APPENDIX A

COMPLETE GEOPHYSICAL METHODS AND RESULTS

OVAI Contract Report #2011-46

Multi-Instrument Geophysical Survey at the Bunker Hill Site (7NC-F-126) near Middletown, Delaware

Preliminary Report

by

Jarrod Burks, Ph.D.

Prepared for:

Versar Inc.
6850 Versar Center
Springfield, VA 22151

Prepared by:

Ohio Valley Archaeology, Inc.
4889 Sinclair Rd., Suite 210
Columbus, Ohio 43229
(614) 436-6926

September 4, 2011

Table of Contents

Geophysical Survey Setting and Project Summary	1
Geophysical Surveys and Instruments: Brief Notes on Their Use	2
Geophysical Survey Results	3
Magnetic Susceptibility Results	8
Magnetic Gradient Results	10
Ground-Penetrating Radar Results	12
Summary and Conclusions	15
References Cited	16

Figures

1. Geophysical survey areas at the Bunker Hill site, 7NC-F-126	1
2. Geophysical survey instruments used during the surveys	2
3. Geophysical anomalies of interest	7
4. Magnetic susceptibility survey results	9
5. Magnetic gradient survey results	11
6. Example radar amplitude slice maps	13
7. View of high-density data collected over Anomaly 19	14

Geophysical Survey Setting and Project Summary

This preliminary report presents the results of a multi-instrument geophysical survey at the Bunker Hill site (7NC-F-126) (Figure 1). The site is located along the north side of Bunker Hill Road. At the time of the geophysical survey the site was covered in harvested wheat stubble, most of which had been mowed down closer to the ground surface to facilitate the survey work. In general the soil conditions were dry, but a heavy rain storm the night before the last day of survey saturated the upper several inches of soil, adversely impacting the radar results.

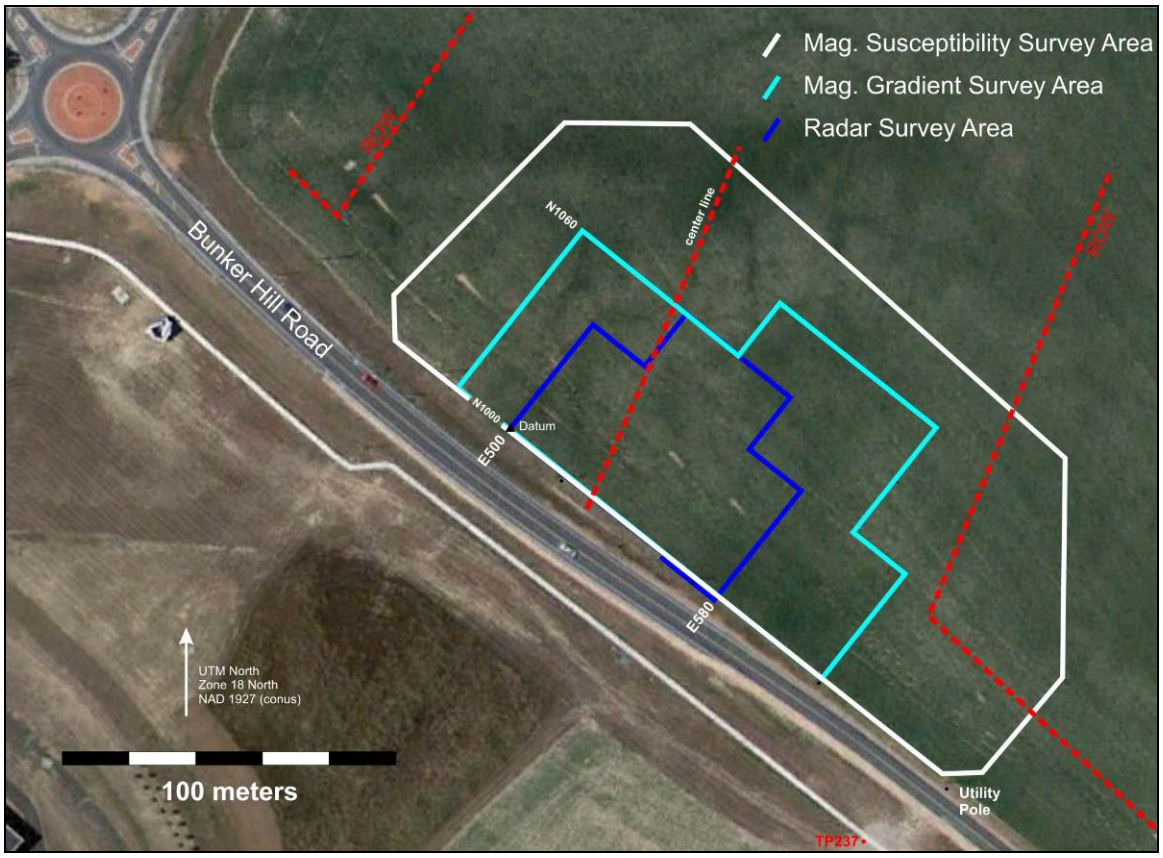

Figure 1. Geophysical survey areas at the Bunker Hill site, 7NC-F-126.

Prehistoric and historic-era objects were found at the Bunker Hill site during the initial Phase I survey work, suggesting the possible presence of midden, pit-type features (Native American), foundations/cellars, and shaft-type features (cisterns, wells, privies). Three geophysical survey instruments were used in an attempt to locate such features: a magnetic susceptibility meter, a magnetometer, and a ground-penetrating radar. All three instruments identified anomalies consistent with what is expected for the target archaeological features. However, there were also some inconsistencies in the geophysical data when compared to other archaeological sites. These and other observations are presented below with the descriptions of the survey results.

Geophysical Survey Instruments: Brief Notes on Their Use

Three geophysical survey instruments were used during the Bunker Hill site surveys: a Bartington MS2 magnetic susceptibility system, a Geoscan Research FM 256 fluxgate gradiometer (a type of magnetometer), and a Sensors and Software Noggin 500 ground-penetrating radar system (500 MHz) (Figure 2).

Ground-Penetrating Radar

Magnetometer

Magnetic Susceptibility Meter

Figure 2. Geophysical survey instruments used during the surveys.

Each of these instruments was used for a particular suite of objectives related to locating prehistoric and historic features at the Bunker Hill site. While shovel testing and surface collection work well for identifying artifact patterning and midden distribution, not all midden is artifact rich. Magnetic susceptibility meters are useful for locating prehistoric and historic midden deposits (Cook and Burks 2011; Dalan 2008; Dalan and Banerjee

1998). Because midden deposits tend to be relatively large, sheet-type deposits located in the plowzone, magnetic susceptibility readings on plowed sites are taken at the surface and can be very low density—such as a reading every 10-20 meters. Usually high susceptibility areas on sites are associated with areas of higher artifact density.

The magnetometer was used to locate pit-type features and other kinds of excavations filled with midden-like deposits. At most sites, the topsoil is more magnetic than the subsoil, which means pits filled with topsoil should be detectably more magnetic than the surrounding subsoil (Clark 2000; Evans and Heller 2003). At the data density used for this project (i.e., 8 readings per meter along transects spaced 50 cm apart), the magnetometer should be able to detect most pit features 50 cm in diameter and larger. Burned earth, if present, should enhance the magnetic signature of features. The magnetometer will also detect iron objects associated with historic-era middens, which tend to be clustered around historic-era structures.

While magnetometers are generally excellent at detecting pit features, ground-penetrating radar excels at detecting stone and brick foundation walls, gravel paths, and other hard targets commonly found at historic farm sites—like wells and lined privy shafts (Conyers 2004). Though harder to detect, earth-filled pits like cellars and unlined privy shafts are also sometimes evident in radar data, especially if these features contain distinctive fill. Radar data are also useful for accurately estimating the depth to detected targets.

Geophysical Survey Results

Figure 3 is an interpretive map of the results from all three geophysical survey instruments. The different anomaly types are color coded, with gray for areas of high magnetic susceptibility, blue for magnetic gradient anomalies, and red for radar anomalies. Each anomaly is described in detail in the list below, including information about which instrument detected the anomaly, the anomaly's type, and an interpretation of what the anomaly might be if it is an archaeological feature. All interpretations are based on past experiences at sites in the Mid-Atlantic region and the Midwest. Those anomalies indicated in red were thought to be the most likely to be cultural features at the time of the initial interpretation.

Anomaly 1 (Mag-monopolar positive, 5.75nT): possible pit-type feature.

Anomaly 2 (Mag-monopolar positive, 8.4nT): probable pit-type feature, fairly strong in terms of peak magnetism, suggests that this possible pit may contain burned earth or other strongly magnetic materials.

Anomaly 3 (Mag-monopolar positive, 4.25nT): possible pit-type feature.

Anomaly 4 (Mag-monopolar positive, 6.12nT): linear anomaly with varying peak magnetic intensities. This is most likely a ditch filled with topsoil or midden-rich soil with high magnetic susceptibility. In some areas this feature fades out, suggesting that it has either been plowed out or it is filled with soil that is not magnetic or not any more magnetic than the surrounding soil. If this is a filled ditch-like feature, how did it come to be located on the topographically higher part of the site?

Anomaly 5 (Mag-monopolar positive, 9.71nT): probable pit-type feature, very strongly magnetic, this pit likely contains burned sediment or other magnetic objects (iron objects or brick). This could also be a large, deep iron object.

Anomaly 6 (Mag-monopolar positive-diffuse, 3.82nT): probably more of the Anomaly 4 linear feature.

Anomaly 7 (Mag): faint linear anomaly, could be related to Anomaly 4.

Anomaly 8 (Mag): faint linear anomaly, could be related to Anomaly 4.

Anomaly 9 (Mag-monopolar positive-diffuse 3.1nT): possible pit-type feature, diffuse magnetic signature suggests that this might not be a feature, but these soils have low magnetic susceptibility, so even weak anomalies could be pit features.

Anomaly 10 (Mag-dipolar simple/monopolar positive 6.28nT): possible pit-type feature located within an area of unusually variable readings (Anomaly 11).

Anomaly 11 (Mag): area of variable positive and negative magnetic readings. Could be an area of disturbed soil or an area of burning—perhaps the location of an outbuilding.

Anomaly 12 (Mag): another area of variable readings much like Anomaly 11. Could be an outbuilding location, though this area contains a number of small, discrete anomalies that might be pit-type features.

Anomaly 13 (Mag-monopolar positive 5.1nT): possible pit-type feature.

Anomaly 14 (Mag-monopolar positive 3.51nT): possible pit-type feature.

Anomaly 15 (Mag-monopolar positive 3.23nT): possible pit-type feature.

Anomaly 16 (Mag-monopolar positive 6.75nT): possible pit-type feature, or iron object.

Anomaly 17 (Mag-monopolar positive 2.25nT): very diffuse anomaly, possible pit-type feature or magnetic soils in the plowzone.

Anomaly 18 (Mag-monopolar positive 5.02nT): possible pit-type feature.

Anomaly 19 (GPR): probable historic-era cellar or other historic-era excavation. Anomaly has square corners and clear, distinctive edges. Such square corners are not common to naturally-made soil features. It appears to be about 7.3 meters long and 6.5 meters wide, though the south side of the anomaly has been impacted by the ditch along Bunker Hill Road. If this is a cellar, there is a possible stairway/bulkhead at the northeast corner that is about 1.7 meters wide. In profile, Anomaly 19 is represented by two distinct layers. At about 50 cmbs there is a distinctive layer that is likely the top of the fill inside the anomaly. The anomaly also has somewhat distinctive edges that could be stone (I saw only one large piece of possible building stone on the surface during the survey and it was located right on top of Anomaly 19). The second distinctive layer is at the bottom of the anomaly, which could be the floor of a cellar. Nearly all of the radar profiles crossing this anomaly produced a strong reflection of the possible floor. This indicates a distinctive change between the bottom of the anomaly and the subsoil below it.

Anomaly 20 (GPR): possible shaft-type feature (well, cistern, privy, grave) with distinctive reflections starting at about 50-60 cmbs and extending down to as much as 120 cmbs. This radar anomaly is about 130-150 cm across north-south.

Anomaly 21 (GPR): distinctive, flat anomaly that occurs at about 45 cmbs. This anomaly is much like Anomalies 22 and 30 and could be a layer of sand or gravel, or perhaps a compact surface. It does not have much depth, perhaps 10 cm, and after the rain it was not visible in the adjacent survey block.

Anomaly 22 (GPR): distinctive, flat anomaly that occurs at about 35-40 cmbs. This anomaly is much like Anomalies 21 and 30 and could be a layer of sand or gravel, or perhaps a compact surface. It does not have much depth, perhaps 10 cm, and after the rain it was not visible in the adjacent survey block. This may not be anything but a slightly deeper bit of plowzone.

Anomaly 23 (GPR): about 110 cm by 50-60 cm in size, this flat, small-area anomaly starts at about 30-35 cmbs. Not sure what this is. Could be some disturbed soil or a patch of gravel.

Anomaly 24 (GPR): Anomaly 24 first appeared nearer to the surface to be much like Anomalies 21 and 22, but while collecting the data in the field I noticed a possible shaft-type feature in the radargrams. The near-surface anomaly in this area is right in the corner of this 20x20 block. The deeper anomaly I saw in the field is rectangular in shape at about 80 cmbs. The deeper part of the anomaly is about 2 meters long and 85 cm wide, and it appears to parallel the main axes of the potential cellar. Distinctive reflections related to this anomaly begin as high up as 50 cmbs and extend down to as deep as about 120-140 cmbs. The reflections are most distinctive around 80 cmbs. This appears to be a shaft-type feature, perhaps a privy, but there is no indication in the radar data of any stone along the edges of the possible privy shaft.

Anomaly 25 (GPR): This flat anomaly is located off the east side of the possible cellar. Though not nearly as strong as the possible cellar, the radar reflections in this area show a discrete, round-to-rectangular feature with clear edges measuring about 3.7 m (grid north-south) x 2.8 m (grid east-west). The anomaly is most distinct at 50-60 cmbs and likely extends outside the radar survey area to the east. This could be an area of gravel or sandy soil, or it could be a patch of rubble from the demolition of the possible building located just to the west.

Anomaly 26 (GPR): This small anomaly is located off the north side of the possible cellar. It is about 50 cm long (grid east-west) and is not evident in the data until about 70 cmbs. While this could be the radar signature of the bottom of a shovel test (I am not sure if one was located here or not), its location in close proximity to the potential cellar suggests that, if a cultural feature, it might be related.

Anomaly 27 (GPR): This linear radar anomaly follows the direction of data collection. Anomalies of this sort are usually line noise and not cultural features. However, this anomaly was detected in two blocks collected separately, which suggests that it is not line noise. That said, there are a number of linear tire ruts in this part of the field that created radar anomalies and this conceivably could be part of one. In fact, higher up in the slice maps there are a number of linear anomalies in this area of the site that are either line noise or plow/tractor related. Since this anomaly persisted some with depth and crossed between two blocks, it was deemed of potential interest. This should be the very last anomaly to be tested, if it is to be examined.

Anomaly 28 (GPR): Whenever a large, structure-related anomaly or feature like a cellar is encountered, it generally is worth looking for other anomalies that follow the same

building alignments. Buildings on a farm, for example, all typically align to the same cardinal directions. Though very ephemeral in the radar data, Anomaly 28 appears to parallel the same east-west alignment as the possible cellar (Anomaly 19). It also cuts across the direction of data collection, indicating that it is not line noise. There is a general cluster of small reflections here that is about nine meters long east-west and about five meters long north-south. At its west end is Anomaly 29. Anomaly 28 is a faint linear feature running along the north side of this anomaly cluster. It could be the edge of a structure. It is most distinctive in the data at about 50-55 cmbs. Uncovering this anomaly in plan view may be difficult and would require a 2x2 meter unit. One good location for such a unit is N1012, E560, where there is a fairly distinctive component of this anomaly at about 50-55 cmbs.

Anomaly 29 (GPR): This is a small anomaly located at the west end of the cluster of anomalies associated with Anomaly 28. It measures about 1.7m x 1m. If Anomaly 28 is a structure, then Anomaly 29 could be a hearth base located at the end of the structure. It certainly has the right size and shape to be a hearth base. Anomaly 29 is most distinctive in the radar profiles at about 50-55 cmbs.

Anomaly 30 (GPR): This is another flat reflector that is similar to Anomalies 21 and 22. It is most distinctive at about 35-50 cmbs and is at least 2 m (grid east-west) by 2.7 m (grid north-south) in size. This could be a lens of gravel or sand, or it could be some property of the plowzone. If it did extend toward the north, its radar visibility in the next block to the north was compromised by the rain.

Anomaly 31 (GPR): Anomaly 31 is a large-area, flat anomaly. It was found in an area of the site surveyed after some pretty heavy rain. It measures about 8 meters by 11.5 meters and is most distinctive in the slices at around 40 cmbs. This feature could simply be an area where the rain soaked deeper into the ground. Or, this could be a patch of sediment with different properties than the soil around. For instance, it might have a different soil texture. Whether or not this is cultural is hard to say without some ground-truthing data. An excavation trench is likely necessary to test this anomaly. A 1x3 meter unit with its SW corner at N1034, E558 (at NW corner at N1037, E558) would be the best area for testing this anomaly. Particular attention would need to be paid to the soil texture changes in the unit profile.

Anomaly 32 (GPR): This long, narrow anomaly has very distinctive edges at about 80 cmbs. While this could be a natural feature, it appears to be following the same north-south alignment as the possible cellar (Anomaly 19) and in fact seems to be heading toward the possible cellar. This could be a road/cart path. Anomaly 32 is about 3-3.25 m wide. The best place to test it is at its southern end. A 3-meter long, grid east-west trench with a SW corner at N1031, E551 is recommended. It may not be evident until about 75-80 cmbs.

Anomaly 33 (GPR): This is a large, somewhat rectilinear anomaly at the west end of the site. It measures about 5 m (grid north-south) by 3.3 m (grid east-west). In the radargrams the reflections appear as flat surfaces and are most distinctive at about 40-50 cmbs. The grid-east side of this anomaly is the most distinctive and if it is tested with excavation units, I recommend cutting across the east edge of the anomaly. As a rectilinear anomaly, this could be structure-related. However, there are a lot of radar reflections in this area of the site that all appear to start at about 50-60 cmbs. Given

how widely distributed these other, probably natural features are, it is possible that Anomaly 33 is simply a natural feature that looks somewhat rectilinear.

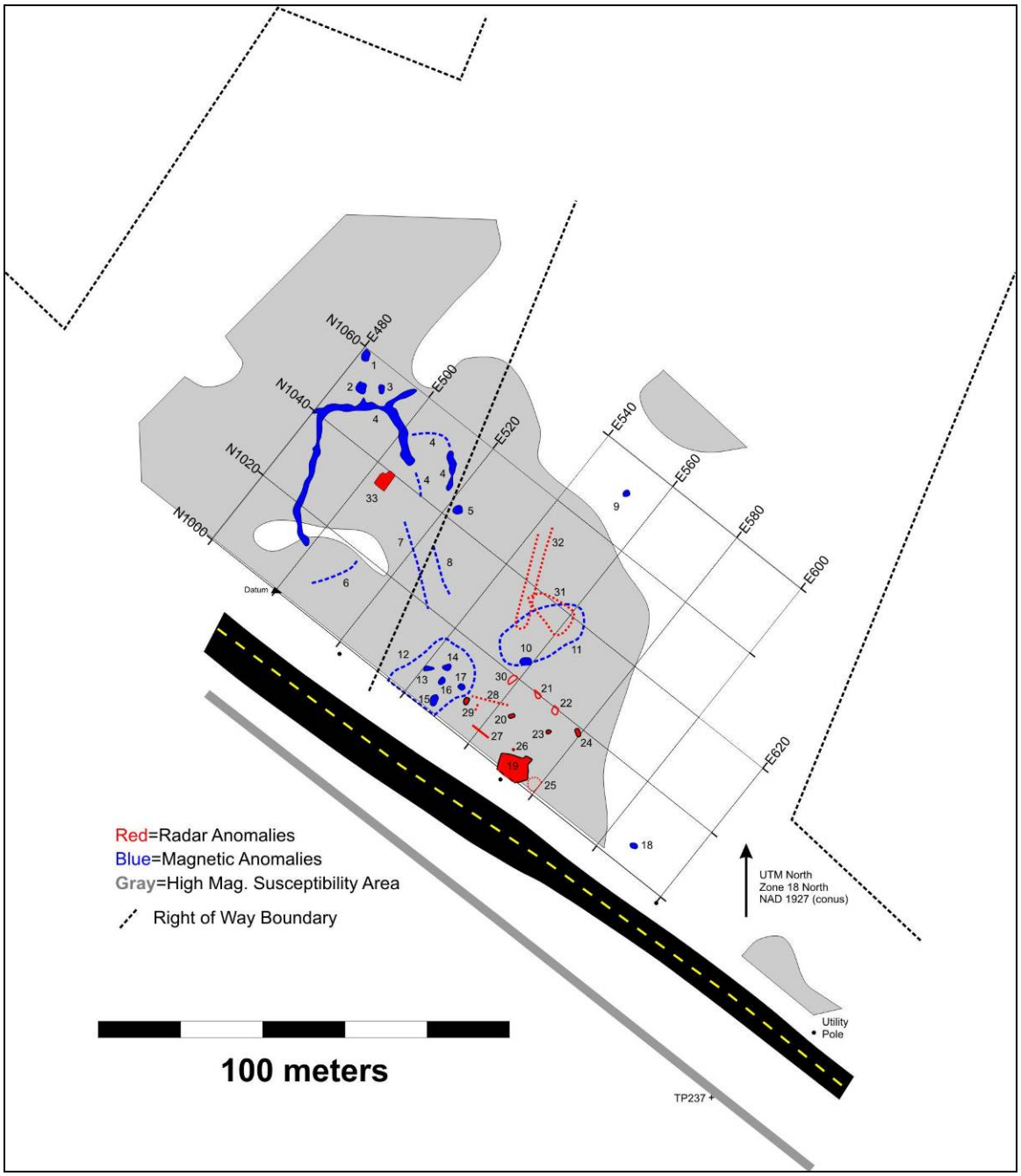

Figure 3. Geophysical anomalies of interest.

No doubt some significant anomalies (i.e., those associated with cultural features) were not picked out of the data. Conversely, there also likely are a number of significant cultural features that were not detected by any of the geophysical survey instruments. These possible undetected features would be either too small in diameter to be detected,

like individual postholes, or might be too shallow to create much of a geophysical signature. Or, undetected features may not contrast enough with the ground that surrounds them. This often happens in areas with lots of other anomalies, be they related to other cultural features or clutter created by numerous iron objects, for example. Large amounts of geophysical clutter can hide cultural features—even if the features are detected, the mass of other anomalies would make it near impossible to identify which are anomalies associated with features interest.

The following sections present and discuss the results from each of the survey instruments in greater detail. Details of the survey parameters are provided up front in each section.

Magnetic Susceptibility Results

> **Instrument Type**: Bartington MS2, with MS2D field loop; **Data Density**: on bare earth, reading every 10 meters; data locations identified with Trimble GeoXT GPS; map created with Surfer, only interpolation for data processing

Figure 4 shows the results of the magnetic susceptibility survey. Readings were taken every 10 meters across about 2 hectares (5 acres) of the site (see Figure 1 for the area surveyed compared to the other techniques). Loose vegetation on the surface was brushed aside and each reading was taken with the MS2D sensor placed directly on the bare dirt. Red areas in the data indicate areas of the site that produced higher magnetic susceptibility readings. Green areas are intermediate readings; blue areas indicate low readings. The magnetic gradient and radar anomalies from the interpretive map (Figure 3) are overlaid on the magnetic susceptibility results.

Like many archaeology sites, the higher susceptibility readings occur in the same location (middle and west end of the site) as prominent anomalies detected by the other instruments. This is also the area where numerous artifacts were found during the Phase I survey. However, there is one concerning aspect to the susceptibility results—the higher susceptibility readings, while present on the topographically higher parts of the site to the north of the center line, continued on to the north and down into a lower area that did not produce many artifacts in the Phase 1 survey (i.e., it is outside of the archaeological site boundary). This is somewhat unexpected for midden-related higher susceptibility values and suggests that the susceptibility data could be tracking natural soil variability rather than midden location. The latter is bolstered by the low overall susceptibility values found at the site—even the strongest susceptibility readings were relatively weak as compared to prehistoric and historic-era sites in other areas of the eastern United States.

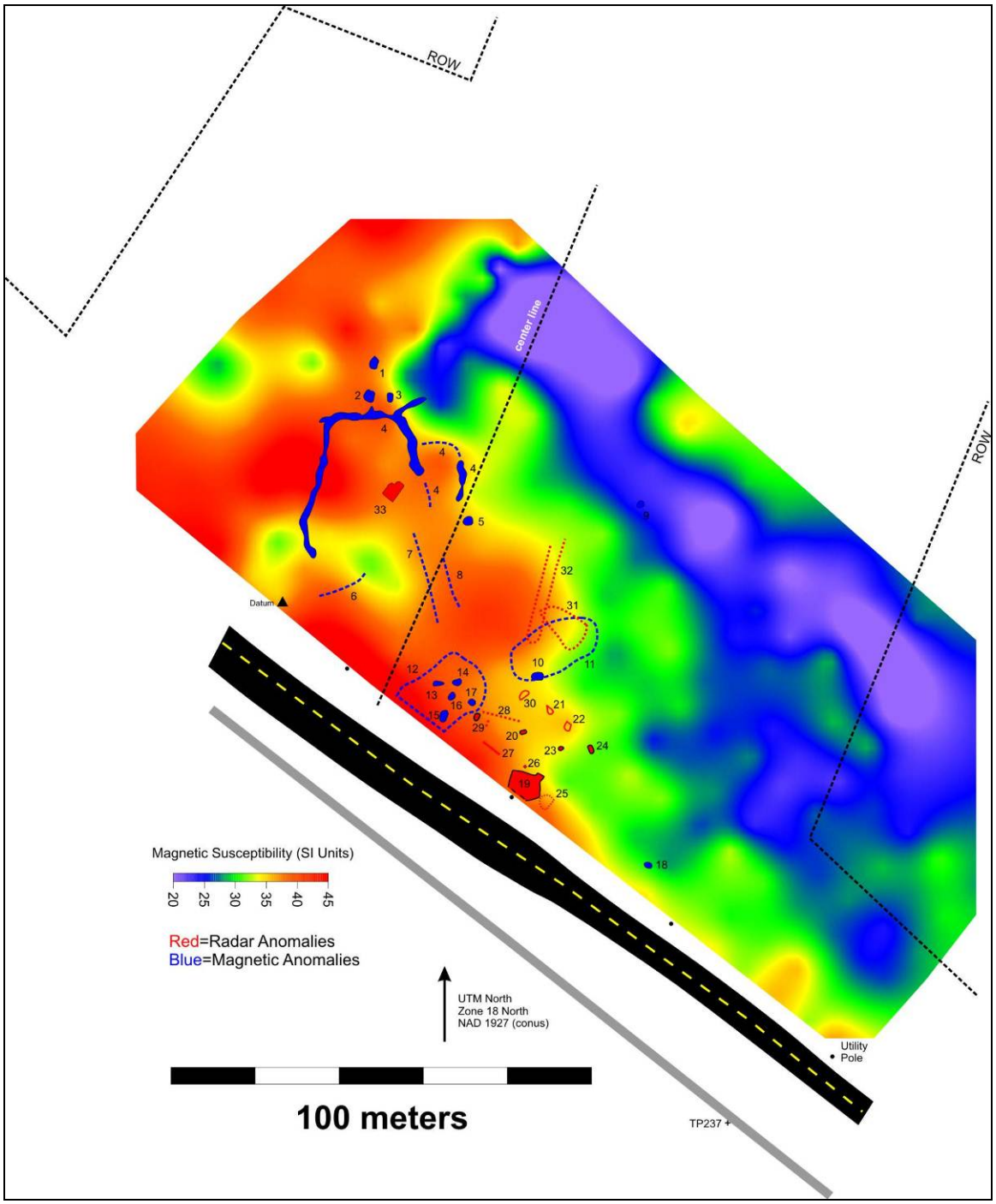

Figure 4. Magnetic susceptibility survey results.

Magnetic Gradient Results

> **Instrument Type**: Geoscan Research FM256 fluxgate gradiometer (50 cm sensor separation); **Data Density**: 8 readings per meter along transects spaced 50 cm apart; **Data Processing**: zero mean traverse, interpolate, low pass filter

Farmstead sites tend to be littered with iron objects, so one would expect a magnetic gradient survey of a historic-era farmstead to be littered with small magnetic anomalies caused by iron objects. However, this does not seem to be the case with the Bunker Hill magnetic gradient data. Figure 5 shows the results of the magnetometer survey. The survey covered 23 20x20 meter blocks (about 0.93 hectares, or 2.3 acres). Dark areas represent higher magnetic gradient values while the lighter areas are lower values. Iron objects, which generally appear as dipolar anomalies (small area of strong positive next to a strong negative—i.e., a small black and white anomaly) are rare and widespread at the Bunker Hill site; there do not appear to be any clusters of these dipolar anomalies, which are common around historic-era houses and other kinds of buildings.

Anomalies 1-18 in Figure 3 are magnetic anomalies of potential interest. Most occur on the north/west end of the site on the higher ground before it dips down into the lower area at the north/west edge of the survey area. Many of these, for example Anomalies 1, 3, 5, and 13-17, look like typical anomalies associated with pit-type features at prehistoric Native American sites (i.e., monopolar positive anomaly, with peak magnetic gradient values between about 3 nT and 8 nT). Anomaly 4 appears to be a linear feature, such as a ditch, filled with topsoil or some other high susceptibility sediment. Of note, Anomaly 19, a distinctive anomaly detected by the radar, was not detected by the magnetometer. Furthermore, there were no other distinctive magnetic anomalies in the near vicinity of Anomaly 19. This is unexpected if Anomaly 19 is a historic-era cellar.

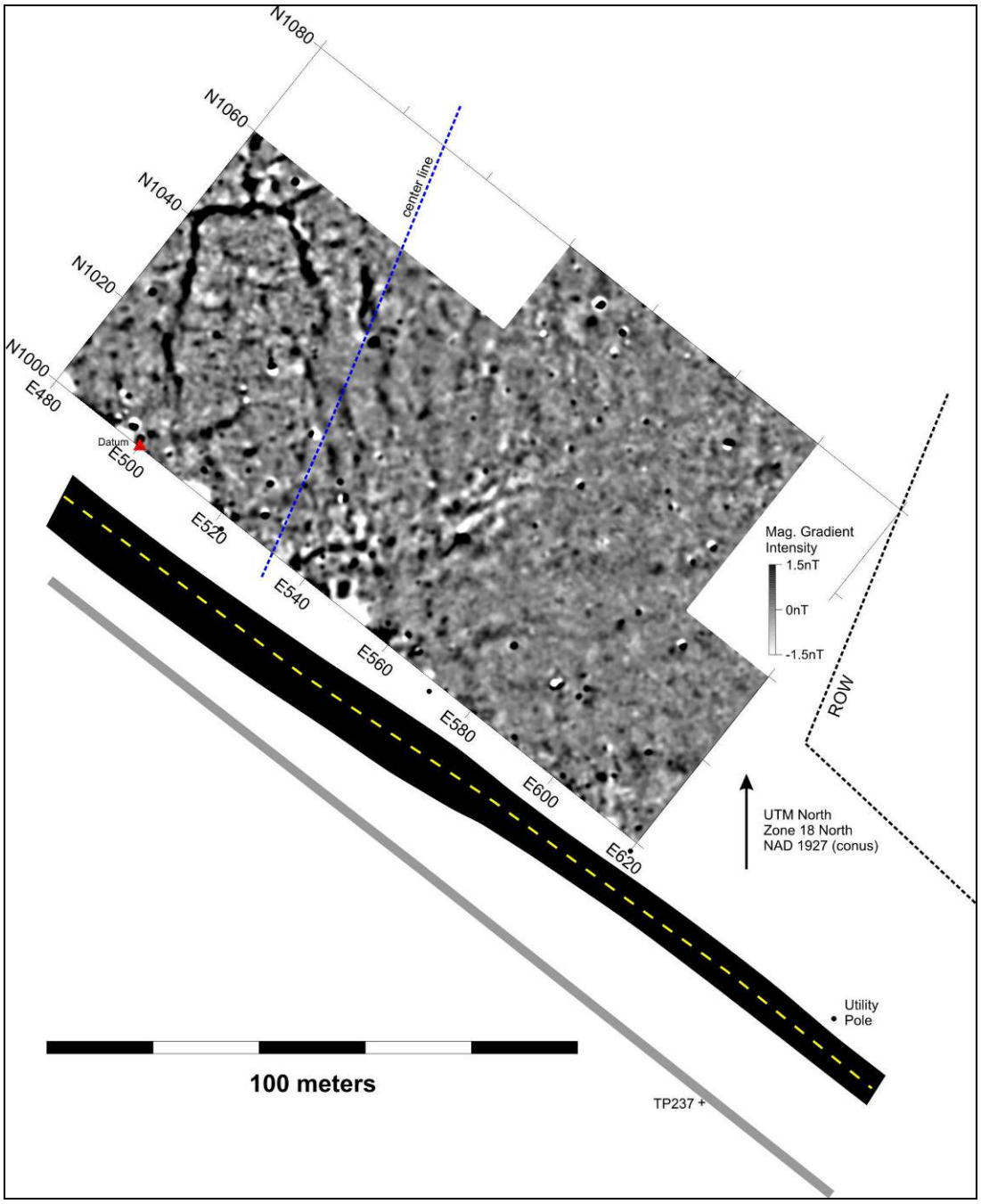

Figure 5. Magnetic gradient survey results.

Ground-Penetrating Radar Results

> **Instrument Type**: Sensors and Software Noggin 500 (500 MHz); **Data Density**: 40 traces per meter along transects spaced 25 cm apart in the Y-direction; a 20x20 meter area around Anomaly 19 was also covered by transects spaced 25 cm apart in the X-direction; **Data Processing**: using Ekko_Mapper 4, dewow, migration, enveloping, background subtraction

The radar survey covered ten 20x20 meter blocks (0.4 hectares, or 1 acre) and Figure 6 shows four radar amplitude slice maps at varying depths. In these maps red areas represent strong reflections while blue areas are weak reflections. Part way through the radar survey a strong rain storm drenched the site. The effects of this added soil moisture can be observed in the 27-42 cmbs slice where one can see a strong band of reflections between E540 and E560 to the north of N1020.

Numerous distinctive radar reflections were detected in the survey area, as well as a strongly reflective layer that begins at about 70 cmbs. Perhaps the most distinctive radar anomaly found during the survey is Anomaly 19. Figure 7 shows a close-up view of the Anomaly 19 area. Too help clear up the shape of Anomaly 19, the radar data in this area were collected along east-west and north-south transects—producing bi-directional high density data. The extremely crisp, straight edges of Anomaly 19, as well as its distinctive corners, suggest that Anomaly 19 is some kind of historic-era excavation, perhaps a cellar. The radargram (or radar profile) of this anomaly (Figure 7, bottom) shows that it contains two reflective surfaces, one at 50 cm below surface and another at about 100 cm below surface. Assuming that Anomaly 19 might be a cellar, the data nearby were closely scrutinized for the kinds of features often found around historic-era cellars, like cisterns, wells, and privies. While no shaft-type features with stone or brick liners were observed in the data around Anomaly 19, several subtle, privy-sized anomalies were noted (e.g., Anomalies 20 and 24).

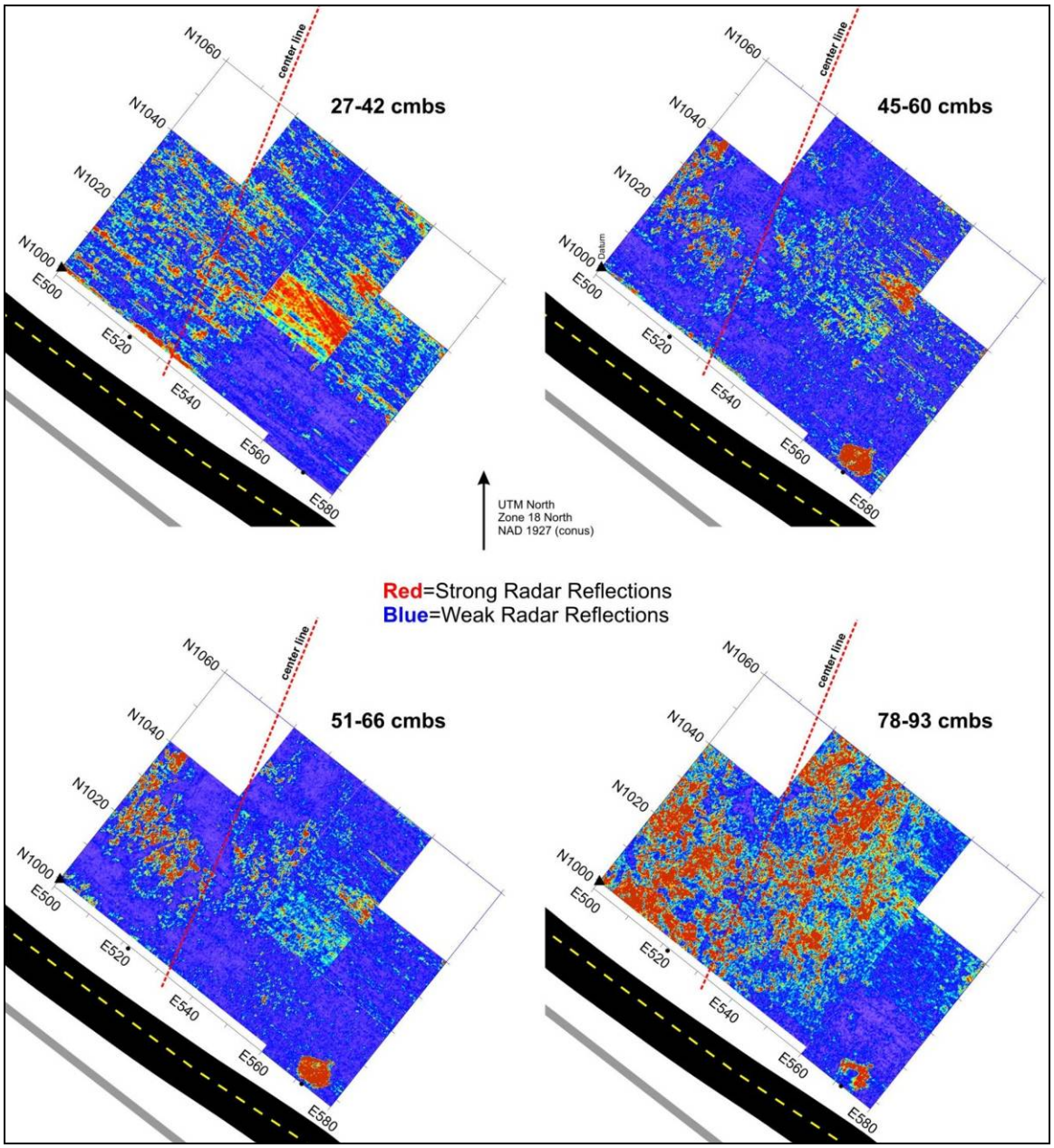

Figure 6. Example radar amplitude slice maps.

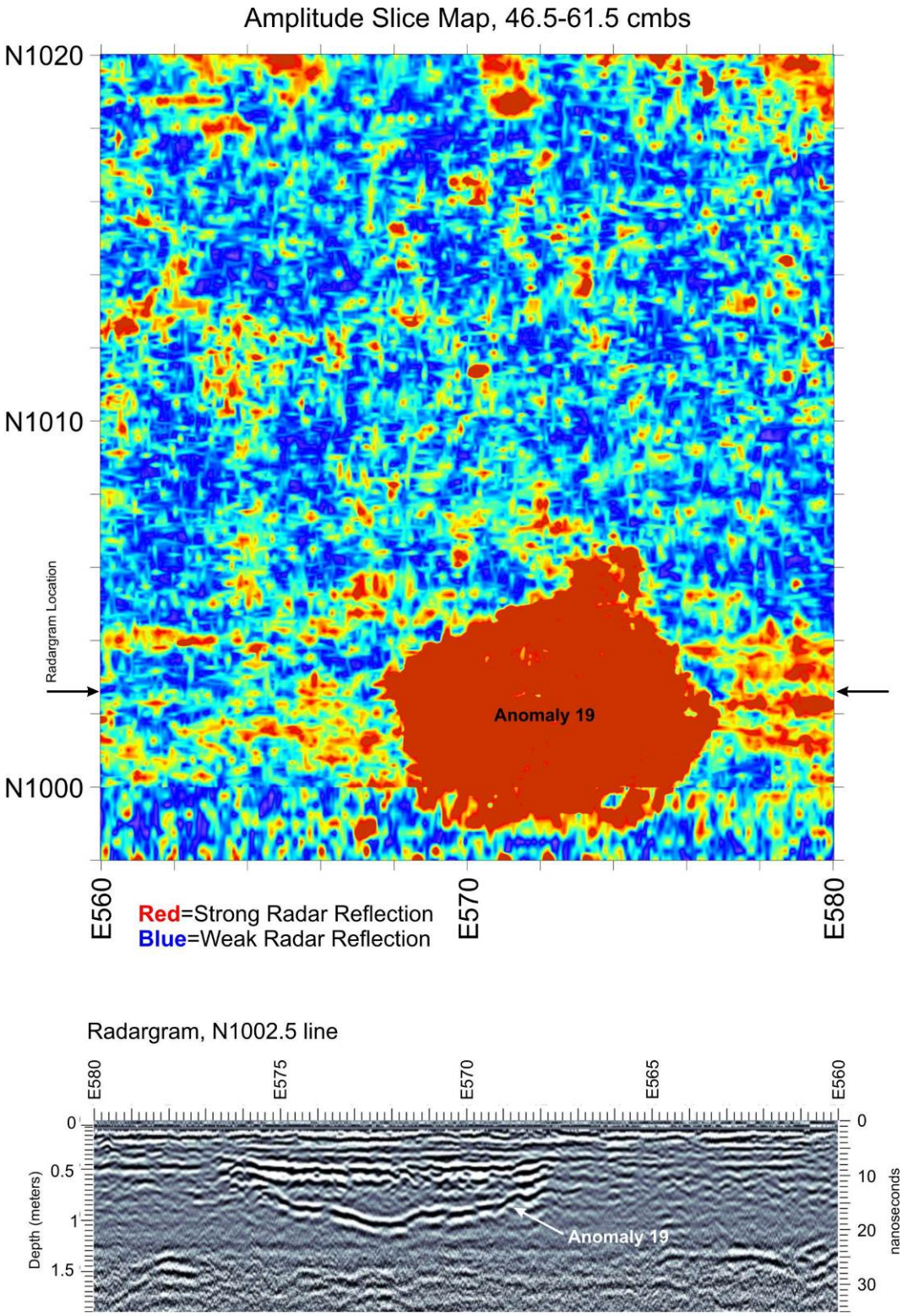

Figure 7. View of high-density data collected over Anomaly 19, amplitude slice (top) and a radargram example (bottom).

Summary and Conclusions

With the goal of identifying prehistoric and historic-era features, three geophysical survey instruments were used to survey the Bunker Hill site (7NC-F-126). All anomalies with characteristics similar to those found associated with excavated historic and prehistoric features from other sites in the Mid-Atlantic and Midwest were identified in the data, described, and recommended for further investigation. The magnetic susceptibility meter was used to cover the largest area in an attempt to identify the edges of plowzone midden deposits. An area of high soil susceptibility was found at the north/west end of the site. A magnetometer was used to identify pit-type features and clusters of iron objects in the core of the site where the Phase I survey located numerous artifacts. Magnetic anomalies consistent with pit-type features and filled in ditches were found but no distinctive clusters of iron objects were detected. Finally, a ground-penetrating radar was used to identify hard targets like foundations and wells, in addition to other kinds of soil-filled features like unlined privies. The radar did detect distinctive anomalies, including an anomaly that appeared to be a cellar.

While anomalies of interest were detected, certain aspects of the possible historic-era anomalies did not seem to fit together. For instance, Anomaly 19 was thought to be a possible cellar. Cellars tend to be associated with numerous iron objects, burned sediments, and other kinds of magnetic materials. But Anomaly 19 lacked these accompanying magnetic anomalies and in fact was not magnetic itself. Furthermore, the magnetic susceptibility data suggested that if a midden was present at the site it was not coincident with this possible cellar. However, the magnetic susceptibility did seem to be strongly correlated to the locations of anomalies that were consistent with prehistoric pit-type features.

In the end, the geophysical surveys were successful in identifying soil anomalies and other kinds of anomalies with characteristics consistent with those found associated with cultural features at other historic and prehistoric sites. The fact that none of these anomalies at Bunker Hill proved to be cultural features shows that equifinality, or the situation in which two or more things produce the same geophysical signature, is a bigger challenge to overcome in Delaware than perhaps in other sites in the Mid-Atlantic and Midwest regions.

REFERENCES CITED

Clark, Anthony
2000 *Seeing Beneath the Soil: Prospecting Methods in Archaeology*. Revised Edition. Routledge, New York.

Conyers, Lawrence B.
2004 *Ground-Penetrating Radar for Archaeologists*. Altamira Press, Walnut Creek, California.

Cook, Robert A., and Jarrod Burks
2011 Determining Site Size and Structure: A Fort Ancient Example. *American Antiquity* 76(1): 145-162.

Dalan, Rinita A.
2008 A Review of the Role of Magnetic Susceptibility in Archaeogeophysical Studies in the USA: Recent Developments and Prospects. *Archaeological Prospection* 15: 1–31.

Dalan, Rinita A., and Subir K. Banerjee
1998 Solving Archaeological Problems Using Techniques of Soil Magnetism. *Geoarchaeology* 13:3-36.

Evans, Michael E., and Friedrich Heller
2003 *Environmental Magnetism: Principles and Applications of Enviromagnetics*. Academic Press, New York.