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Independence

A Geophysical Survey

in Two Basements

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prepared for: Paul Y. Inashima
Applied Archeology Center, NPS
12200-A Plum Orchard Drive
Silver Spring, MD 20904

by: Bruce W. Bevan
Geosight
P. O. Box 135
Pitman, New Jersey 08071

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A Geophysical Survey in Two Basements

This survey was done with a ground-penetrating radar and a resistivity meter. Both instruments could reveal some features below the floors of two basements, although not to a large depth. The radar could profile to a depth of about 3 - 5 ft, while resistivity soundings could detect strata as deep as about 7 ft. The radar was limited by rather conductive soils, and also echoes from overhead ceilings; the resistivity measurements were limited by rubble in the soil and the area available for the work.

The Sites

These measurements were made in the basements of two historical buildings in Philadelphia; both are part of the Independence National Historical Park. The buildings are both on the north side of Walnut Street and next to Third Street. The Bishop White House is on the west side of Third Street, while the Merchants' Exchange is on the east side of Third Street.

It is planned to dig a trench for utility lines in the basement of the Bishop White House, and the survey there was designed to give some archaeological guidance along the path of that proposed trench. At the Merchants' Exchange, archaeological investigations are being done in order to understand the history of the building prior to its future modification.

A sketch of the floor of the basement of the Bishop White House is given in Figure 2; the dashed line marks the path of the radar profile. The northern part of the profile line goes over a pavement, while the southern half went over wooden boards which covered the soil. The reference point of the profile was the wall at the northern end of the profile; this was the S0 point. The line was parallel to the architectural direction and 2 ft from the eastern edge of the face of the fireplace which is at the northern end of the line. The line passed through two doorways: at S18.5 and S35 ft along the path. A wooden ceiling was at a height of about 7.5 ft above the floor; this ceiling contained metal ducts and wires.

A sketch of the floor in the basement of the Merchants' Exchange is given in Figure 5. A reference grid was set up here by Paul Inashima, with wire flags at 10 ft intervals along the eastern and western walls of the building. Unlike the Bishop White House, which is currently used as a historical building, the Merchants' Exchange is currently being renovated and there are no occupants, offices, or

historical exhibits in the building. The recent concrete flooring has been almost completely removed, exposing bare fill soil and other early surfaces below. A concrete floor remains near W30 on the south side of the basement, and several concrete foundations are visible at the surface. A gravel layer fills the space between two foundations at W45. A wide layer of cinders was found in the vicinity of W15 N30 and several piles of soil or gravel are found on the surface of the floor. Some shallow archaeological excavations were open in the soil of the basement. A brick ceiling is at a height of about 14 ft above the floor; a metal surface is partly exposed about 2 - 3 ft above that. During this geophysical survey, an NPS crew was measuring the locations of architectural features in the basement.

The Geophysical Surveys and Their Interpretation

The radar survey was done with a model SIR System-7 ground-penetrating radar, manufactured by Geophysical Survey Systems. Two different radar antennas were tested during this survey; both are sketched in Figure 1. A small antenna allowed shallow features to be detected with a high resolution; this antenna has a characteristic frequency of 315 MHz and is a model 3102. A larger antenna had lower resolution, but had the capability for profiling deeper into the soil it was a model 3105 antenna with a characteristic frequency of about 180 MHz. This lower resolution antenna detected stronger echoes from overhead structures, for its upper surface is not as well shielded as is the higher resolution antenna.

Both antennas were affected by an unusual interference; this noise was often quite periodic, and was detected at intervals of about 24 s. The left side of Figure 8 shows it as thin vertical bands. The electrical noise was indeed most distinct when the antenna was on the western side of the building. It was also detected in the Bishop White House; while not periodic at the time, Figure 4 shows the type of noise that was found. This noise did not harm the interpretation of the radar profiles.

The total length which was profiled in both basements was 779 ft. The profiles did not reveal any good hyperbolic echo arcs for a calibration of the pulse velocity and therefore the depth scales of the profiles. By a comparison with sites having similar resistivity and profiling depth, it is estimated that the velocity of the radar pulse in this soil could be about 0.3 ft/ns; an error of 30 per cent in this velocity and the depth estimates is possible.

the geophysical surveys and their interpretation

Resistivity soundings were done only in the basement of the Merchants' Exchange. A small battery-powered resistivity meter was used for the measurements, and the meter is sketched in Figure 1. The offset Wenner configuration of the electrodes was used, and the electrode spacing was as great as 4 - 7 m. The locations of the five electrodes where they were at the greatest spacing are plotted by the circles in Figure 5; these are connected by a dotted line. With the offset Wenner configuration, five equally-spaced electrodes are driven into the earth, but only four are used at a time. The measurement which is made with the four electrodes on the left is averaged with the measurement made with the instrument's contacts shifted to the right. This averaging removes much of the effect of lateral changes in the soil; this is important, since the analysis assumes that there are no lateral changes.

The soil was rather clayey and soft in most of the area of the southern sounding. However, rubble or gravel in the soil made it difficult to make a good electrical contact with the earth at the soundings made in the north and east side of the basement. Metal spikes were driven for these electrodes, but water was not poured on the soil in their vicinity.

The resistivity soundings are plotted in Figures 9, 12, and 13. The solid line shows the averages of the two resistivity measurements which were made at each spacing; the broken line shows the values found at one of the offsets. Differences between these two curves reveal lateral variations in resistivity, and also errors in the measurements caused by poor electrical contact with the earth.

The soundings were first analyzed using curve matching with the publication by E. Orellana and H. M. Mooney (Two and three layer master curves and auxiliary point diagrams for vertical electrical sounding using Wenner arrangement). The analyses were then made more precise with the computer program of S. K. Sandberg, Einvt4 (NJ Geological Survey Open-File Report 90-1).

The geophysical survey was done on July 29, 1997.

The Findings of the Geophysical Surveys

A single line in the basement of the Bishop White House was examined with both the high resolution and the medium resolution radar antennas. Figure 3 is the profile made with the high resolution antenna. The undulating black bands in the figure are echoes of the radar pulse. Interfaces as shallow as 0.5 ft were found. It is

unlikely that echoes from below a depth of 5 ft were detected.

The radar pulse travels about three times slower in the soil here than it does in air; the depth scale assumes that the pulse travels through the soil. Since there are metallic objects in the ceiling at a height of about 7.5 ft, echoes from these objects can begin to appear in the radar profiles at an apparent "depth" of somewhat more than 2 ft. It is possible that the dipping interfaces which are revealed on the profile of Figure 3 are caused by the ceiling, however, this high resolution radar antenna is fairly well shielded from echoes coming from overhead, and it is more likely that these interfaces are caused by true soil contrasts at a depth of 2 - 3 ft. The very flat horizontal bands below an apparent depth of 10 ft in Figure 3 are caused by the electronics of the radar itself.

The same line at the Bishop White House was examined with the lower resolution radar antenna, and the profile is included as Figure 4. The traverse speed was somewhat faster for this profile, so it has a somewhat greater lateral compression. The lower resolution of this antenna is visible by the wider echo bands, and also the fact that shallow objects are poorly detected or not detected at all. The echo bands from below a "depth" of about 4 ft are likely to be caused by overhead objects. The irregular echo patterns in the span from S25 to S45 match the area where the high resolution antenna found an interface underground. An object at S25 was detected by both antennas at a depth of 0.7 ft.

Features on the floor of the Merchants' Exchange are mapped in Figure 5; this can be compared to the radar echo map of Figure 6, and it is seen that there are almost no correlations. Also, the map of Figure 6 does not reveal any clustering of echoes or other patterns which appear to be valuable. While there are two echoes at the line of the brick foundation near W77, the radar adds little information about this known feature. The circles and lines in Figure 6 probably do indicate reliable echoes from underground objects. The lines which were profiled are mapped in Figure 7; the spans were shorter for lines at N40 and N50 because of the elevator shaft at the western end.

An example of a radar profile is given as Figure 8. Since the metallic surface of the ceiling is at a height of over 15 ft in this basement, it should appear at an apparent depth of about 5 ft; the rather horizontal echo at that depth is indeed likely to be caused by the ceiling. All of the echoes at a depth greater than 5 ft therefore

cannot be trusted as coming from underground; they could just be complex reflections between two or more objects which are overhead.

The high resolution radar antenna was also tested in the basement of the Merchants' Exchange, but it showed a maximum profiling depth of about 2 ft; the medium resolution antenna gave the possibility for detecting interfaces between a depth of about 1 ft and 5 ft.

The three resistivity soundings which were done in the basement of the Merchants' Exchange have their locations plotted with small circles and dotted lines in Figure 5. These are called the southern, eastern, and northern soundings. The analysis of these soundings is shown in Figure 14, with the same S, E, and N arrangement.

The soil resistivity is listed in the figure in ohm-meters; higher values mean that the soil more strongly limits the flow of an electrical current. High values of resistivity can be caused by sand, gravel, rock, dry soil, and air. Low values of resistivity can be caused by moist or saline soil, or by clay and silt in the soil.

Human modification of the soil can also lower the resistivity. It appears likely that cinders can have a low resistivity, perhaps because of the sulfides which they contain. The eastern sounding found the lowest resistivity values, less than 10 ohm-m. Since there were cinders or clinkers at the surface of the middle of this sounding, they were likely the cause of the low values.

Clay can have a resistivity of roughly 20 ohm-m. The soft soil found during the measurements of the southern sounding suggested that clay might be underground there, and the values of about 20 ohm-m there may reveal this clay. Distinctly more rubble was detected at the location of the northern sounding during the driving of the electrodes; this rather rocky material may have caused the resistivity to be somewhat higher there.

It is possible that salts may concentrate at basement floors also. This is because moisture in the soil carries salts toward the surface, where the water is evaporated, leaving the salts behind. An efflorescence of salts was visible on the walls of the basement of the Bishop White House, although not on the floor; also, the radar profiles there did not suggest the extremely strong attenuation which can be caused by a small amount of salt in the soil. While no efflorescence of salt was visible in the cellar of the Merchants' Exchange, salts could contribute to the low resistivity which was measured.

The resistivity values greater than 100 ohm-m in Figure 14 indicate that the soil could be sandier or more gravelly at those depths. These high resistivity layers were always found to be at an intermediate depth underground, never at the surface or at the greatest depths. The exact thickness and resistivity of these intermediate layers cannot be precisely determined; the difficulty is described by the geophysical term: equivalence. This is illustrated by the analysis of the southern resistivity sounding which is in Figure 10. The solid line indicates the calculated resistivity sounding for the layers plotted at the bottom of Figure 14. If the thickness of the middle layer is halved, and its resistivity is doubled, the resulting calculated resistivity is indicated by the broken line in Figure 10. This does not differ very much from the solid line, and this indicates that there can be an error in the analysis of the thickness and character of the layers.

Earlier soil corings within the basement of the Merchants' Exchange have revealed layers of gravel and peat; both of these materials typically have a high resistivity. It is possible that the high resistivity layers of Figure 14 (which are dotted) could be these materials, or it is also possible that these gravel and peat layers are only found below the depth of exploration of the resistivity soundings.

This depth of exploration was tested, and the curves of Figure 11 give some information about the greatest depth at which a high resistivity layer would be detected. The calculation is based on the analysis of the southern resistivity sounding. The calculated values were determined if a high resistivity bottom layer (200 ohm-m) had its upper surface at different depths below the strata shown in Figure 14. Figure 11 shows that if this layer was at a depth of 10 ft or more underground, it would only cause an insignificant change in the resistivity sounding. However, if it was shallower than 7 ft, it is likely that it would be detected, for it would cause a distinct upward arc of the sounding curve at the right-hand side.

Resistivity soundings require that a good length of ground be available in order that the electrodes can be spread to a large spacing and therefore explore to a good depth. In order to explore a depth of about 7 ft, the total span of the five electrodes must be about 50 ft, much greater than the depth. This is a limitation of resistivity sounding in a basement. Another general limitation of

the findings of the geophysical surveys

resistivity soundings (and most other geophysical surveys) is that a layer cannot usually be detected if it is thinner than the depth to its upper surface.

The resistivity sounding which was made at the northern side of the basement is plotted in Figure 12. The separation between the solid and broken lines in this figure means that there are unknown features underground near the middle of this sounding (W50 N58). While the location and character of these features cannot be determined with any accuracy, these features are clearly in this vicinity, and not in the vicinity of the other soundings.

Conclusion

The radar profiles may have revealed a stratigraphic interface at a depth of 2 - 3 ft below the basement floor of the Bishop White House. The radar had little success at the Merchants' Exchange; the soil there caused a strong attenuation of the radar pulse, and the profiling depth and clarity were poor. However, the resistivity soundings revealed soil strata which the radar could not detect.

These two basements had conditions which are rather typical of many basements. While there were no significant metallic objects (such as furnaces) off to the side, there were metallic objects overhead to cause difficulties for the radar. Neither of the floors were constructed of reinforced concrete; this would have made all geophysical surveys impossible (except for a gravity survey). The general stratigraphic complexity and likelihood of rubble below the basement of the Merchants' Exchange basement made that survey somewhat more uncertain than usual. While salt could accumulate at the floor of some basements, it did not appear to be a severe problem at these two locations. Because of the iron and other metal which was in these basements (and most others) neither magnetic nor conductivity surveys were suitable. The bare soil of the Merchants' Exchange allowed the resistivity surveys to be done there; if a hard pavement was there, the resistivity work would have been difficult or impossible.

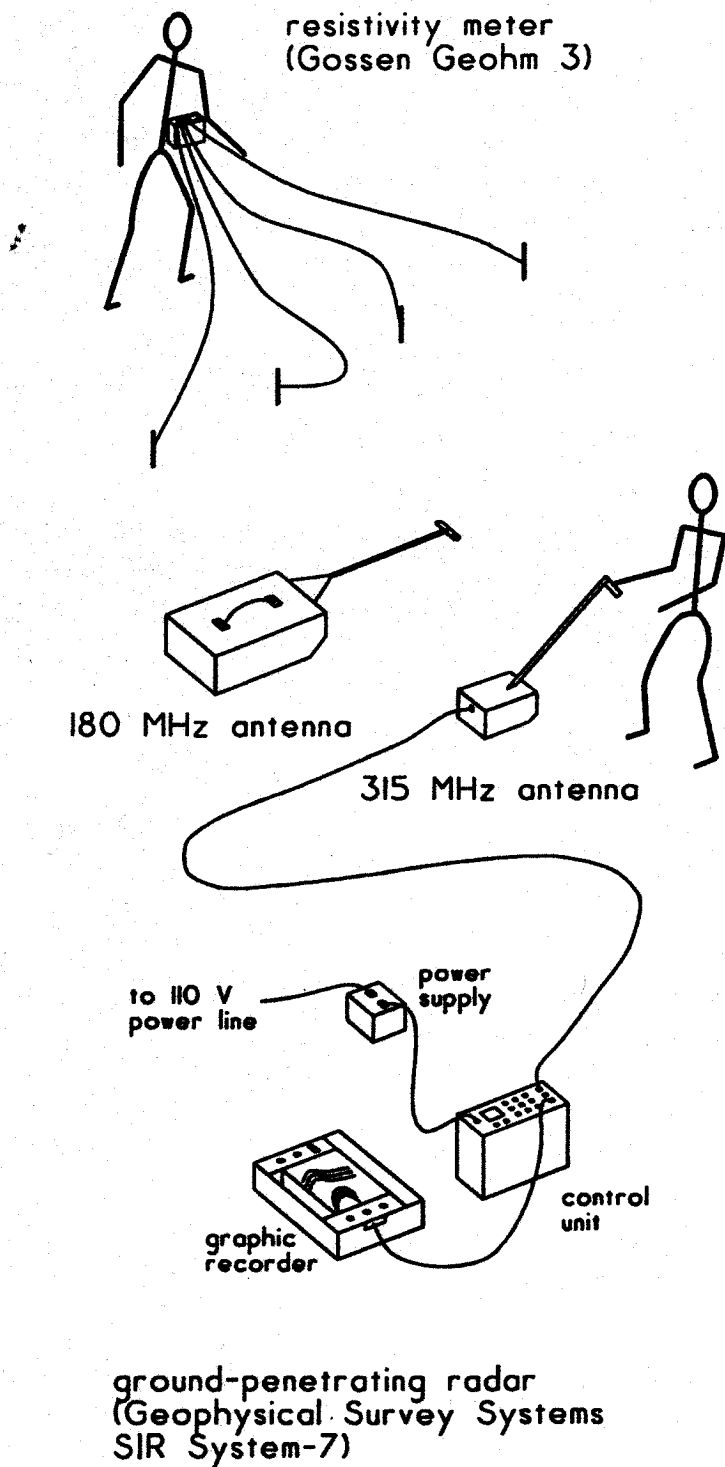


Figure 1: The geophysical instruments of this survey. The resistivity meter furnished estimates of the stratification of the earth in three locations. Profiles from the radar yielded cross-sections of soil interfaces along eight lines.

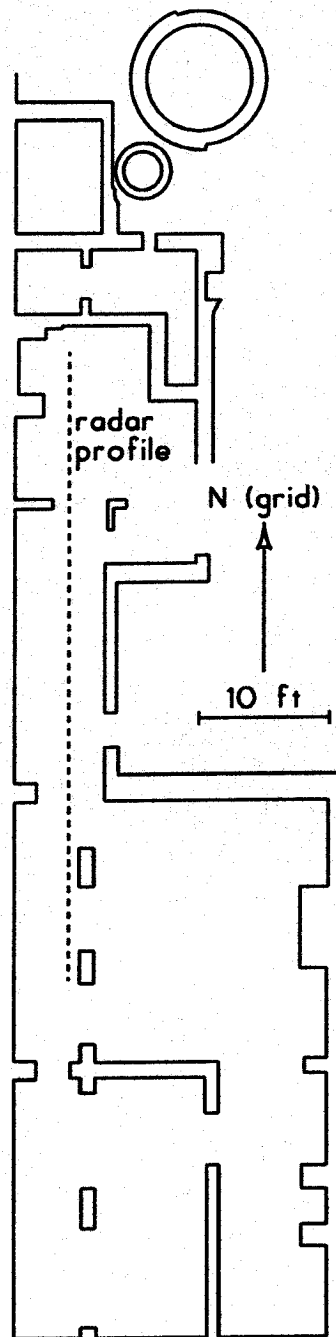


Figure 2: The basement of the Bishop White house. The broken line approximates the path of the radar profile. The straight solid lines are estimates of the locations of walls; the circles locate a well and a cistern. This is derived from a map from the National Park Service.

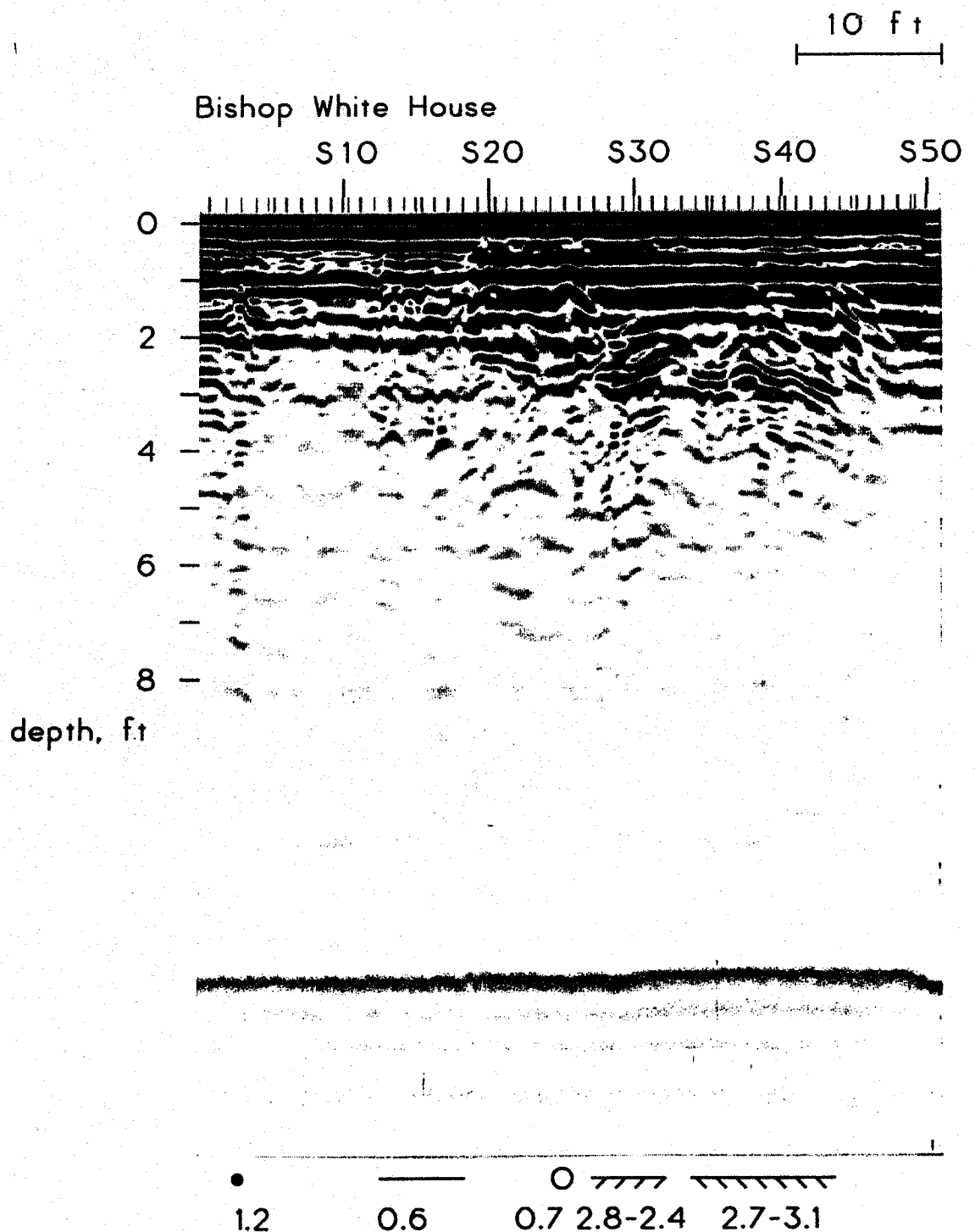


Figure 3: A high resolution radar profile. Echo bands between a depth of 0.2 ft and about 5 ft may be caused by subsurface interfaces. The tick marks at the top of the profile are at intervals of 1 ft. Echo symbols at the bottom of the profile show the major reflection and their depth, in feet.

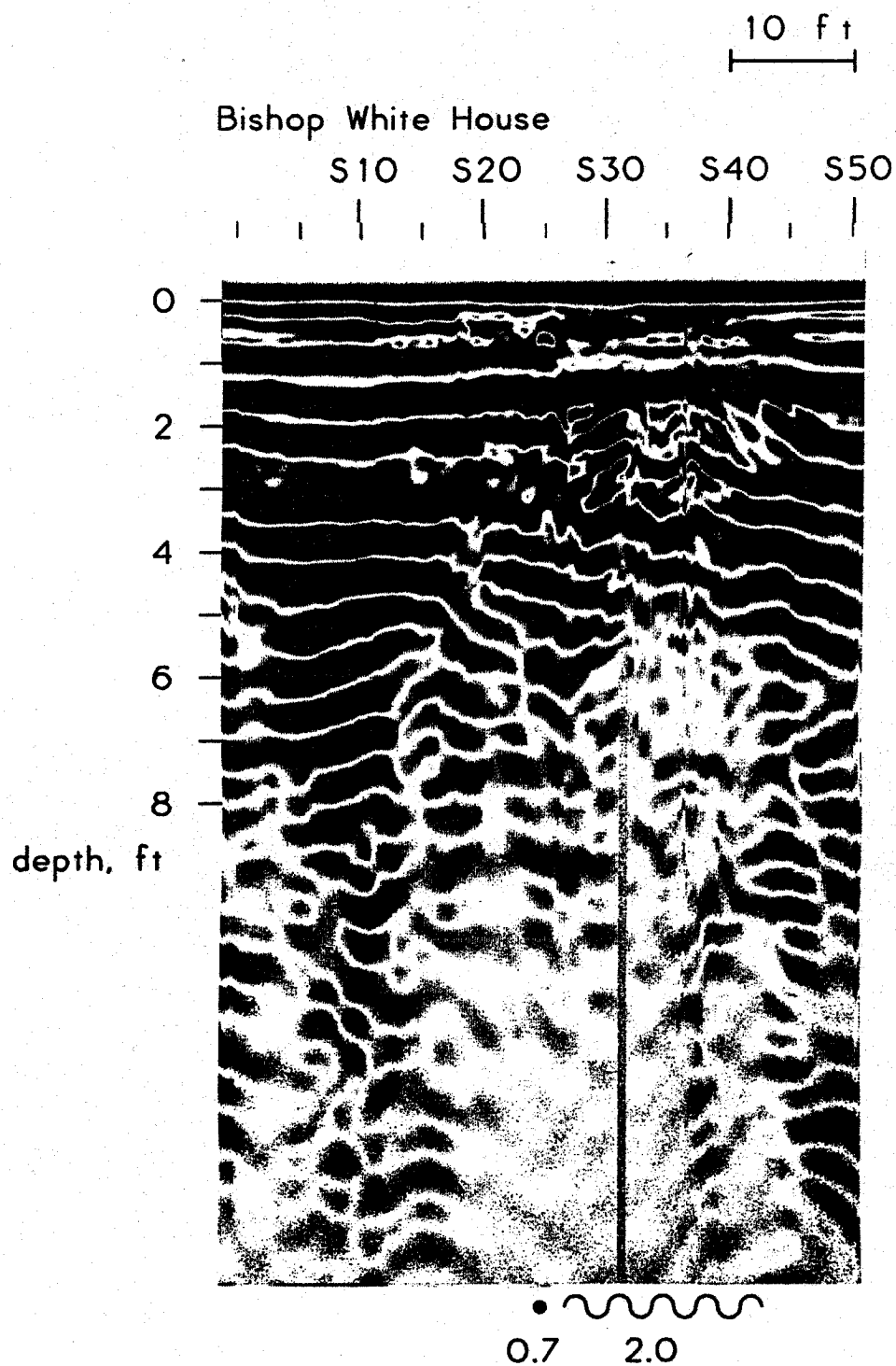


Figure 4: A medium resolution radar profile. This follows the same line as that of Figure 3, and tick marks are now at intervals of 5 ft. Most of the echo bands from below an apparent depth of 3 ft may be caused by objects which are overhead.

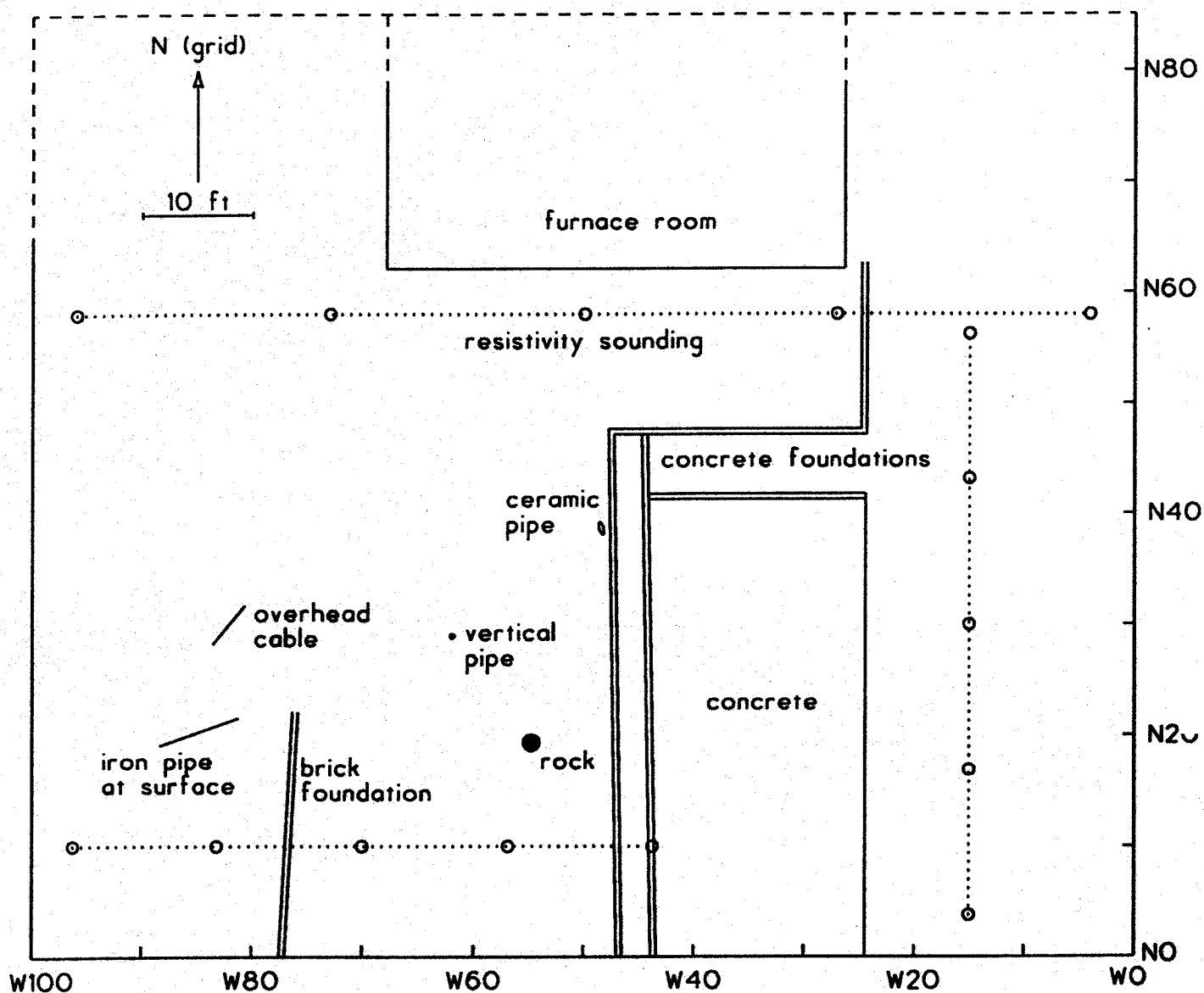


Figure 5: The basement of the Merchants' Exchange. The scale is the same as the map in Figure 2. The surface features here were located approximately during this survey. While a small rectangular area is covered by concrete, the rest of the surface is soil. Three resistivity soundings are indicated with dotted lines.

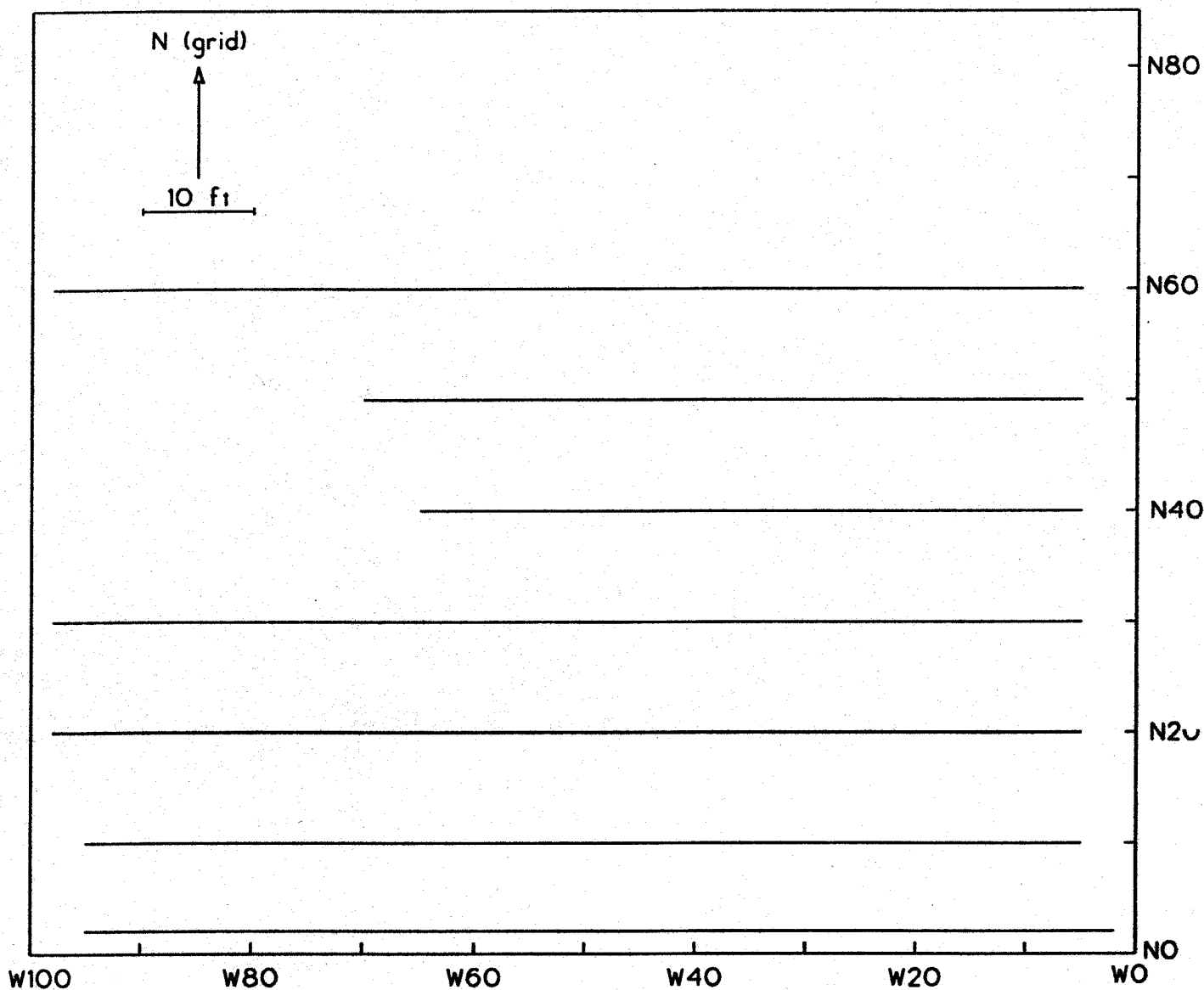


Figure 7: The lines of the radar profiles at the Merchants' Exchange. These lines were spaced by 10 ft, and the traverses were made going toward the east.

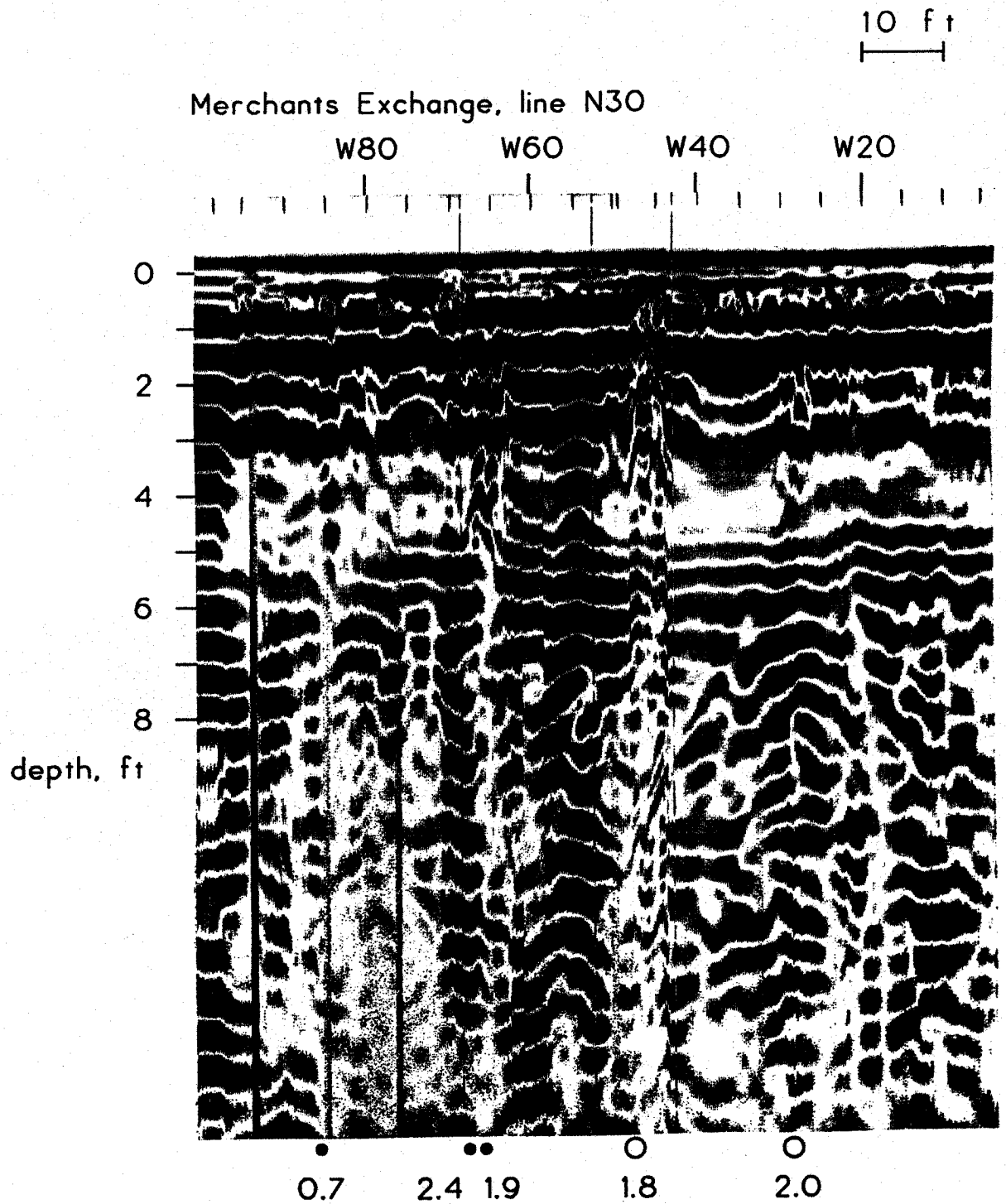


Figure 8: A medium resolution radar profile. It starts at about W98 and ends at W5. The rather flat echo band at an apparent depth of about 5 ft is caused by a reflection from the ceiling of the cellar.

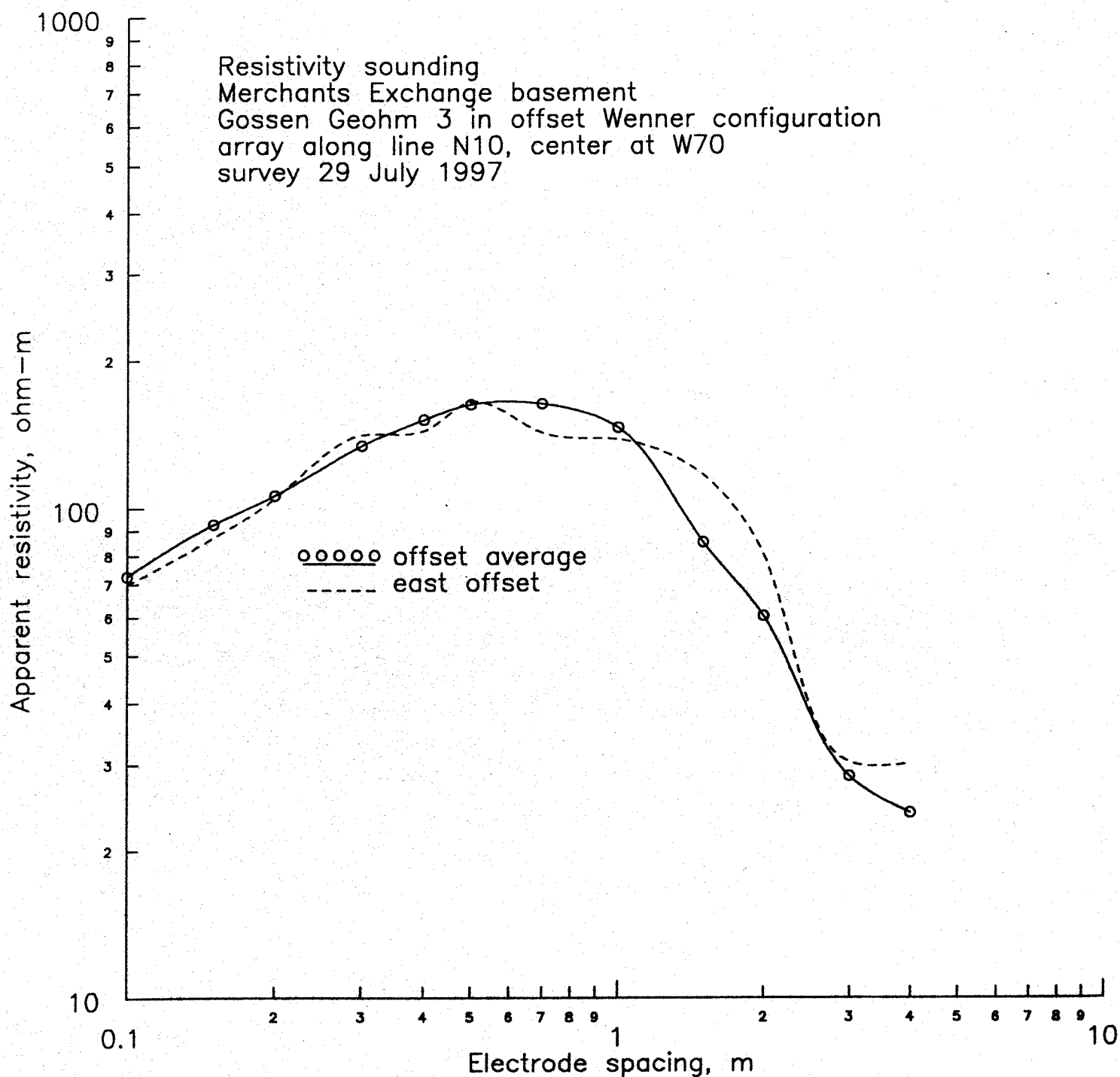


Figure 9: The southern resistivity sounding. The change in apparent resistivity with increasing electrode spacing indicate that three major strata were detected.

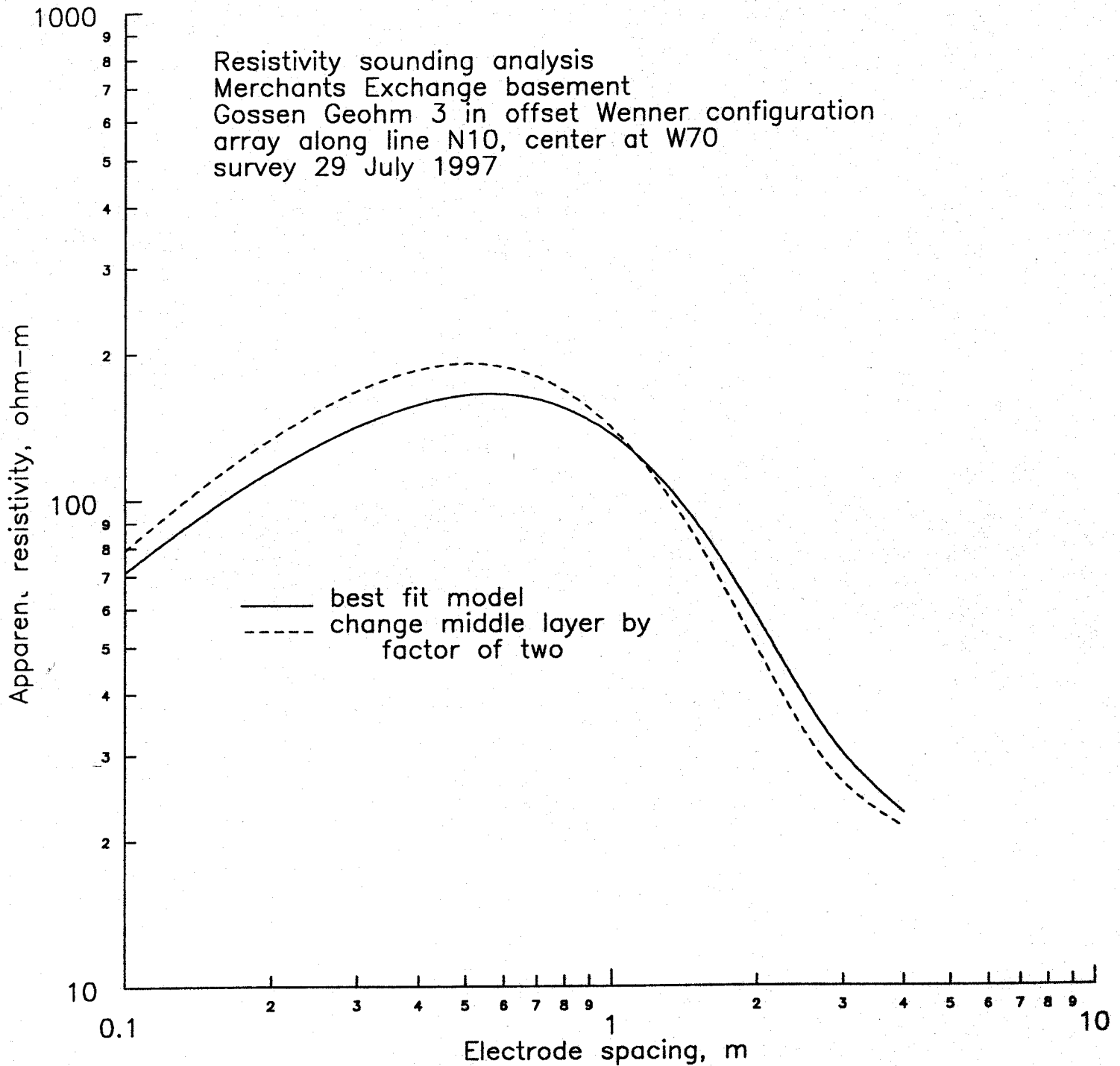


Figure 10: A test of equivalence. A large change in the resistivity and thickness of the middle layer does not change the calculated resistivity values very much. This means that the estimated values of the resistivity and thickness are not very accurate.

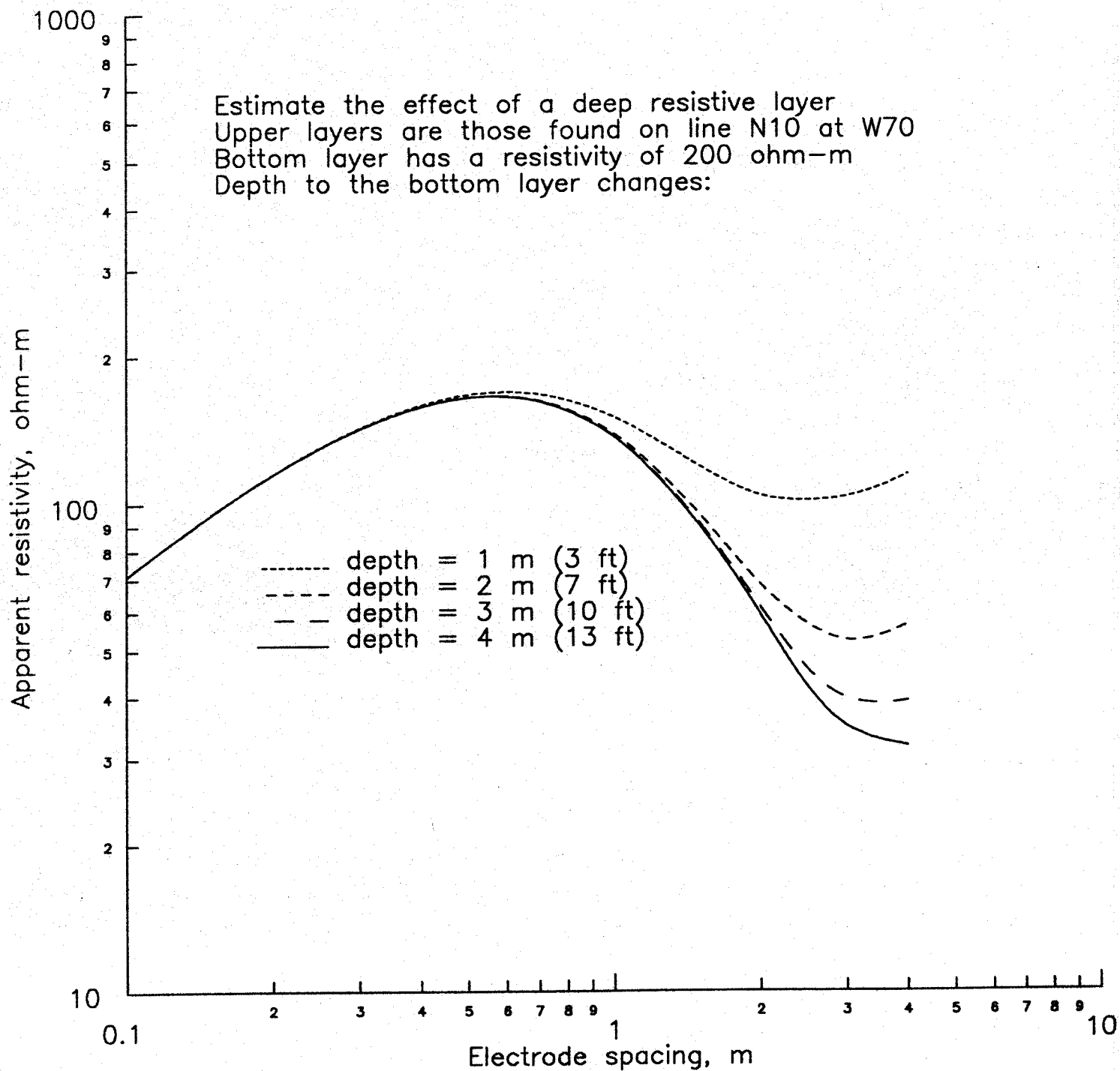


Figure 11: The detection of a deeper layer. A deep high resistivity layer may be detected if its upper surface is less than about 7 ft underground.

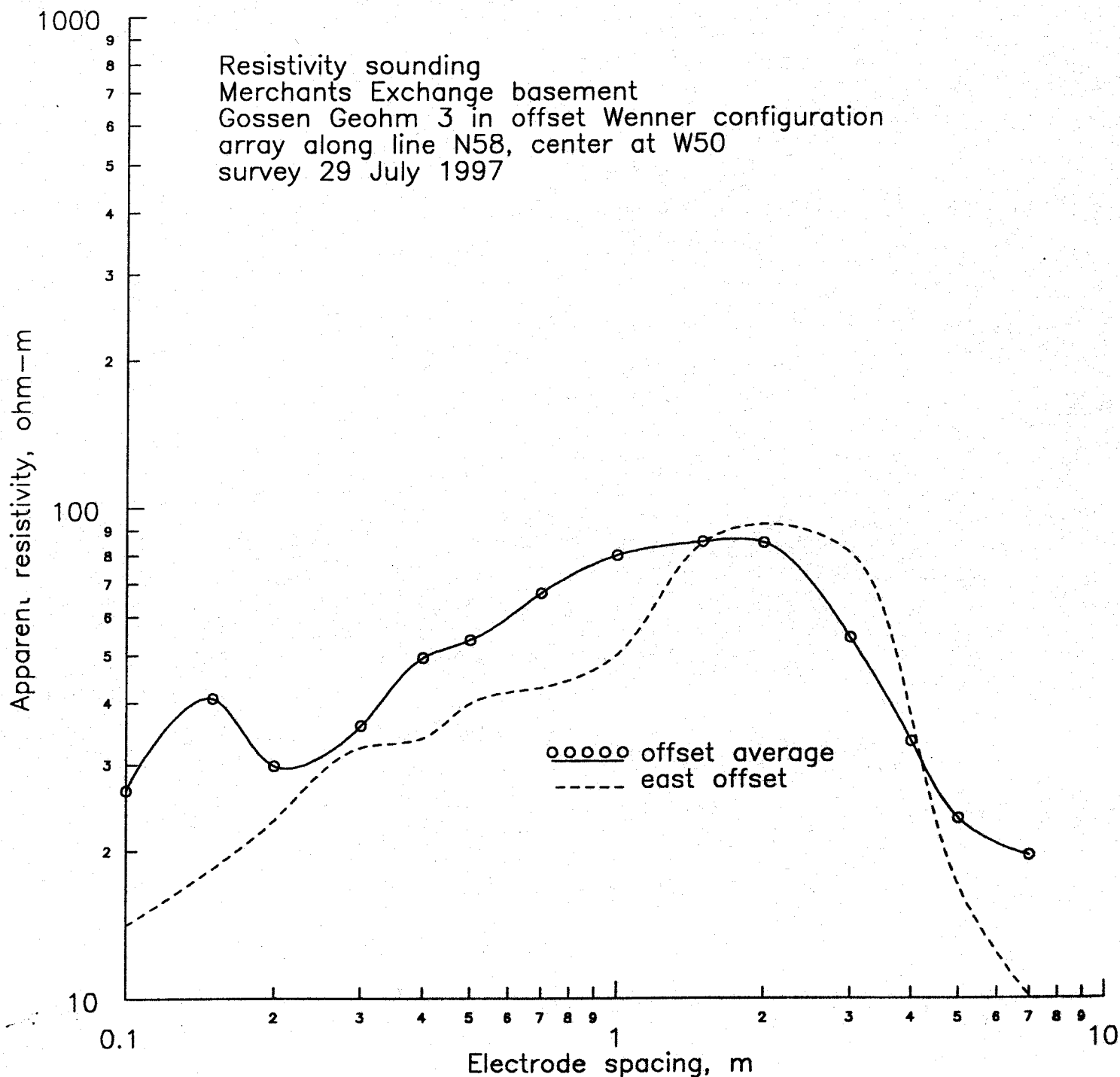


Figure 12: The northern resistivity sounding. It shows three layers similar to the southern sounding, although the resistivity is lower. The solid line is a plot of the average resistivity, while the broken line indicates the resistivity measured on the eastern offset. The separation of these lines indicates that there is a large lateral change in resistivity at this location.

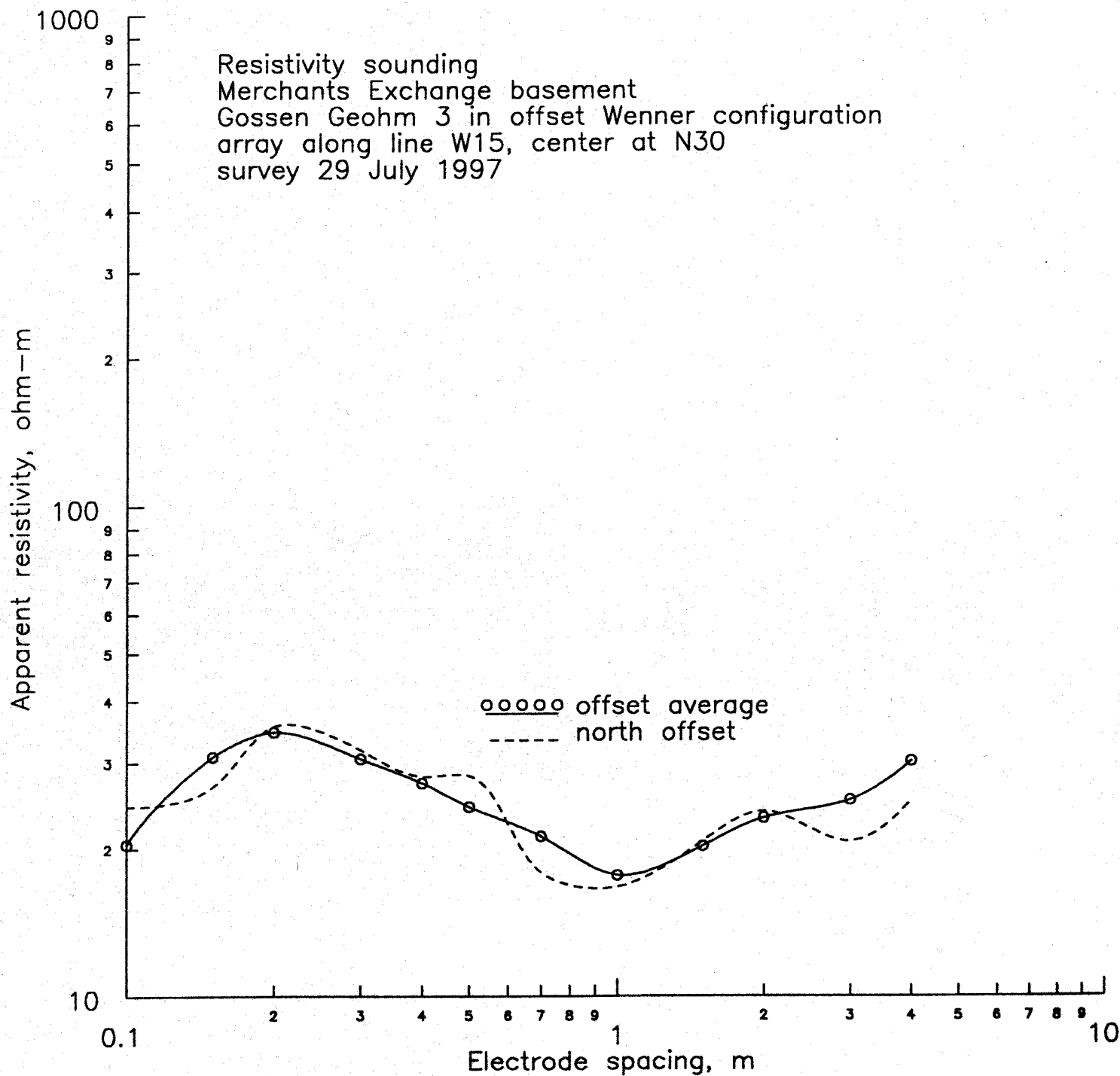


Figure 13: The resistivity at the eastern sounding. The values are very low; this may be caused by the cinders which are visible at the surface here.

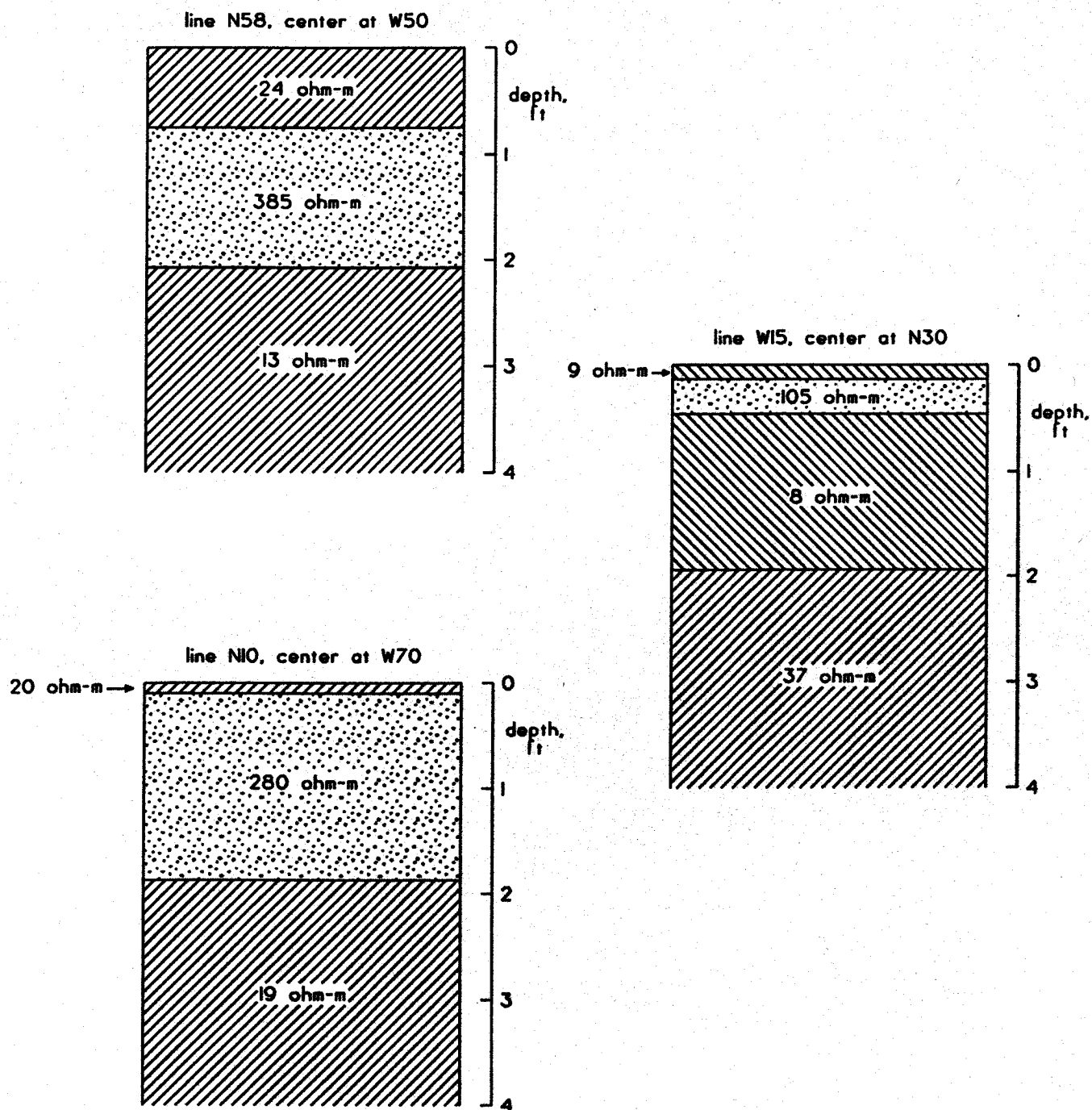


Figure 14: An analysis of the three resistivity soundings. The dotted areas indicate high resistivity, while the hachured areas have a low resistivity. The analysis assumes that the strata have abrupt and horizontal interfaces.

The different radar echoes and their symbols

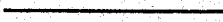
	irregular strata
	planar reflector
	strata rising
	dipping strata
	distinct echo
	weak echo
	reverberating echo. metal

Figure 15: A key to the radar echoes. The patterns of the echoes were classified into one of these seven types. Undulating lines mark where the strata are moderately unusual and complex. An asterisk may mark where there is metal at a shallow depth.

H3015 (DSC-RPA)
INDE 412C-43 & 412F-43

April 27, 1998

Memorandum

To: Doris Fanelli, Chief, Cultural Resources Management,
Independence National Historical Park

From: Paul Y. Inashima, Archeologist, Applied Archeology Center,
Resource Planning, Denver Service Center

Reference: Independence National Historical Park, Packages 412C and 412F,
Parkwide Utility Distribution System, Project Types 43

Subject: Transmittal of Technical Study

Attached for your archives are five copies of the report, "A Geophysical Survey in Two Basements," by Dr. Bruce Bevan of Geosight. The geophysical surveys were conducted on July 29, 1997, and the reporting was completed on August 25, 1997.

The goals of the surveys were twofold. The first goal was to detect cultural features and structures which might underlie the exposed basement floors of the Bishop White House and the Merchants' Exchange building. The second goal was to locate the relative depths of a gravel layer which had been identified during earlier engineering soils borings in the Merchants' Exchange building. The intent of the second goal was to utilize the relative location of the gravel layer in defining the former contours of the south bank of the historic Dock Creek.

Ground penetrating radar was employed at the Bishop White House. Both ground penetrating radar and soil resistivity were used at the Merchants' Exchange building. Although the radar readings at both locations encountered interference from metal within the first floor substructures, the survey at the Bishop White House did detect a possible buried soil interface as well as at least one potential cultural feature. Radar was less successful at the Merchants' Exchange, although soil resistivity did suggest stratigraphic information.

Attachments (5) *in TIC*

cc (w/ 1 att.):
Mark Shaffer, Pennsylvania SHPO
Allen Cooper, Chesapeake/Allegheny SO
David Orr, Valley Forge Archeology Center

bcc (w 1 att):
DSC-MS-Jodie Morrison
DSC-PM-Bucholtz
DSC-RPA-Inashima
DSC-RPA-Files (3, 1 w/att.)

PYInashima:cle:(301)-344-6260:4/27/98:bevan2b.trn