Working with the EM38 Earth Conductivity Meter: Geophysical Survey at the Hopeton Earthwork, Chillicothe, Ohio, May, 2001

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Introduction

The following report accomplishes two things. First, it discusses several problems involved in the archaeological use of the Geonics Ltd., EM38 and other electromagnetic (EM) survey equipment. Overall, this discussion should lead to a greater appreciation of this class of geophysical survey instruments. Secondly it reports the results of an EM survey of portions of the Hopeton earthwork with an EM38 during the May, 2001, National Park Service Workshop in geophysical survey.

In North America, EM survey has been widely used in environmental analysis and the commercial equipment has been specifically developed in response to environmental monitoring; only secondarily has it been used in archaeological applications. New types of environmental analysis have led to the continued development of the hardware, most recently the survey and identification of unexploded ordnance (UXO) responding to accelerated military base closings in the United States. By contrast, other types of geophysical survey hardware have been developed more specifically with archaeological applications in mind and archaeologists themselves have developed the more successful and widely used equipment.

The importance of EM hardware, and specifically the Geonics EM38 used in the Hopeton survey, lies in its availability, its data collecting speed, and its particular geophysical sensitivity. It also can be used to measure two types of geophysical information, earth conductivity (measured in mS/m or millisiemens/meter) and magnetic susceptibility (measured in ppt or parts per thousand) although it is not clear how useful the second measurement is in archaeology when made with this instrument. However, because it is widely available, it is quite possible that an archaeologist can borrow the hardware within a university; it is a standard tool in earth science departments in colleges and universities, government soil science laboratories, and other government agencies where it is often underused in my experience. Because of its potential speed of ground coverage, it may be used to cover wide areas quite rapidly. This is important in surveying large archaeological features like earthworks and plowed down mounds where, quite often, pattern recognition depends upon getting a large-scale view of the anomaly. Because of its particular sensitivity, the EM 38 is especially valuable in certain types of archaeological situations such as the survey of plowed down mounds and earthworks, less so in others. The instrumentation does well what it does well. Its ability to potentially measure two geophysical modes is an aspect that has been generally ignored but it provides another "dimension" of earth geophysics. Finally, a conductivity survey is a helpful adjunct to other types of geophysical survey. For example, because ground-penetrating radar (GPR) tends to be attenuated by clayey soils, a prior conductivity survey is a convenient way to establish the feasibility of the more intensive, slower, and expensive GPR survey.

Along with these advantages, the results of an EM survey can be difficult to interpret because of the state of the technology, a problem that Bruce Bevan has covered in some detail (1998:29-43). EM hardware is sensitive to extraneous, environmental, electromagnetic noise like power lines and lightning, limiting its use in particular contexts. An instrument like the EM38, although small, light, and convenient to use, is subject to electronic drift due to changing temperatures during hot weather. Perhaps most importantly, the EM technology responds to a wide range of metals, both ferrous and non-ferrous. There are certain situations, for example an abandoned lot with a history of recent occupation or industrial use, where the presence of near-surface metal can make any reasonable interpretation of survey results unmanageable. As an extension of this problem, conductivity technology faithfully records the presence of buried metal wires and piping and, because of its depth sensitivity (up to 1.5m for the EM38), the signals these produce can also make interpretation difficult. Finally, a feature that is strikingly brought out by the Hopeton survey, conductivity technology responds to chemicals and these may obscure the archaeological results one seeks.

Added to these technical problems, there is a wide gulf between how non-archaeologists and archaeologists use EM technology. For example, a recent article by soil scientists indicates that 300 readings of mS/m were taken hectare in a study of soil erosion (Davis et. al. 1997). By contrast, archaeological use of mS/m typically records *20,000* readings per hectare and more if it were within the bounds of the available software to do so. Archaeological use of EM technology remains an application that is essentially being invented by archaeologists as they do their work. It involves problems of recording precision and data density, and the questions of interpretation that go with them, that have not been widely discussed in print. This is not so for other types of geophysical survey instrumentation which can point to 40 or more years of incremental development in survey strategies (Clarke 1990).

While EM technology may be rented readily on a project-by-project basis, I have found that the problems of data collection (strategy and implementation) and interpretation are significantly complex, such that a first time or infrequent archaeologist user may become frustrated by his or her results. In short, the machine takes time to master and this is difficult to impart by the most detailed of instructions. This is partly a product of the directions EM technology development are taking in North America, toward the specific recognition of unexploded shells and the like. Few manufactures are stressing the sort of “patterned landscape recognition” which is important in archaeology. Perhaps this leads to archaeologists’ general frustration with any geophysical survey data that is not immediately "obvious" of interpretation. In part it also reflects a failure to use EM survey where appropriate and treat the data accordingly.

Hopeton Survey, The Workshop Geophysics Grid

At the 2001 National Park Service geophysics workshop, a grid of sixteen, 20m squares was laid out running east-west intersecting the end of the avenue leading into the circle/octagon complex from the southwest (Figure 1). This grid (Figure 2) was planned to cross a small circular enclosure that appears as an appendage of the northern wall of the avenue in early surveys (Squirer and Davis 1848: Plate XVII). It also crossed a small portion of the bank surrounding the square enclosure. All traces of the earthwork associated with the avenue--including the circle--have been plowed down although these were probably never very high. On the other hand, the segment of the square enclosure is well preserved and largely intact (protected by an historic fence row), standing to a height of at least 2.5m. At the time of this survey the plowed down avenue was planted in a mixture of alfalfa (possibly an old, thinning stand) and a small grain cover crop (wheat, rye). The weather was highly variable and survey was halted on two occasions by rain. There was no standing water on the site and the earthwork area appears to be underlain by well-drained soils.

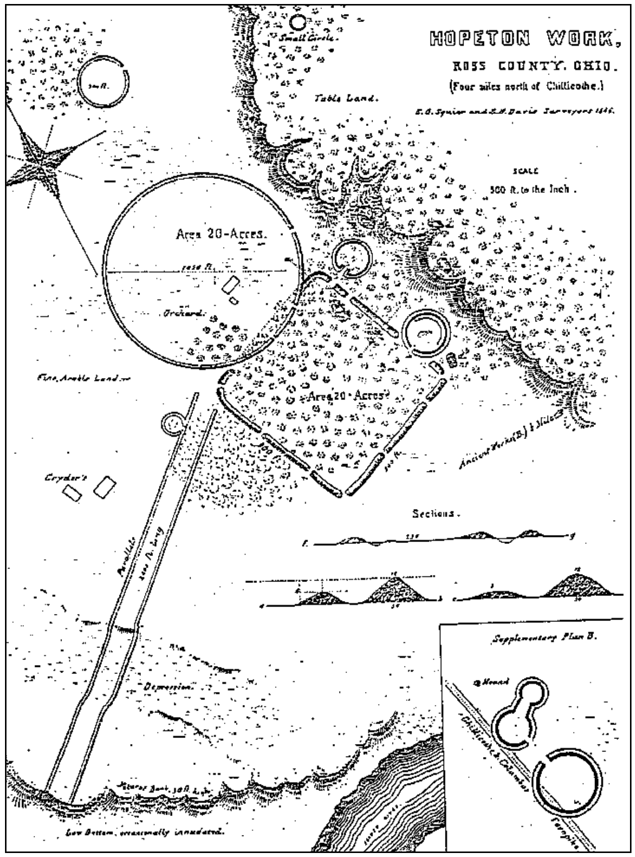

Figure 1. The Hopeton Earthworks (Squier and Davis 1848, Plate XVII)

The northwest square in the grid was used for instrument demonstration during the workshop. I have not included the results from it in the following discussion because I made errors in planning data collection from it. These do not reflect discredit on the enthusiastic students but rather my attempt to experiment with what for me was a new approach to data collecting with the EM38. This is an example of the sort of technical problems which can beset the new user of the EM38, or an experienced one simply trying a new approach.

For the balance of the Workshop grid, data were collected at 50cm intervals on transects 1m apart with the help of Jennifer Pederson of Hopewell National Monument. The EM38 was carried in a foam cover (although this was probably not necessary because of the cool weather) at a height of about 20cm above the ground surface. This produced 800 readings of mS/m per 20m square or 12,000 readings of mS/m for the total survey. With just the two of us moving marker ropes and collecting the data, the survey went rapidly and we were able to cover a square in 15-17 minutes. MS/m readings were recorded automatically with a Polycorder 720 data logger (normally supplied with the EM38) set to read at .5-second intervals while my walking pace was timed to cover 1m per second. A zigzag survey pattern was followed, north on one transect and south on the adjacent transect.

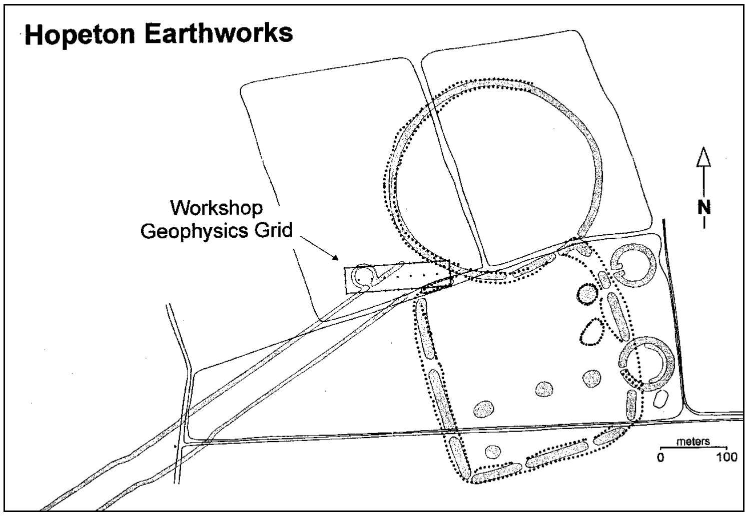

Figure 2. Hopeton Workshop Survey Grid

It is rather slow to try to record mS/m readings manually while surveying. This is an obstacle for the initial user of this specific technology and a separate data recorder should be used for high density readings (although other EM instruments record data internally). If recorded manually, the readings must then be entered in a computer for processing, doubly increasing the time involved. This difficulty could be overcome in part with the use of a small, high fidelity recorder carried in the shirt pocket (making sure that the metal mass does not affect the EM38) recording the measurements automatically as they are observed for later transcription.

The data were downloaded using a Geonics program (DAT38) as x (easting), y (northing), z (mS/m) files and first examined in Surfer 7 (Golden Software) in the form of contoured and gray scale images (Figure 3). Following this, the data were transferred to Geoplot 3.00 (Geoscan Research), making sure that the Surfer files "fit" the Geoplot file parameters (another story), for various types of processing. I have also used Didger 3 (Golden Software) in the preparation of graphics. It is a measure of the difficulty in using this class of geophysical survey instruments that it took me four software packages to get from the survey instrument to presentation graphics. This reflects primarily the fact that the EM38 was not designed to do archaeology.

Data Processing

Initial Surfer Processing – In Figure 3 the conductivity data are displayed in two formats using Surfer 7, as a contoured map and as a gray scale image. The contoured map is perhaps the least successful way to display conductivity data despite the lavish use of color. The significant range of variation in these data is relatively narrow, probably less than 5 mS/m, and this means that the contour interval must be quite small. As a result, detail is lost in a welter of contour lines. The gray scale image graphic produced in Surfer is more successful. It reveals that the portion of the square enclosure still standing (in the southeast corner of the survey) is low in conductivity. Furthermore, there is a suggestion in the western end of the survey of the outlines of the circular enclosure attached to the avenue.

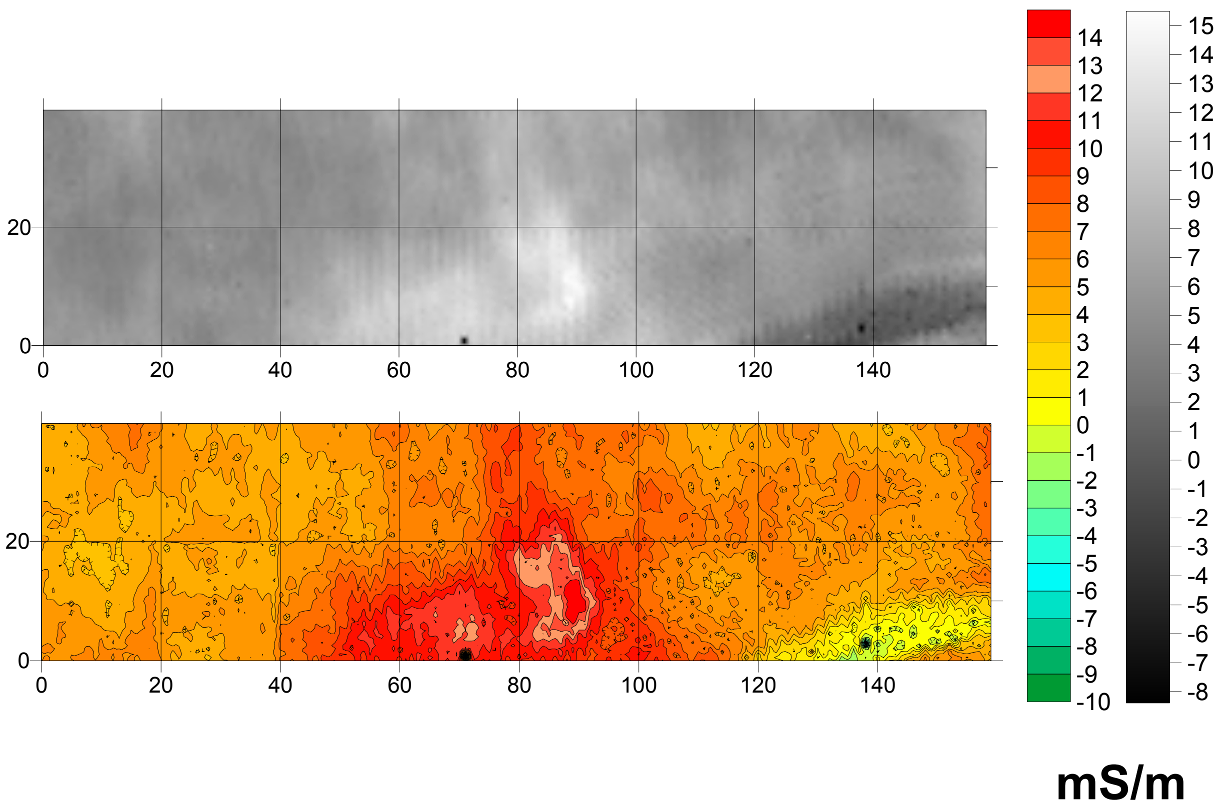

Figure 3. Surfer 7 Gray Scale and Contoured Images of Workshop Conductivity Data.

Processing in Geoplot – The Geoplot 3.0 software package is somewhat more flexible in dealing with gray scale, "image" maps than is Surfer. By contrast, it cannot produce the contour maps that are the graphic mainstay of Surfer. Transfer of the data from Surfer to Geoplot is relatively straightforward although the strict file dimensions of Geoplot must be observed in the conductivity files as well (using this data collecting protocol, Geoplot files must contain *only* 800 readings of mS/m per 20m square that are evenly distributed every .5-meter along each transect).

In Figure 4 the conductivity data are presented in a gray scale image generated in Geoplot as the data were imported from Surfer. Note here that in the Geoplot image the colors are reversed from the Surfer image: *dark* indicates higher conductivity while *light* indicates lower conductivity. There are several observations that can be made. First, the conductivity range (-8 to 15 mS/m) over the surveyed area is fairly large, far greater that would be expected in a "normal," undisturbed soil context (I would expect a range of not more than 10 mS/m). Secondly, the gray scale graphic suggests considerable fuzziness and "grooving" in the data, that is variation between adjacent survey transects. The wide range in mS/m values suggests that the survey specific points of high/low mS/m (dipole signals) suggests that the range is not caused by metal (which would also produce a wide range in mS/m).

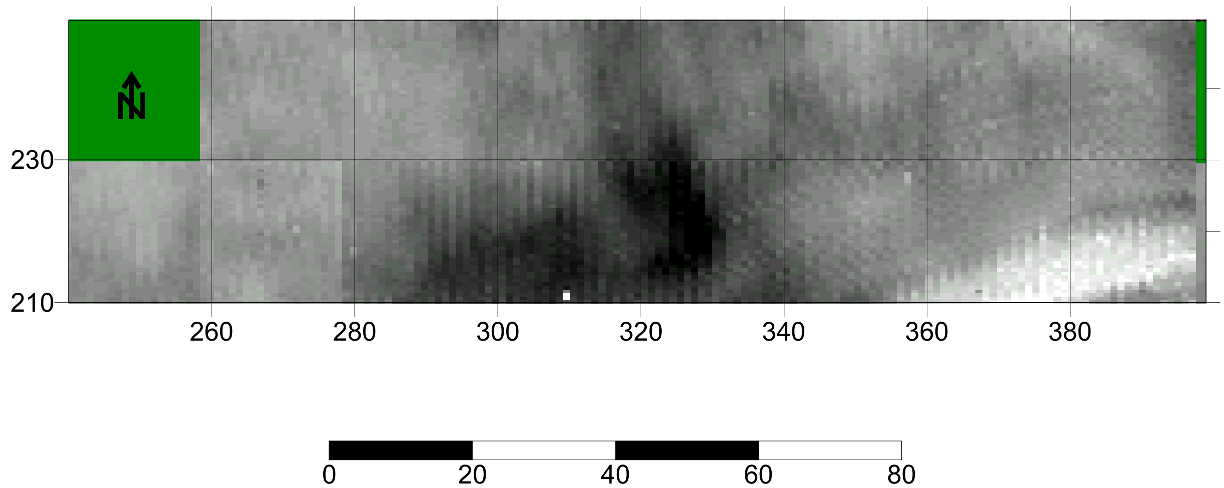

Figure 4. Conductivity Data as Imported into Geoplot 3.0.

The data grooving in Figure 4 is simply an artifact of the survey procedure with this particular EM38. As Figure 3 indicates, the problem can be totally missed if conductivity data are displayed in contour maps alone. To properly interpret these data they must first be corrected. The whole problem can be avoided in EM survey using the EM38 by the simple expedients of either surveying in parallel as opposed to zigzag traverses or reducing the speed of the traverse (while maintaining the zigzag pattern) and effectively pausing for .5 second at each reading. Because either of these corrections considerably slows down the rate of ground coverage, the “normal walking speed, zigzag survey pattern” remains attractive to me despite the problems it causes, and I continue to use it in most survey situations because the defects may also be eliminated by data processing. In my experience, which Bruce Bevan corroborates from his own experience with the EM31 (1998:41), this problem only exists for EM38 conductivity meters that have digital (as opposed to analog) output and are distinguished by a built in digital LED display as opposed to a meter needle.

The *digital* EM38 provides a continuous output digital signal that is a running average of mS/m produced over a time interval of approximately .5-second (I am not sure whether the signal averaging is a function of the EM38 itself or the DAT38 software used to record it in the data logger). Data averaging is important in smoothing the output of the meter and reducing the "noise" in the data so that it will not obscure a low value target. However, the measurement does not represent a point measurement of mS/m, rather a running average of mS/m over the past .5-second. But if the instrument is moving at a speed greater than approximately .5-meter per second, a "pseudo" spatial lag (I call it pseudo because the value of mS/m remains a running average and not a point value) is introduced between the recorded coordinates for the "point" of measurement and the value of mS/m that is obtained for it. At a carrying speed of 1 meter-second this translates into a 50 cm offset. In a zigzag survey pattern this same lag occurs again, but going in the opposite direction and this translates (again at a ground speed of 1 meter-second) into a total offset between adjacent rows of data of about 1 meter: the two offsets are added together.

If uncorrected, it is almost impossible to get any resolution of conductivity anomalies with these offsets built into the data beyond as sense of gross features. If parallel transects are used, the potential 50cm offset remains in the data (given a ground speed of 1m per second) but it causes no resolution problems because all offsets occur in the same direction. This 50cm offset may or may not be important in interpreting the data. This whole problem of data management, here the result of using a specific instrument (the EM38) in three software packages (Dat38, Surfer 7, and Geoplot 3.00), is important to varying degrees in *all* types of archaeological geophysical survey as we attempt to resolve (that is identify) smaller and less contrastive geophysical features. It is often less important to non-archaeologists who may seek to resolve more robust targets.

I have been able to correct this offset using a processing routine in Geoplot 3.00 called "Destagger" that was designed to adjust the coordinates of adjacent transects in zigzag surveys by adding or subtracting measurements to every other one to bring them into alignment and generating additional values to fill in the missing gaps. By adding two measurement units to alternate transects the lag is effectively removed (Figure 5). A certain amount of grooving still exists adjacent to areas of high or low conductivity reflecting the overpowering effect of these areas in computing the running average of mS/m (in short it takes a noticeable period of time to work a high or low value of mS/m out of the running average as I cross it at 1meter a second).

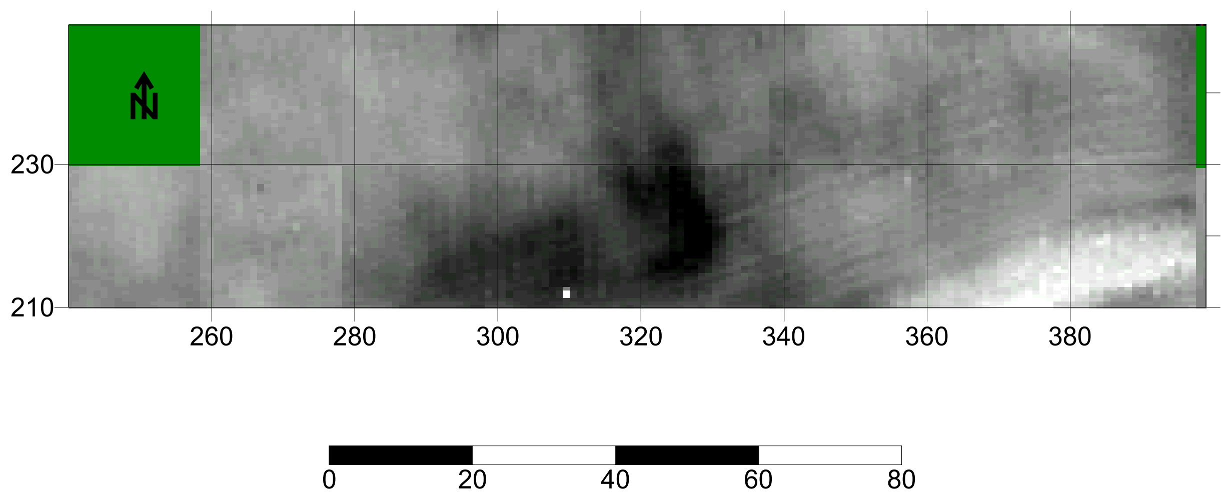

Figure 5. Spatially Corrected Conductivity Data.

This whole problem may also be avoided by using an EM38 with an analog scale, probably now regarded as an "older" and less sophisticated instrument, although it is a "noisier" machine. However, in my experience visual recording of individual readings of mS/m from the analog meter (a needle against a scale) is quite tedious. Furthermore, the analog machine lacks the averaging function that is important in surveying in noisy conditions. But if the EM38 is going to be used for taking individual readings (not collected by an electronic data logger) it is very helpful to have the digital readout. Because I do more and more "prospecting" with the EM38 in the form of random transects and traverses just to get a sense of site variation in mS/m, the digital model is almost essential.

The spatially corrected conductivity data indicate higher conductivity striations both parallel to the preserved earthwork remnant and at a slight angle to the survey grids (most pronounced at the eastern end of the survey area). Both were effectively obscured by the digital lag generated by the initial survey. In fact, it was only *after* I discovered how to correct for the lag that I became aware that the EM38 very effectively reveals all sorts of plow scarring typically found in agricultural fields. Being also a farmer, I recognize these striations as the results of recent agricultural practice. Those at the workshop will recall that the survey grid was at an angle to the edge of the field, thus at an angle to the direction of recent farming practices across the field (see Figure 2 above). Thus the striations could represent cultivation marks (probably disking rather than plowing) running the length of the field and "clean up" passes at right angles to these finishing the turns at the end of the rows, created when the cover crop (rye?) was established.

Relating the irregular conductivity high in the middle of the surveyed area to agricultural practice, my first thought was that it represents a chemical signature perhaps caused when the spray rig paused in the turn while applying a chemical to control broad-leafed weeds or grasses in the grain stand. I checked with Jennifer Pederson at Hopewell who informed me that no chemical had been used. My second thought (which I have not run by Jennifer as yet) is that the high represents a fertilizer signature, perhaps of anhydrous ammonia (which is conductive), applied to encourage the small grain. As such it is an artifact of very recent agricultural practice (the past 2-3 months). I suggest that the fertilizer was applied in liquid form by a spray rig, that the striations running with the field indicate applications as intended, and the concentration at the end of the field (so obvious in the conductivity data) represents either a spill, or a slowing down of the spray rig in the turn.

Whatever the cause of the conductivity high, its presence obscures the information which we seek, that is the remains of the plowed down earthwork which are probably low conductivity (given the characteristics of the preserved portion of the earthwork). In Figure 3, even in the unprocessed data, there is a suggestion of the circular component of the earthwork in the conductivity data. Further data processing attempts to identify other portions of the structure *in the range of variation observed for the circular earthwork on the west end* and enhance the resolution of those (the circle) that seem to exist.

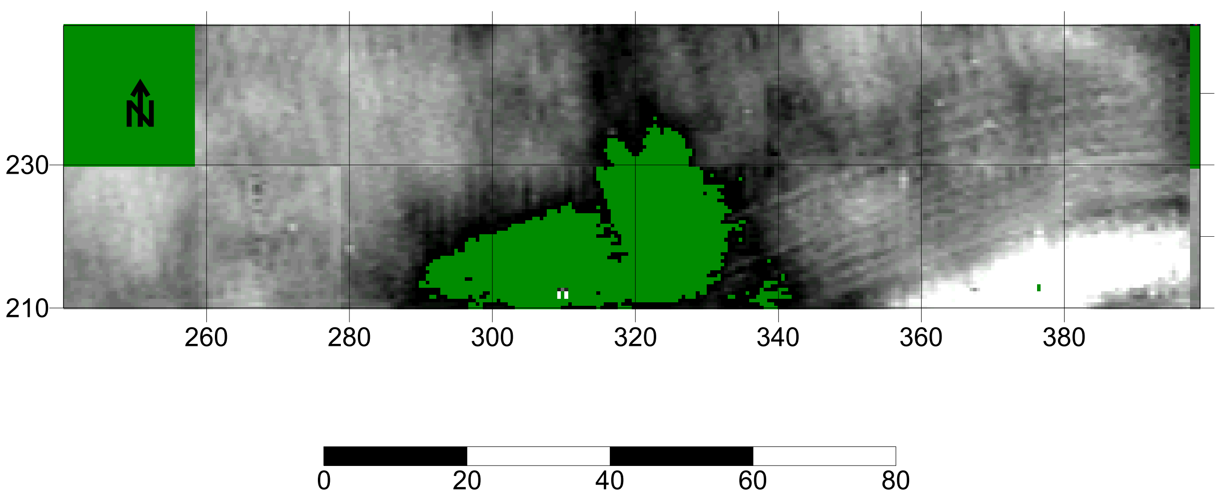

Figure 6. Blanked Conductivity Highs to Reveal Low Contrast Variation.

One approach is to deal straight forward with the fertilizer signal and try to eliminate or minimize it. To do this, all values above 5 ms/m and below 2 mS/m were replaced with a dummy value (in the case of Geoplot 3.00, the obscure value of 2047.5) such that they do not enter into the generation of the gray scale image (Figure 6). The effects of this on the resolution of the circular earthwork portion of the avenue are immediately obvious which begins to resolve into an exterior circle of low conductivity, an interior circle of low conductivity, a center of somewhat higher conductivity, and in the center a rectangular feature of low conductivity. However, at the eastern end of the surveyed area another circle is seemingly apparent although it appears different in nature from that on the west.

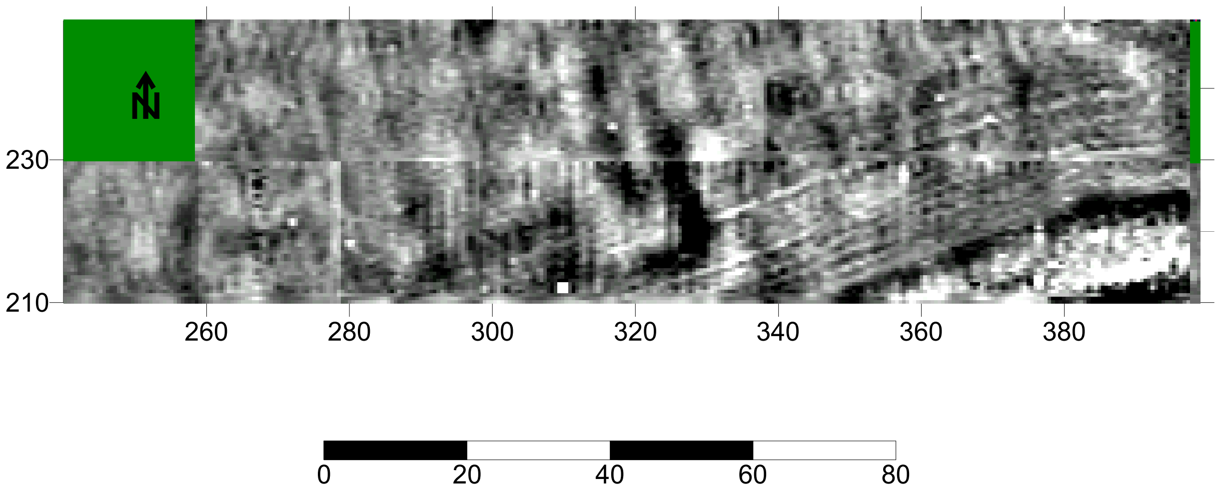

Figure 7. Effects of Low Pass Filtering of Conductivity Data.

A second approach (Figure 7) was then taken to deal with the irregular high which dominates the survey area, an approach which allows us to see through the conductivity high, not simply eliminate it (together with any information obscured by it). The data were high pass filtered using a Geoplot 3.00 routine, High Pass Filter, after first using the "Interpolate" function to add an additional row of X values creating a symmetrical distribution of data points. A high pass filter "may be used to remove low frequency, large scale spatial detail. A typical use is the removal of a slowly changing geological "background" response commonly found in resistance surveys" (Geoplot: 9-63). "High Pass Filter scans the data with a gaussian or uniformly weighted window, which may be square or rectangular. It calculates the weighted average within the window and subtracts this from the central reading in the window. All other readings remain unchanged…" For the Hopeton data set, the window was set to a square, ten readings by ten readings.

This processing removes the concentrated high mS/m signal in the center of the surveyed area without affecting the more limited high mS/m signals, in short it has done very nicely what is was supposed to do. It also emphasizes the strong patterning hypothetically caused by the fertilizer spray rig. In short, the "patterned" high mS/m has been revealed within the heavy overlap caused by the fertilizer concentration in the center of the survey area. This patterning reinforces my interpretation (as a farmer) that it is caused by a spray rig because the circular patterning at the end of each row, caused when the rig reversed direction, is clearly evident, overlain by a number of passes along the edge of the field to finish off the application. While it still does not explain why there was the fertilizer concentration, it reveals the possible "circular" signal on the eastern end of the survey as a product of the spray rig, not a possible circular earthwork.

In this interpretation of the Workshop data the circular earthwork is still visible, as is the well-preserved interior rectangle. These data suggest that any other portion of the enclosure either cannot be registered with earth conductivity, or is obscured by agricultural practices. It is difficult to determine if the large circular earthwork east of the surveyed area is registered in the conductivity data principally because so little of it has been surveyed. As a final processing step (Figure 8) multiple low pass filtering was used to shift the mean of the mS/m distribution toward the range of the circular earthwork and providing further resolution. The circular earthwork is an exterior (though completely plowed down), circular bank of low conductivity. There is a gap in this bank on the south, probably the entrance to its interior from the avenue. Inside this is a narrow band of low conductivity, perhaps a ditch. This cuts across the entrance. Finally, in the center of the circle which is somewhat higher in mS/m, possibly reflecting an unmodified earth surface, there is a distinct rectangle of somewhat lower conductivity that suggests an interior feature.

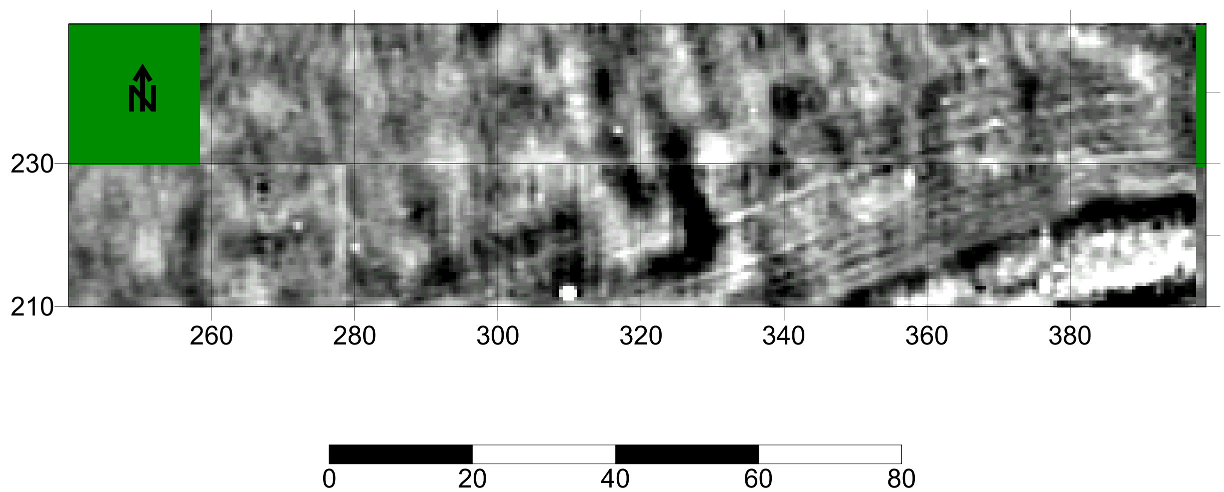

Figure 8. Effect of Multiple Low Pass Filterings on the Conductivity Data.

This survey example I think demonstrates why it is useful to aim at collecting large data sets covering as wide an area as is feasible given time and other resources. It is far easier to suggest what is going on in the archaeology from a wide area coverage. If this survey had been limited to a single 20m square it would be considerably harder to recognize the apparent landscape patterning.

Interpreting the Hopeton Earthwork

One should end any geophysical survey with the caveat, “pending further archaeological examination, I think…” No one should attempt to make categorical interpretations of geophysical anomalies without additional some level of conventional archaeological examination. That said, it should come as no surprise that these data suggest a feature inside this appendage to the Hopeton avenue. In their atlas of Scioto Valley earthworks, Squier and Davis (1848) reported other circles with interior features, most of which were interpreted as mounds. A close examination of their plan of Hopeton (Squier and Davis 1848: Plate 17) (Figure 1 above) suggests that they found this small circle covered with trees: they may simply not have been able to distinguish any features in it.

One such example was excavated during the 1930s and we know a little more about it. In their Plate XXVII, Squier and Davis pictured a variety of earthworks in the vicinity of Portsmouth, Ohio, on both sides of the Ohio River. Their earthwork "D" in Kentucky (Figure 9) is now known as 15GP8, the Biggs Site (Hardesty 1964)(Figure 10). Their plan of this earthwork suggests that the feature inside is a mound, not surprisingly, they suggested that virtually all features inside circular earthworks were mounds. The site has a characteristic plan with an exterior bank, an interior ditch cutting across the entrance, and a raised center within (representing the old ground surface). These three features are also suggested for the Hopeton example from the geophysical data although Hopeton is quite a bit smaller overall.

It was not clear from the excavation data that the structure inside the Biggs circle was a "mound" in the sense of a "burial mound" but there was some sort of thermal feature below it, possibly a central clay platform with fire basin upon which evidence of a human cremation was found. Associated artifacts included mica, hematite, celts, and a handful of pottery that James B. Griffin identified as "Hopewell."

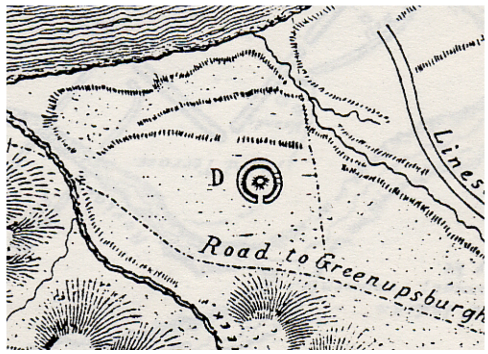

Figure 9. The Biggs Earthwork (Squier and Davis 1848: Plate XXVII).

Figure 10. Photograph of the Biggs Earthwork (1930s) (UKMA 3192).

Lacking more concrete information one should reserve judgment on the nature of *all* activities connected with the features inside these small circles and certainly the one at Hopeton. The safe thing to say is that they mark activity areas that, for some reason, were mounded over with earth. In some cases these seem to mark the beginnings of accretional burial mounds that then grew in size but it is not clear that only mortuary activities were conducted within the circles (Clay 1987).

Perhaps the most significant aspect of the Hopeton example was that it was an appendage to the avenue that led into the circle/square complex. Unlike Biggs, this circle and its interior feature was structurally linked to another earthwork. In a way that Biggs was not, the Hopeton example may have been tied into ritual involved in the procession of those who used the larger earthwork complex from the exterior, into its interior.

Acknowledgments

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