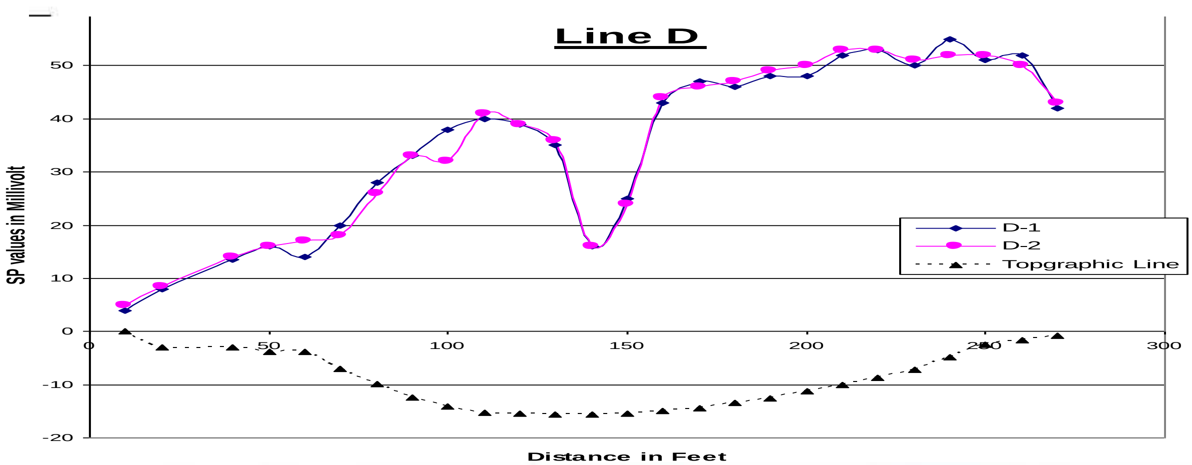
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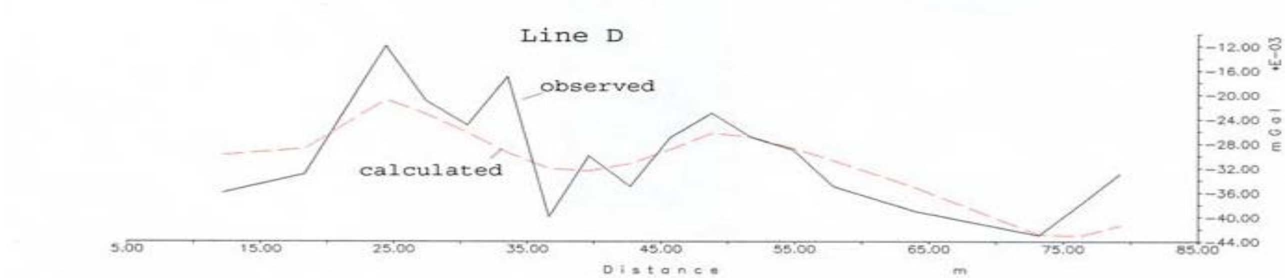
SP values in Millivolt
D-1
D-2
Topgraphic Line
Distance in Feet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observed
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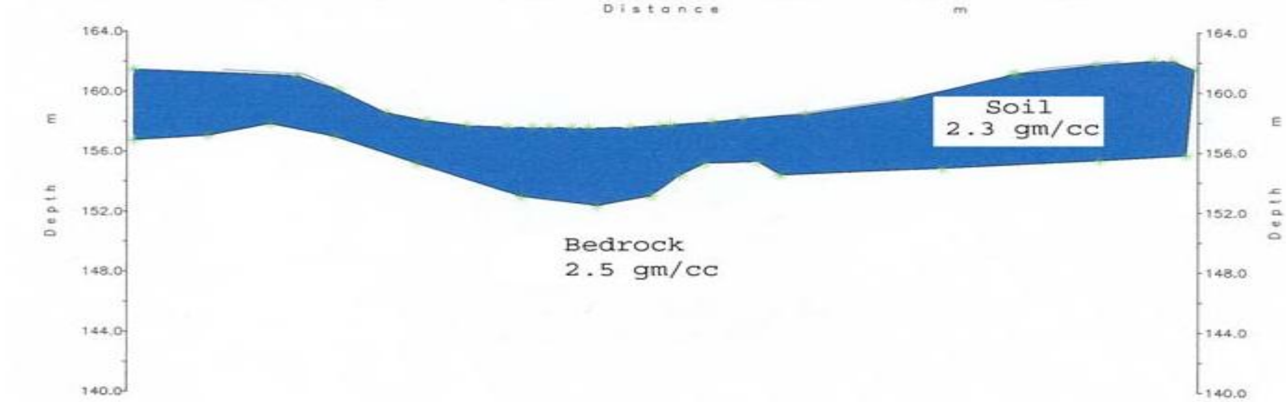
Distance
m
mGal
*E-03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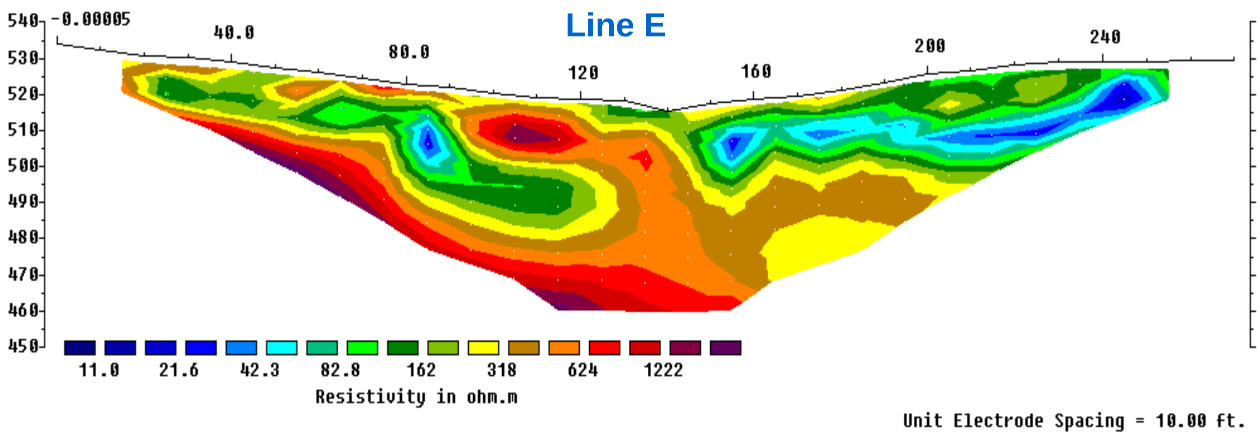
Bedrock
2.5 gm/cc
Depth
m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Resistivity in ohm.m
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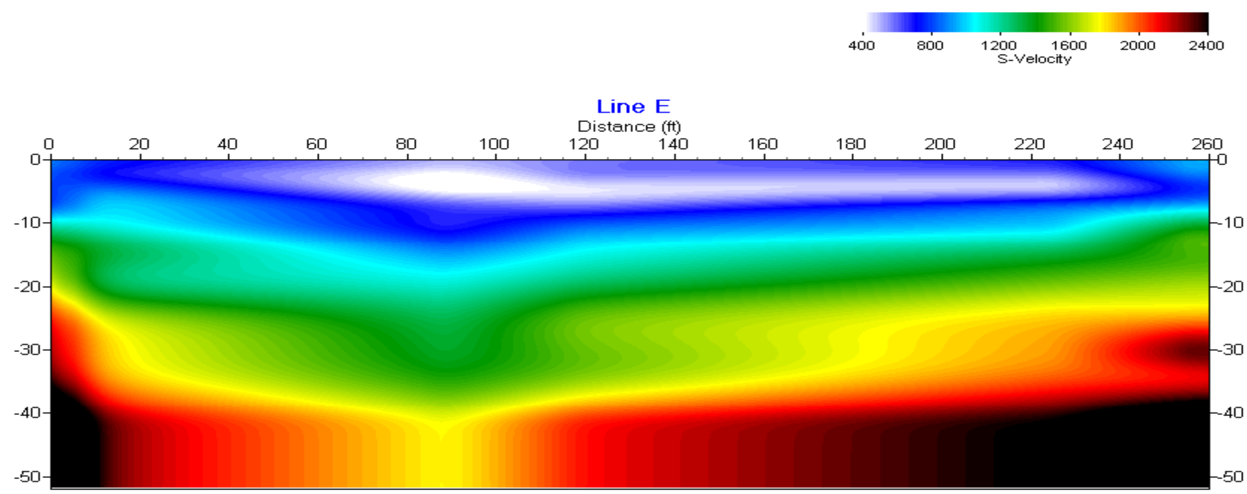
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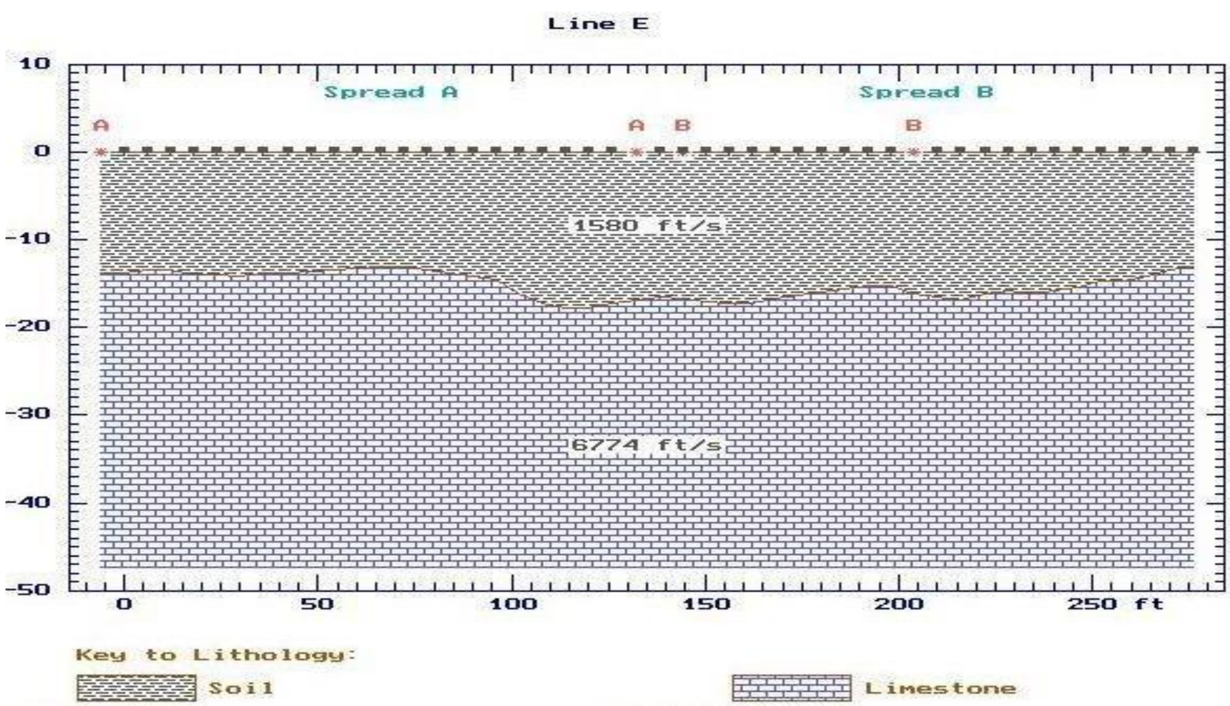
Line E
Distance (ft)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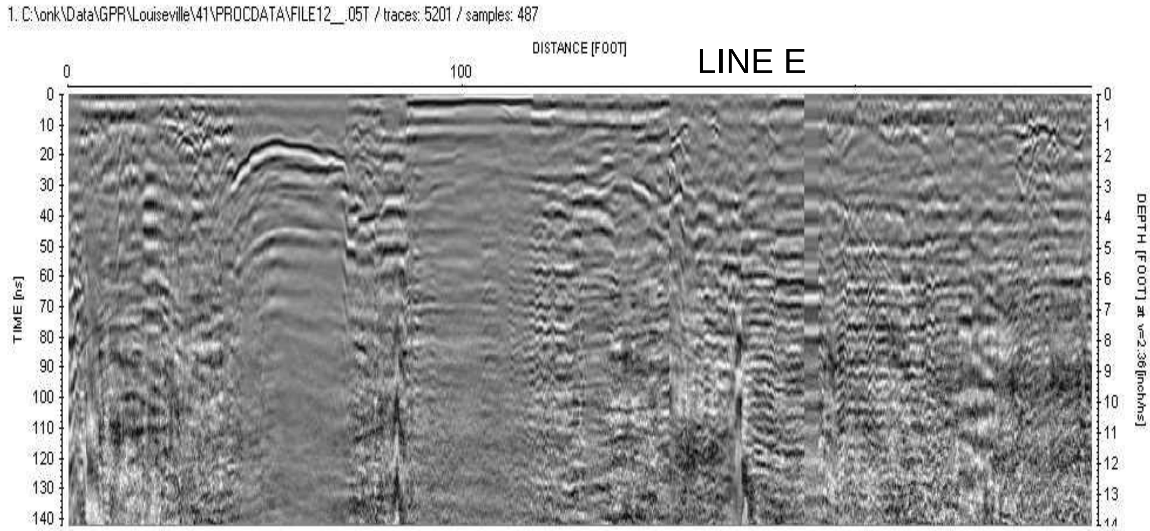
Key to Lithology:
Soil
Limestone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LINE E
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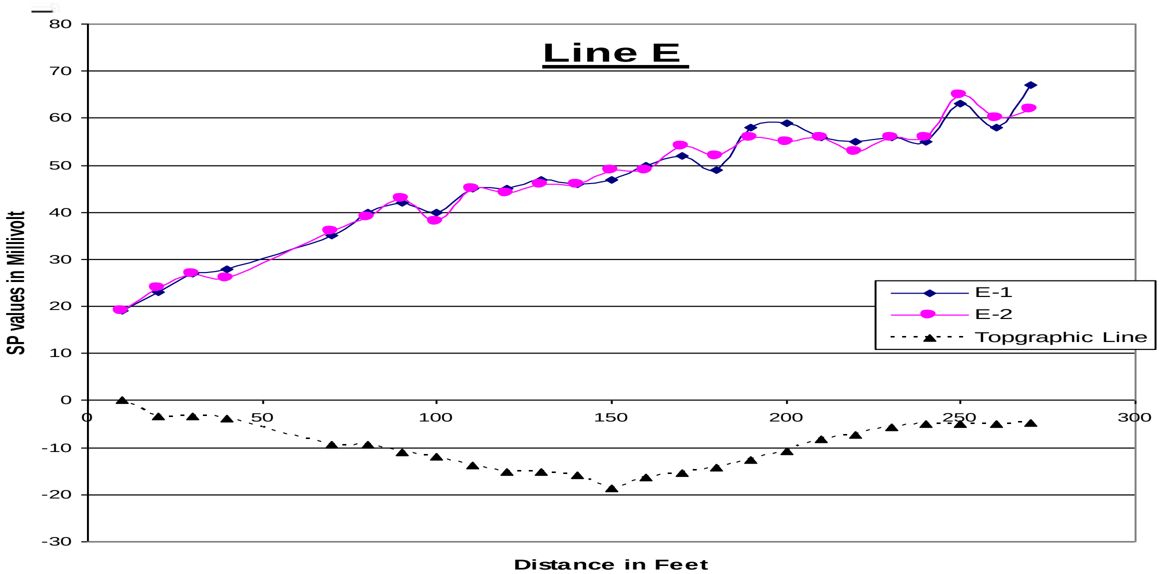
TIME [ns]
DEPTH [FOOT] at v=2.36[inch/ns]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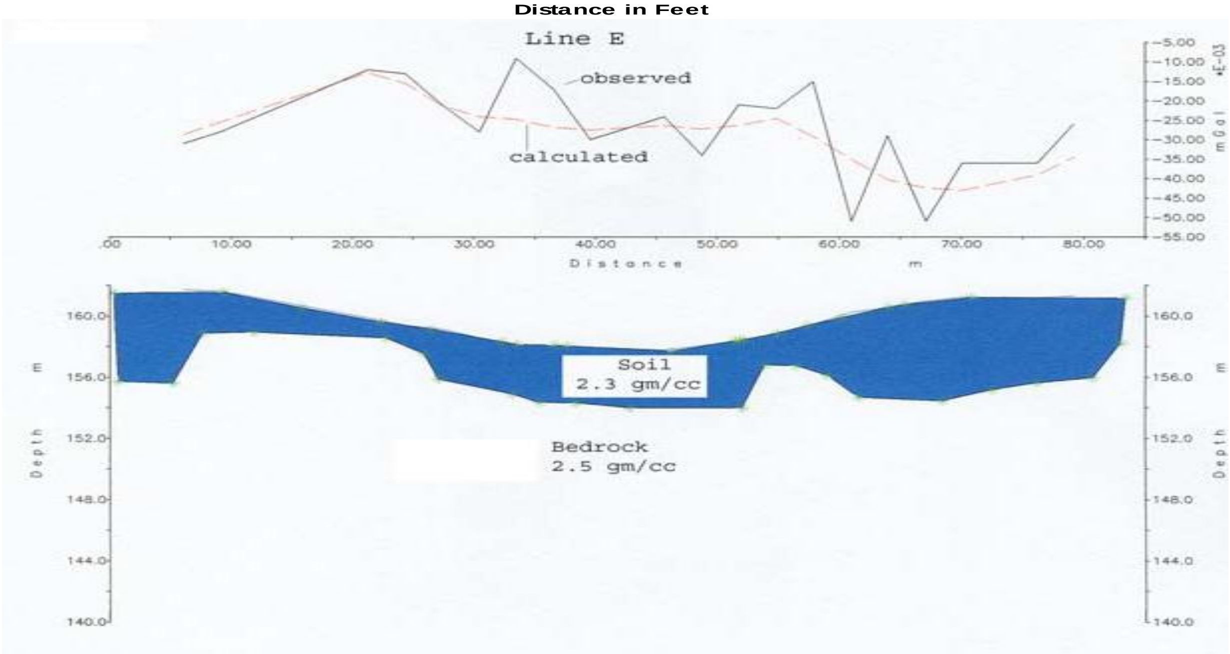
SP values in Millivolt
E-1
E-2
Topgraphic Line
Distance in Feet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observed
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Distance
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Soil
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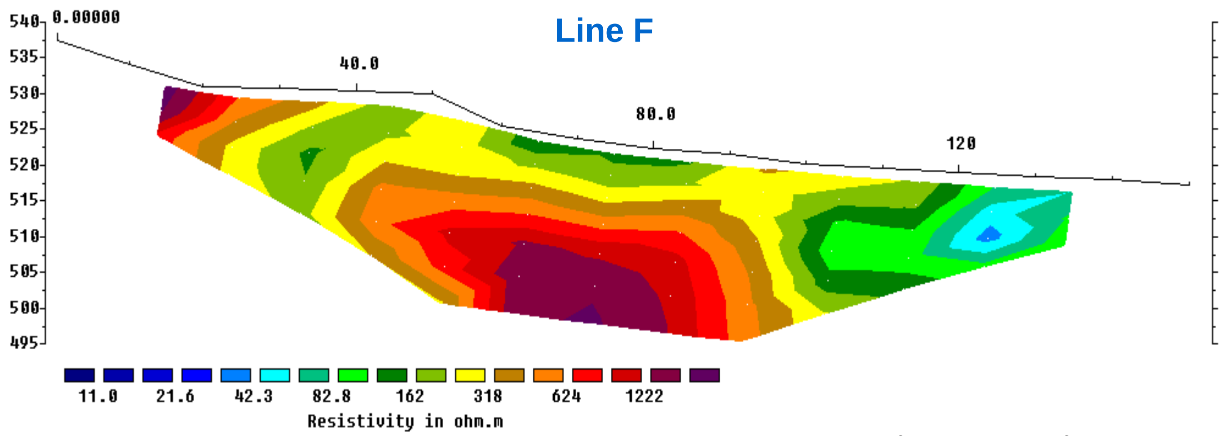
Bedrock
2.5 gm/cc
Depth
m


Line F
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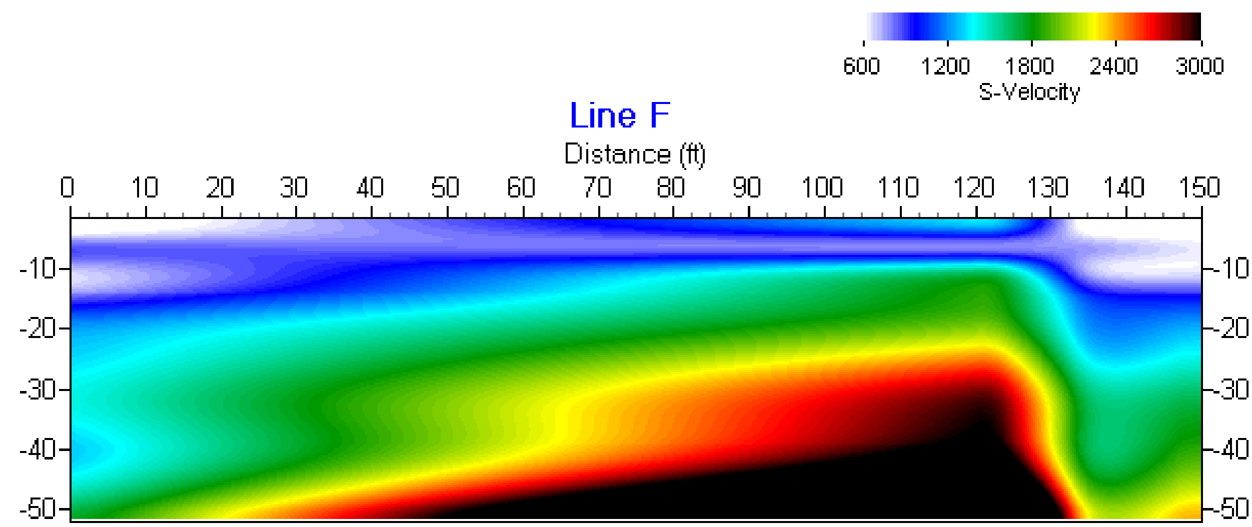
82.8
162
318
624
1222
Resistivity in ohm.m
Unit Electrode Spacing = 10.00 ft.


600
1200
1800
2400
3000
S-Velocity
Line F
Distance (ft)
0
10
20
30
40
50
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70
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-20
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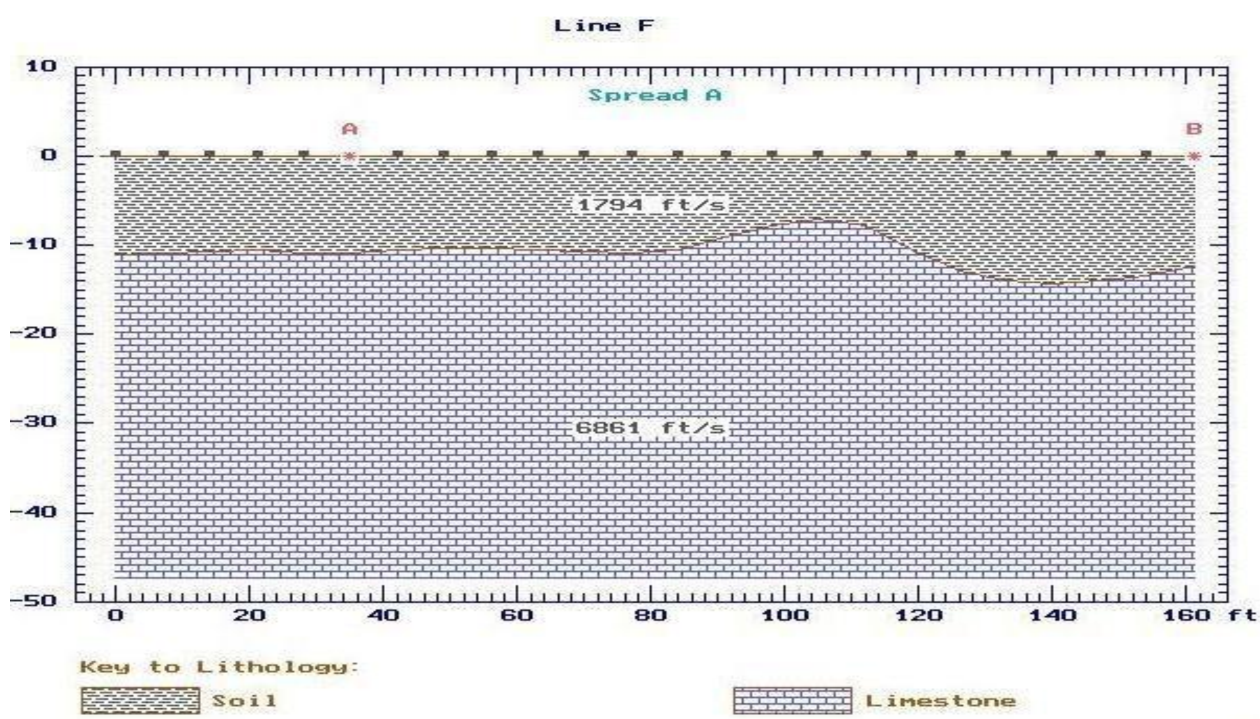
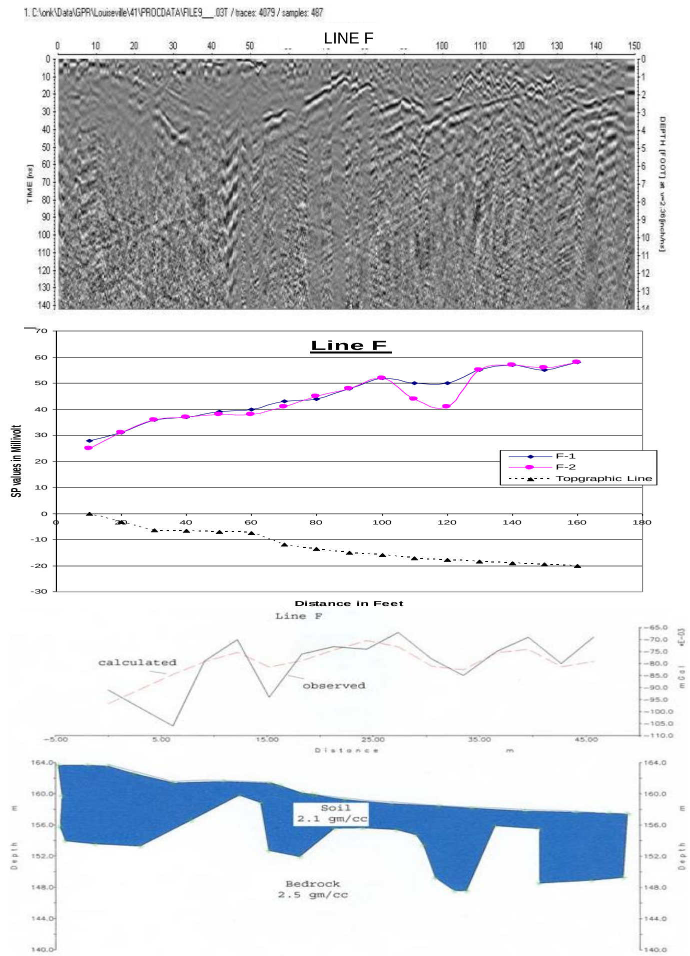
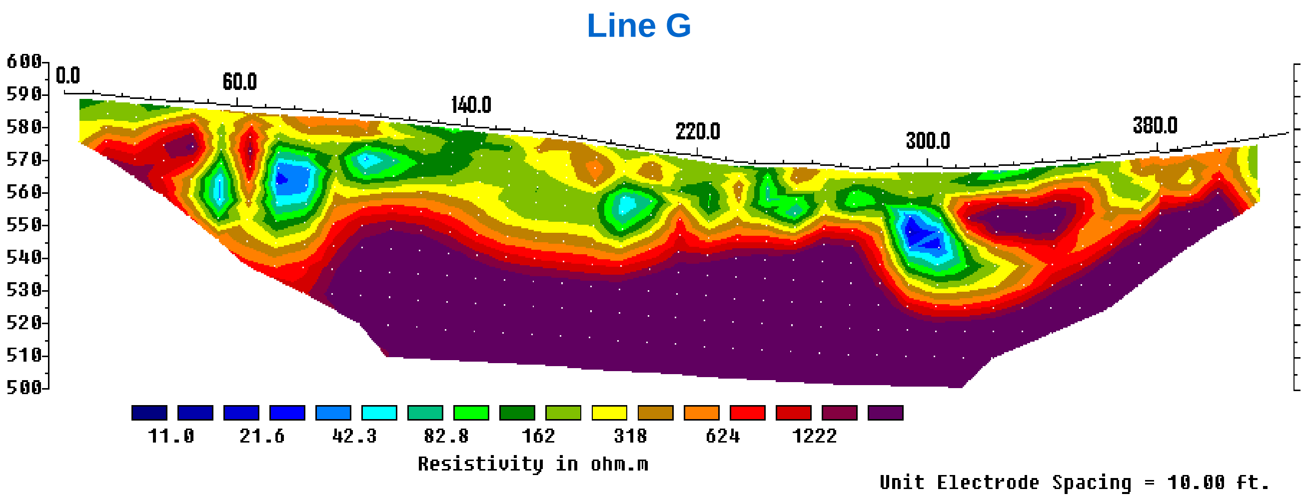
-40
-50


Line F
Spread A
A
B
1794 ft/s
6861 ft/s
10
0
-10
-20
-30
-40
-50
0
20
40
60
80
100
120
140
160 ft
Key to Lithology:
Soil
Limestone


LINE F
Line F
SP values in Millivolt
F-1
F-2
Topgraphic Line
Distance in Feet
Line F
calculated
observed
Soil
2.1 gm/cc
Bedrock
2.5 gm/cc


Line G
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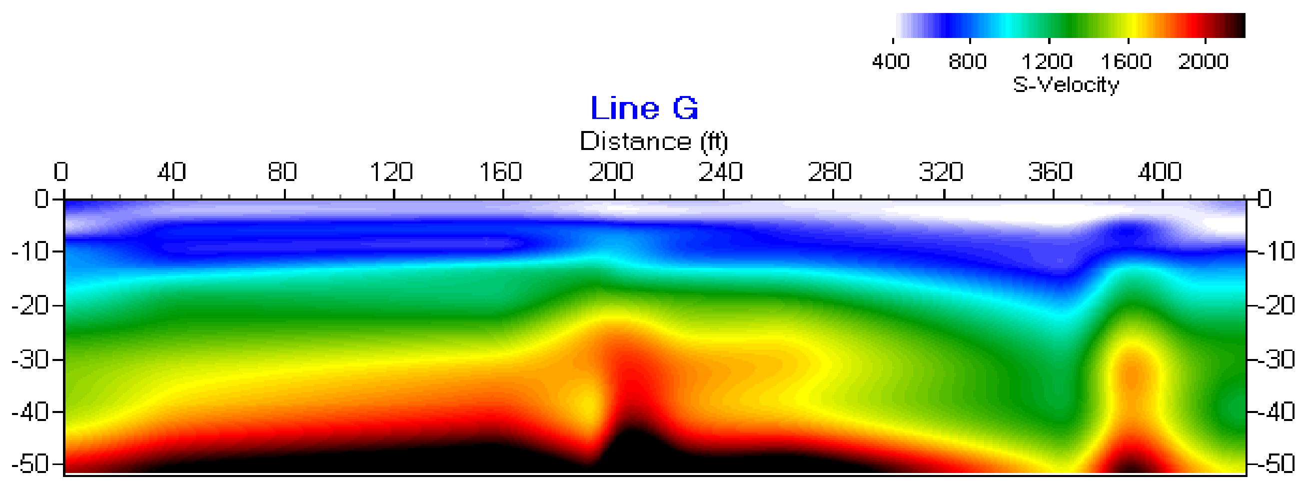
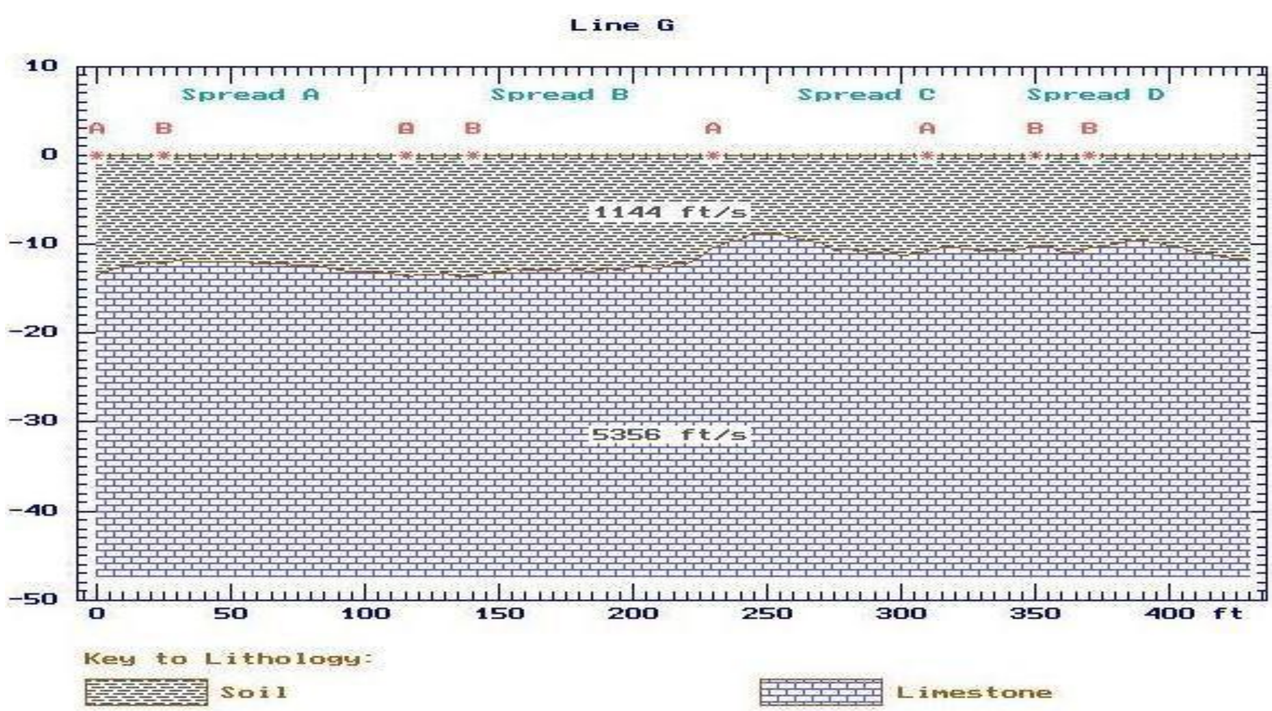
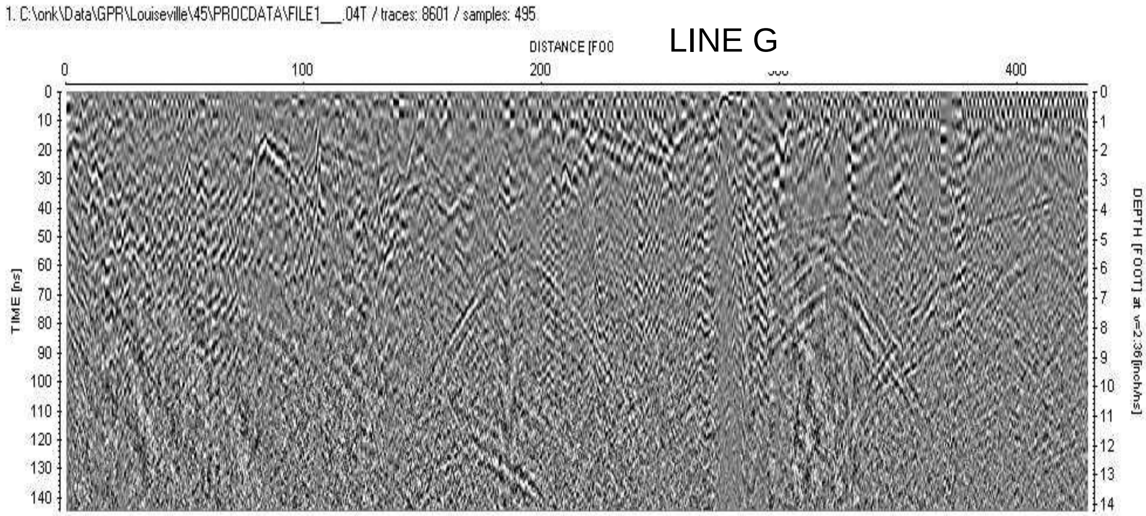
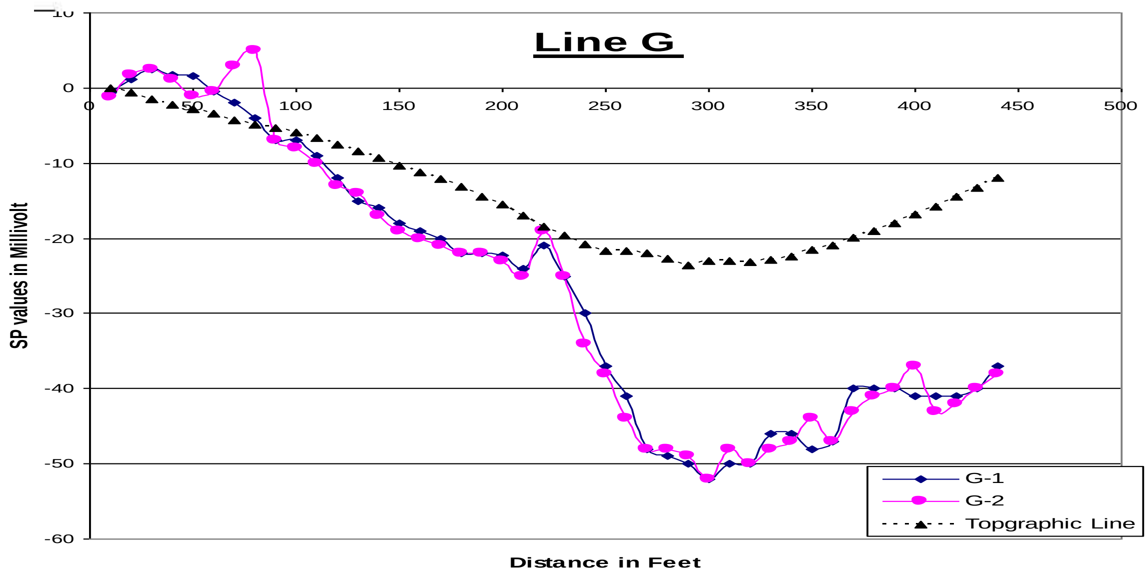
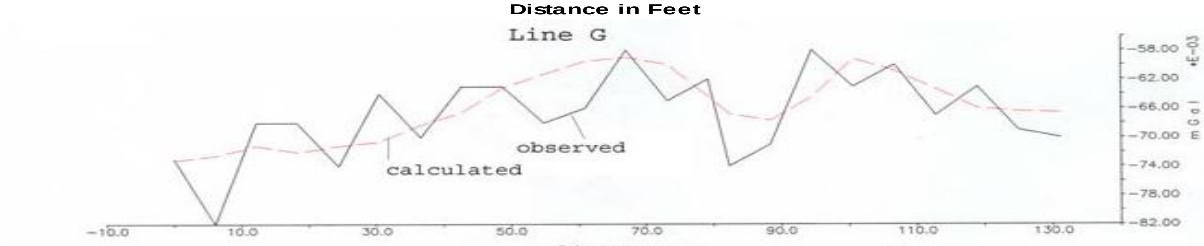
140.0
220.0
300.0
380.0
11.0 21.6 42.3 82.8 162 318 624 1222
Resistivity in ohm.m
Unit Electrode Spacing = 10.00 ft.

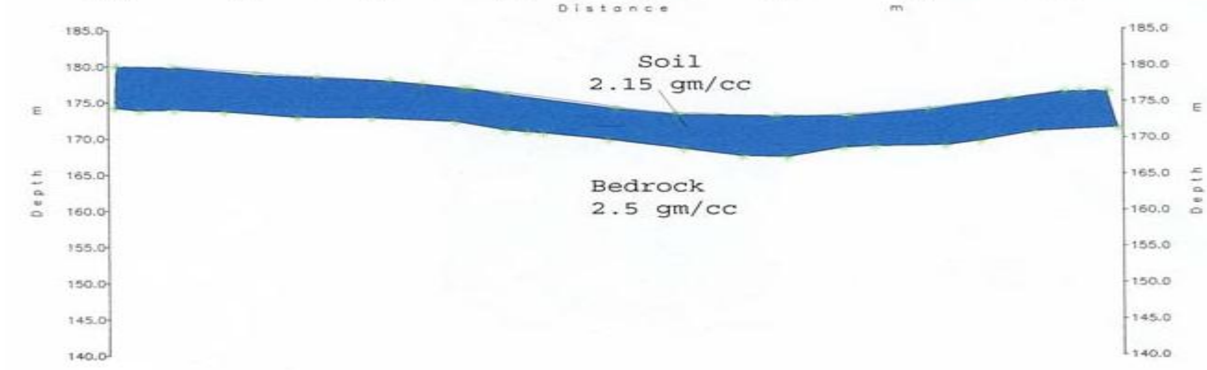

400 800 1200 1600 2000
S-Velocity
Line G
Distance (ft)


Line G
Spread A
Spread B
Spread C
Spread D
1144 ft/s
5356 ft/s
400 ft
Key to Lithology:
Soil
Limestone

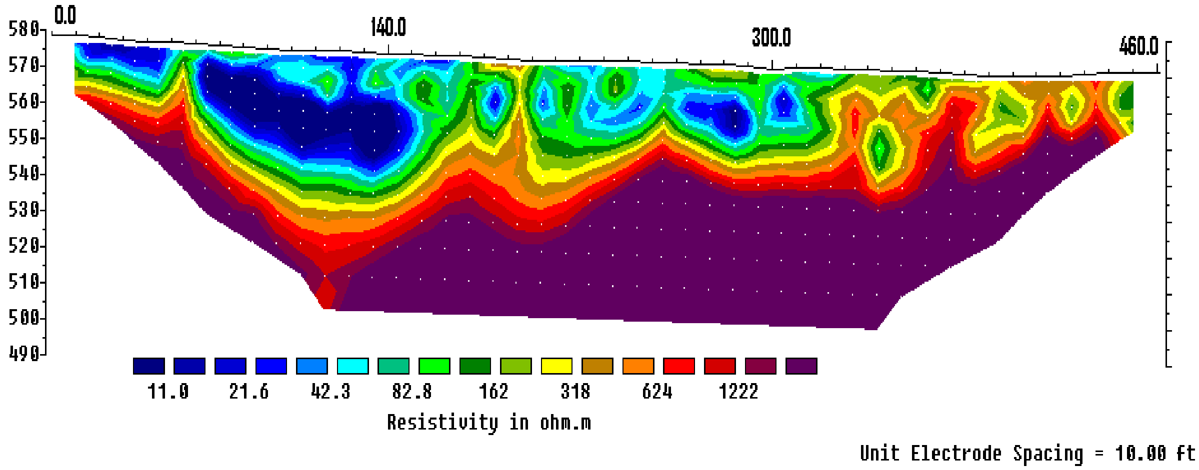

1. C:\onk\Data\GPR\Louiseville\45\PROCDATA\FILE1___.04T / traces: 8601 / samples: 495
LINE G
DISTANCE [FOO
TIME [ns]
DEPTH [FOOT] at v=2.36[inch/ns]


Line G
SP values in Millivolt
Distance in Feet
G-1
G-2
Topgraphic Line

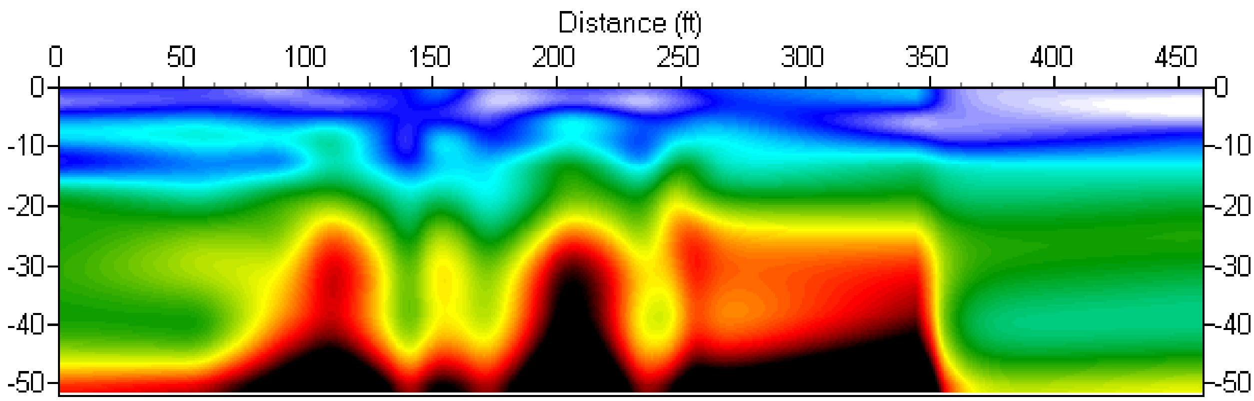

Line G
observed
calculated
Distance
m


Soil
2.15 gm/cc
Bedrock
2.5 gm/cc
Depth
m

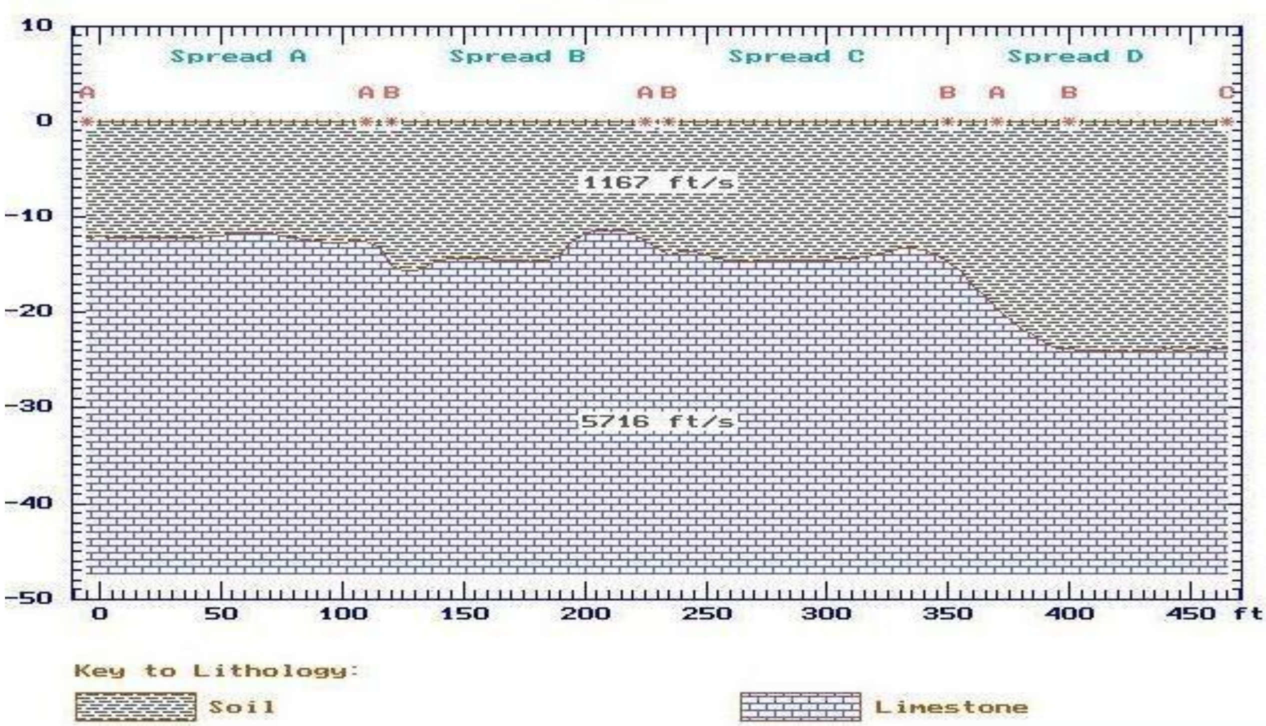
## Line H

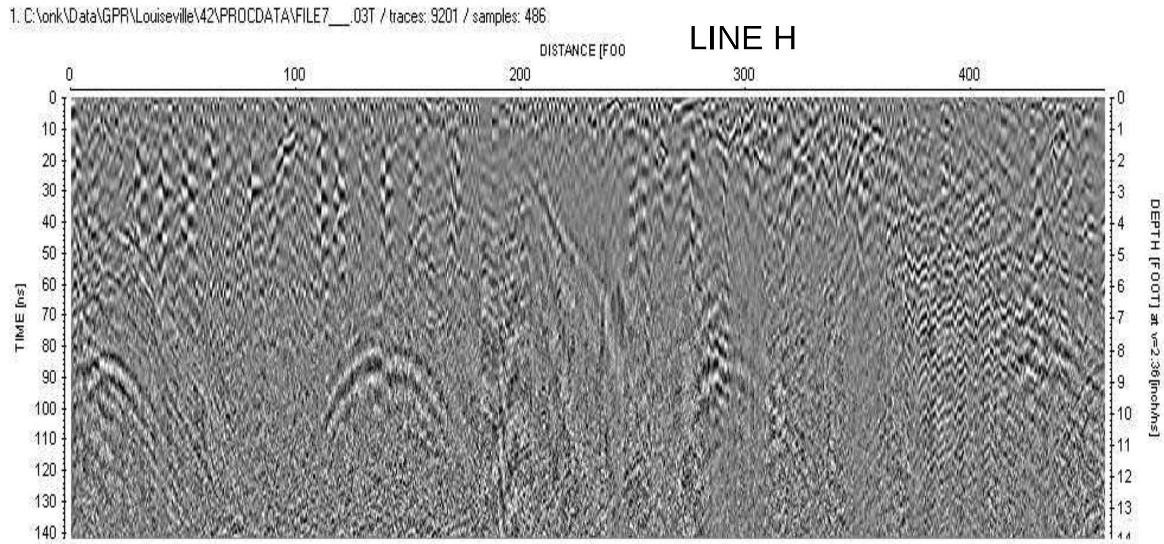


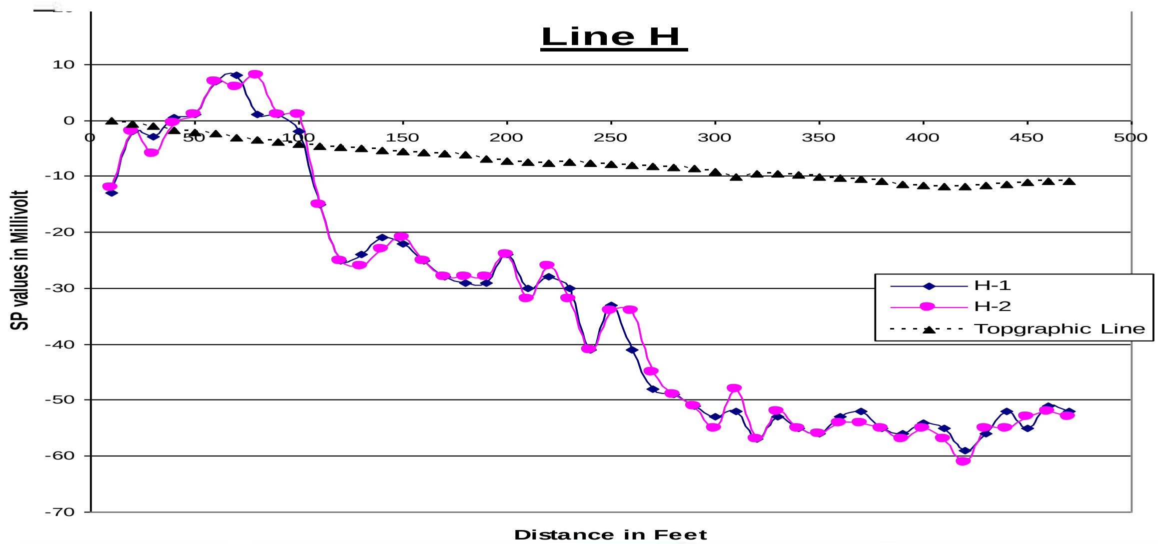

## Line H

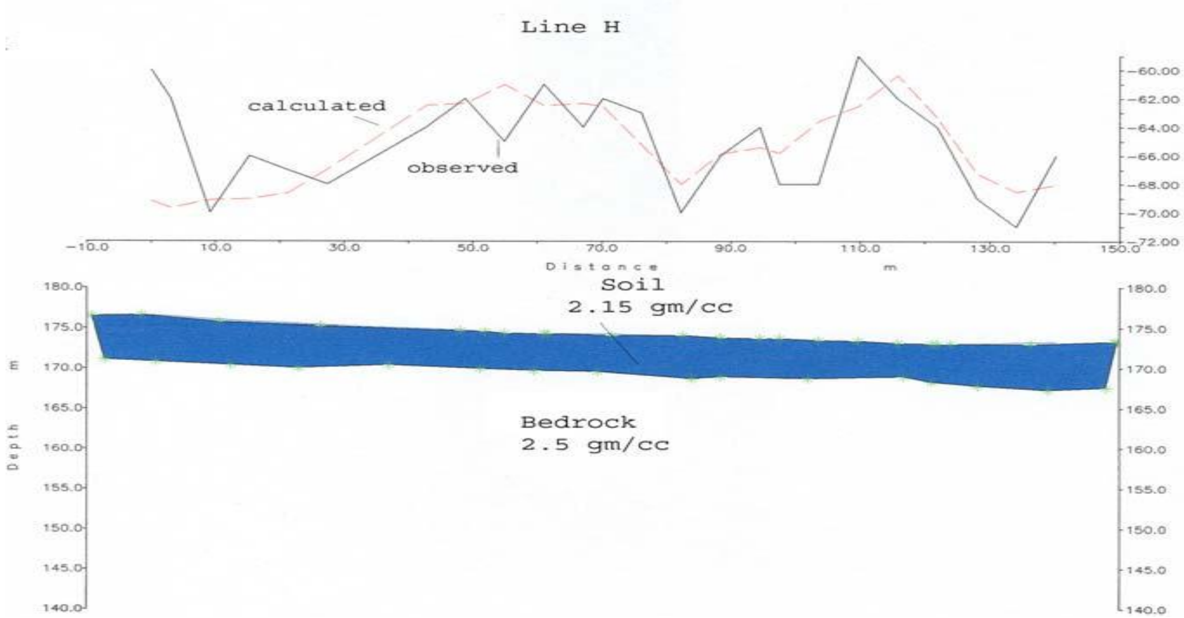


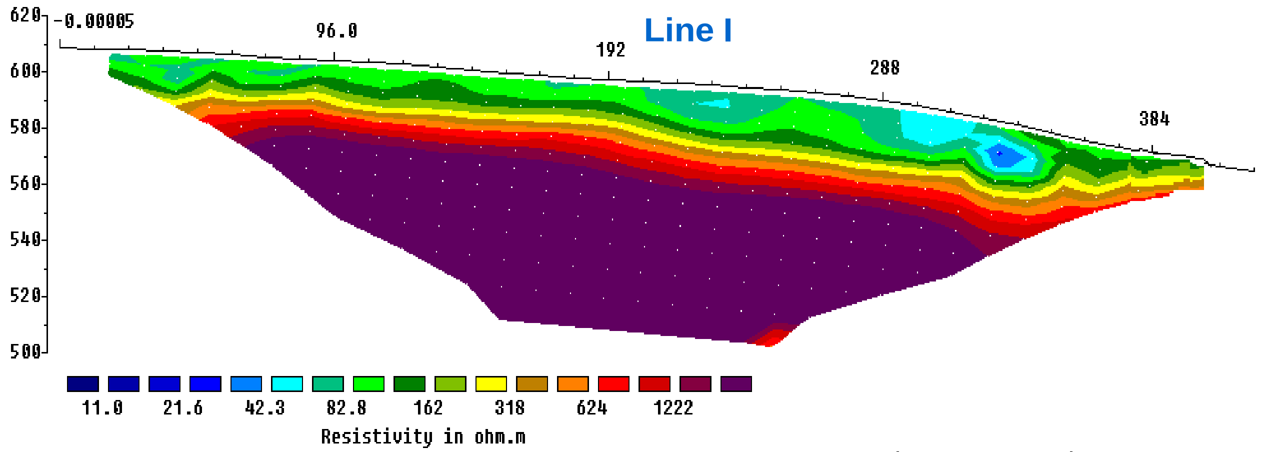

**Line H**

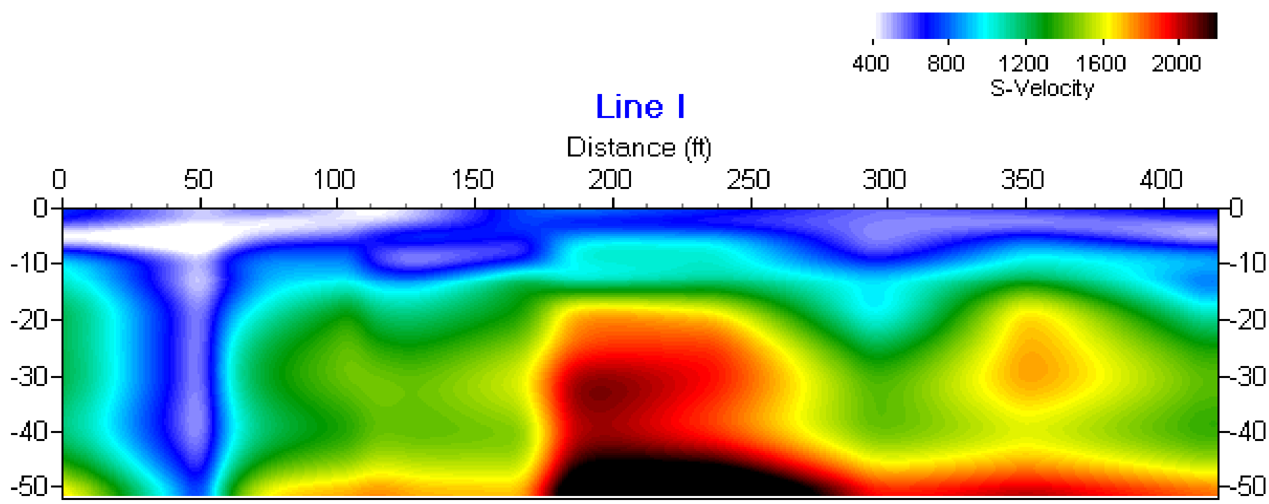


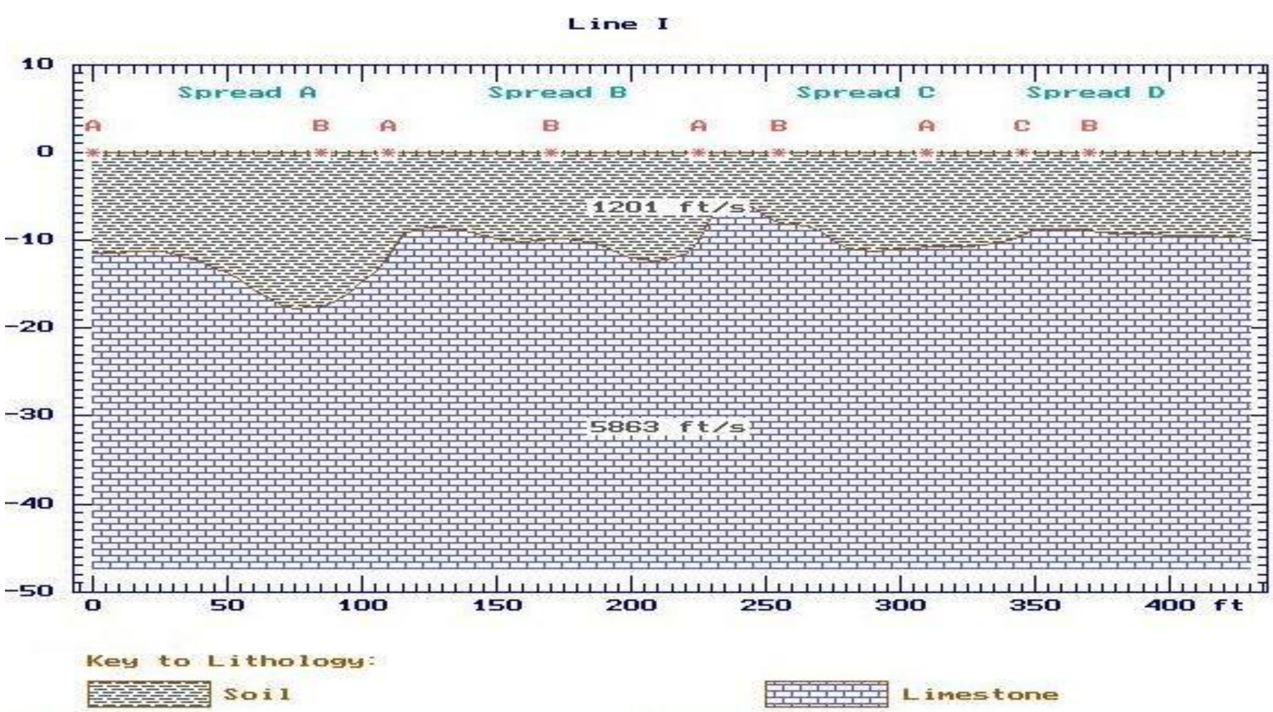

1. C:\onk\Data\GPR\Louisville\42\PROCDATA\FILE7__.03T / traces: 9201 / samples: 486
LINE H
DISTANCE [FOO
TIME [ns]
DEPTH [FOOT] at v=2.36[inch/ns]

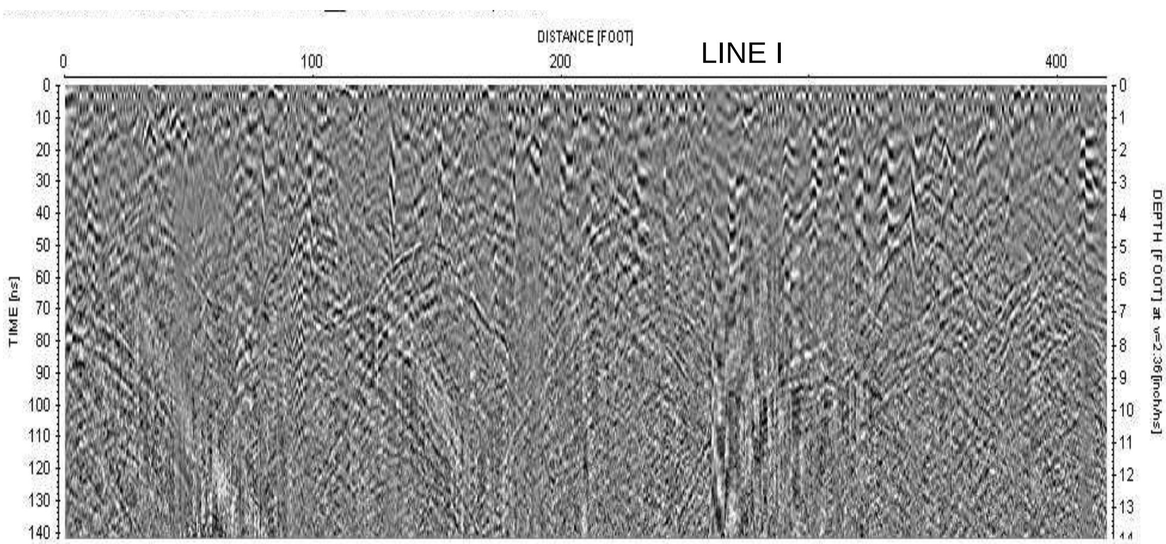

Line H
SP values in Millivolt
Distance in Feet
H-1
H-2
Topgraphic Line

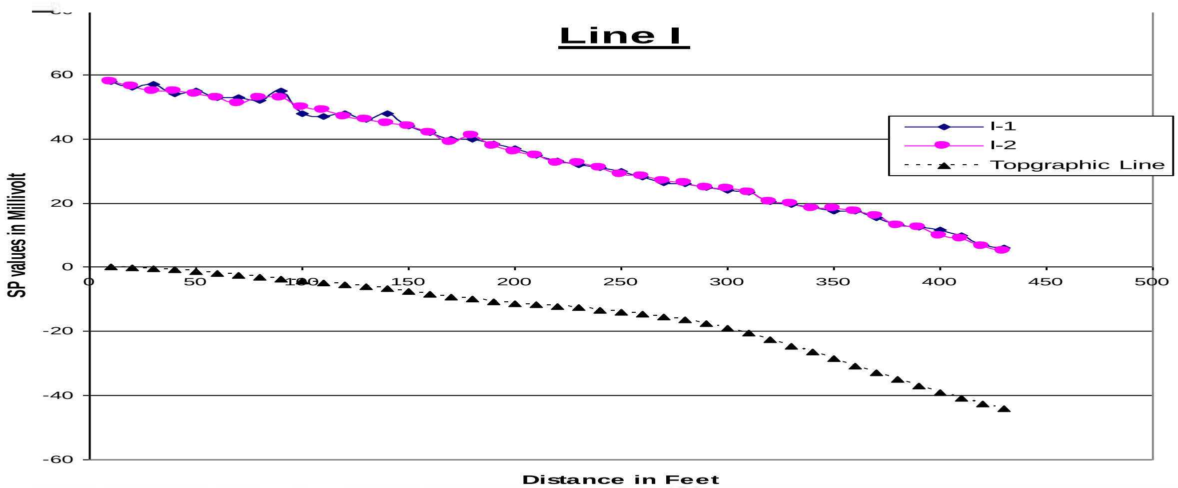

Line H
calculated
observed
Distance
m
Soil
2.15 gm/cc
Bedrock
2.5 gm/cc
Depth

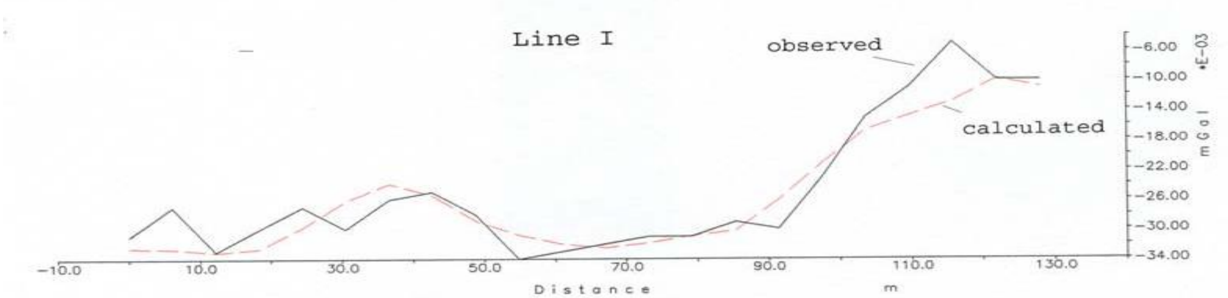

Line I
-0.00005
96.0
192
288
384
620
600
580
560
540
520
500
11.0
21.6
42.3
82.8
162
318
624
1222
Resistivity in ohm.m
Unit Electrode Spacing = 10.00 ft.

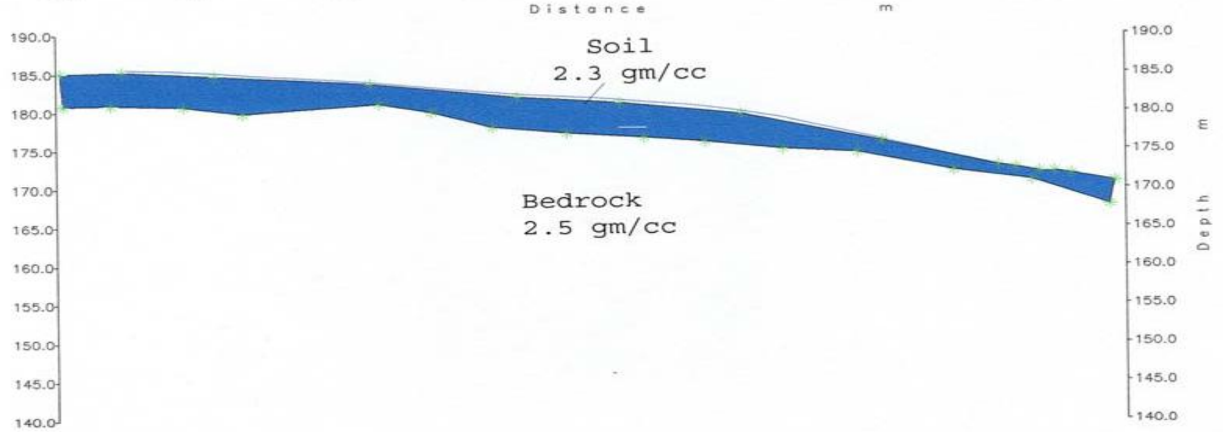

400
800
1200
1600
2000
S-Velocity
Line I
Distance (ft)
0
50
100
150
200
250
300
350
400
-10
-20
-30
-40
-50


Line I
Spread A
Spread B
Spread C
Spread D
1201 ft/s
5863 ft/s
10
0
-10
-20
-30
-40
-50
0
50
100
150
200
250
300
350
400 ft
Key to Lithology:
Soil
Limestone


DISTANCE [FOOT]
LINE I
TIME [ns]
DEPTH [FOOT] at v=2.36[inch/ns]


Line I
I-1
I-2
Topgraphic Line
SP values in Millivolt
Distance in Feet


Line I
observed
calculated
Distance
m
mGal
*E-03


Soil
2.3 gm/cc
Bedrock
2.5 gm/cc
Depth
m