Geophysical Mapping of Historic Cemeteries

Geoffrey Jones

ABSTRACT

Although the non-invasive nature of geophysical survey recommends it for mapping unmarked graves, cemeteries can present a number of technical challenges that can limit the method's usefulness. Ground-penetrating radar (GPR) is often the only geophysical method considered for mapping historic cemeteries, but its success is very dependent on favorable site conditions. Other methods can be very successful when appropriately applied, and may be favored by settings unsuitable for GPR. An examination of GPR, electrical resistance, and magnetic surveys in historic European American cemeteries is presented, with a discussion of the capabilities and limitations of the methods, and their appropriate application. Other approaches and factors important to geophysical mapping are highlighted as well.

Introduction

Cemeteries are unique in many ways as a subject of study in archaeology. Whether archaeological investigation is undertaken for preservation, cemetery management, or research, respect for the dead and for descendant communities is of paramount importance. Related ethical and legal considerations affect every aspect of archaeological practice. On a methodological level, this generally means that disturbance to the site must be minimized, if not entirely avoided.

Because geophysical survey is non-invasive, it would seem an obvious choice for cemetery investigations, and several geophysical methods have been successfully used to map historic graves. Very often, however, geophysical surveys of cemeteries have failed to yield useful results. From intermittent success and failure have come many lessons about applying geophysics in a challenging context, and an acceptance that conditions at some cemeteries may not be suitable for any geophysical method.

When appropriately applied, geophysical survey has a very strong likelihood of yielding useful results. Not only does appropriate application include designing surveys that can resolve cemetery patterning, but it also means fully integrating geophysical methods with the goals and methodology of the archaeological investigation.

Although minimizing impact to the site is a primary concern in cemeteries, geophysical survey has other potential benefits for archaeological investigations generally. Most significantly, it can provide unique information unavailable by other means, it can expand the area that can be effectively studied, and it can lower the cost of research.

This paper provides archaeologists and historians with an overview of both the potential and the limitations of geophysical survey in historic cemetery studies. It does not seek to enable non-specialists to perform geophysical surveys; this requires considerable investment in specialized training and equipment. A general understanding of the subject may be useful to researchers in order to help them conceptualize the use of geophysical surveys in their research, in interfacing with specialist practitioners, and in understanding survey results.

Three of the most successful methods, ground-penetrating radar, electrical resistance, and magnetic survey, will be discussed, with an emphasis on case studies and general application concerns; specific technical parameters are not examined in detail. Prehistoric cemeteries, while subject to similar ethical and legal considerations, present a different set of technical challenges, and are outside the scope of this paper. Clark (1996) and Gaffney and Gater (2003) treat geophysical methods for archaeology in greater depth.

Applications for Geophysics in Cemetery Investigations

The most basic need in cemetery investigations may be the documentation of the presence of graves and the extent of the cemetery. Missing or misplaced grave markers are very common in historic cemeteries, and records may be absent or inexact. Often even the limits of the cemetery are unknown.

Some of the specific uses of geophysical survey include: locating unmarked burials; finding the extent of a cemetery; fitting historic cemetery plats to their physical location; determining used/unused areas for cemetery management; cost assessments and planning for exhumations; and targeting exhumations and minimizing exploratory excavation. Other less typical uses of geophysics can include: locating clandestine graves (historic or modern); locating mass graves associated with battles or massacres; and verifying past exhumations or cemetery removal.

Geophysical survey is most often used in conjunction with other complementary methods of investigation, both archaeological and historical. Multiple sources of data can contribute synergistically to a much more effective interpretation. The effectiveness of geophysical survey for achieving research goals should therefore be considered in terms of its role in an interdisciplinary program.

Ground-Penetrating Radar (GPR)

GPR is probably the best known and most widely applied geophysical method used for cemetery investigations. Under good conditions it can be very effective, and can detect small targets at greater depths than other methods. Unfortunately, GPR is subject to severe limitations, and is not effective for many—perhaps most—cemeteries. Its success is very dependent on specific site conditions, and can be very difficult to predict. Examples of GPR surveys are shown in Figures 1 and 2.

GPR functions by sending high-frequency electromagnetic waves into the ground from a transmitter antenna. Some of these waves are reflected back to the surface as they encounter changes in the dielectric permittivity of the matrix through which they are traveling, and are detected by a receiver antenna. The amplitude and two-way travel time of these reflections are recorded and used to construct a two-dimensional plot of horizontal distance versus travel time. Data collected in the field are stored for later analysis, and may be viewed in real time during data collection. A more complete and technical discussion of the method

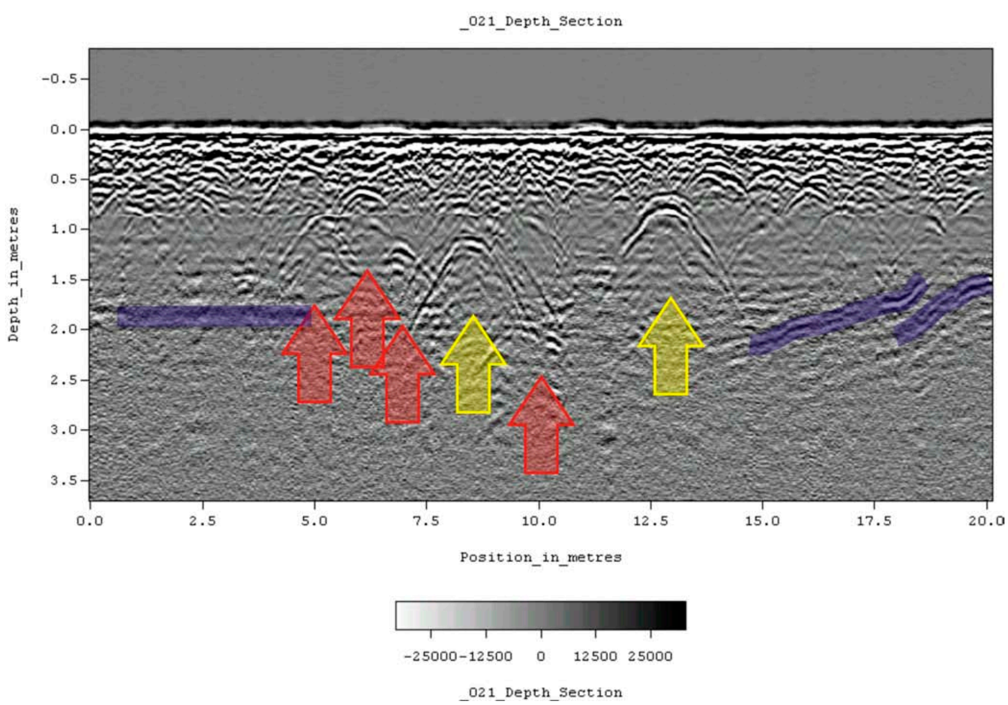

Figure 1. GPR profile from an historic cemetery in Alabama. Blue lines indicate horizontal and sloping reflectors, probably limestone bedrock. Yellow arrows indicate distinct hyperbolic reflections due to discrete subsurface objects. Similar, but less distinct reflections are indicated with red arrows. These correlate with an area containing depressions and possible vernacular grave markers, and are thought likely to result from burials. The shallower hyperbolic reflections are likely caused by tree roots (Jones 2004).

can be found elsewhere (Annan and Cosway 1992; Conyers and Goodman 1997; Conyers 2004).

GPR data are traditionally examined as profile maps of individual transects. Time slicing is a technique for constructing plan-view maps of an area with specific depth ranges isolated. This not only makes interpretation of the data in the horizontal plane much more intuitive, but also allows the user to isolate specific depths for examination, or more properly, the two-way travel times of reflected waves. Data for time-slice analysis must be collected systematically at closely spaced (generally ≤50 cm) transect intervals.

GPR can detect human burials in several ways. It may detect the disturbed soil of the graveshaft, or breaks in the natural stratigraphy or soil profile (Bevan 1991). It may also detect the coffin, bones, clothes, and other articles in the burial. Reflections may be caused by air voids within coffins, or as Mellet (1992) suggests, within the skull. It has also been suggested that the decomposition of bones may leach calcium salts into the surrounding soil, which over many years may change the electrical properties of the soil, making it visible to the radar (Mellet 1992).

In general, sandy, homogeneous soils favor the use of GPR, and in these conditions it is often the preferred geophysical method. Clayey, silty, and alkaline soils tend to have high electrical conductivity, which can cause excessive attenuation (conductive loss) of the GPR signal, limiting both depth of investigation and resolution (Annan and Cosway 1992). Rocky or heterogeneous soils can also greatly reduce the chances of success by scattering the GPR signal and by causing extraneous reflections (poor signal to noise ratio). Other conditions that can negatively affect GPR data are excessive moisture, large amounts of

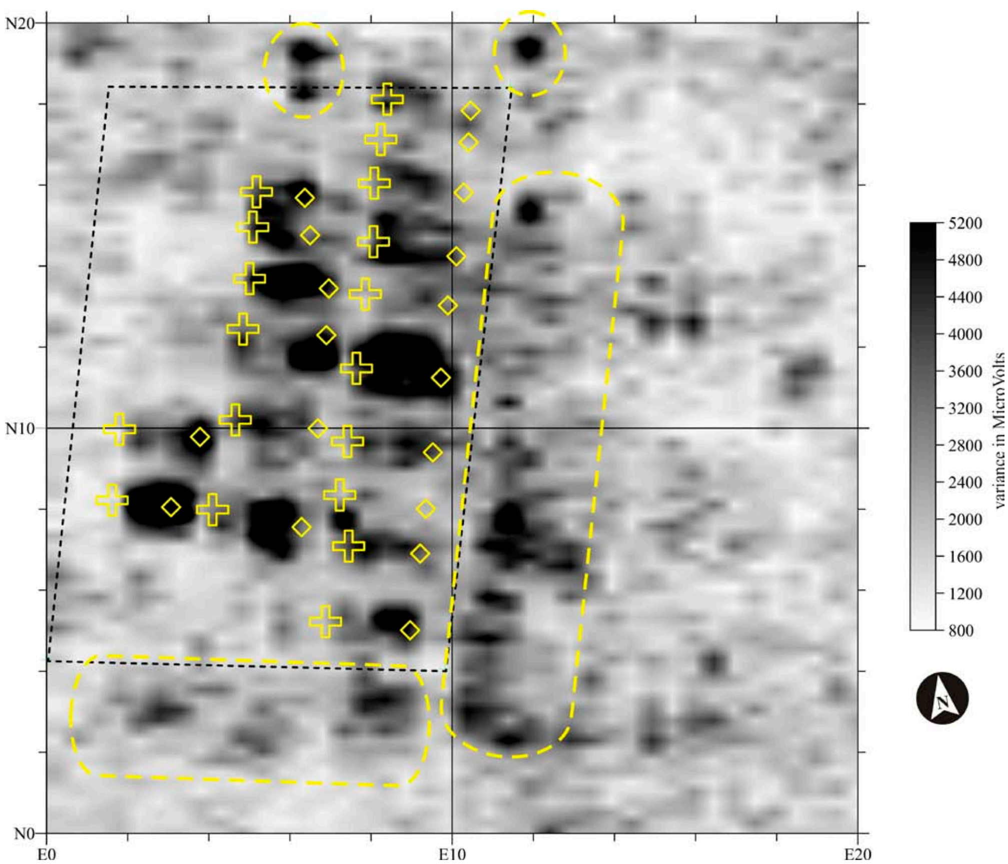

Figure 2. Time slice (plan view) map of GPR survey results from the Ellis Cemetery. The Ellis Cemetery dates from the mid-19th century. It is on what is now Fort Bragg, North Carolina. Graves in this family cemetery are not as closely spaced as those in most public cemeteries, and individual graves are generally well defined. Less distinct patterning outside the modern fence suggests the possibility of unmarked burials (Jones and Maki 2003).

metal above or below ground, rough terrain, and excessive numbers of physical obstacles.

Resistance Survey

Although resistance methods are more limited than GPR in their ability to detect low-contrast features at great depth, they may detect patterning caused by the disturbed soils within graveshafts. Resistance survey may be undertaken where site conditions limit the effectiveness of GPR, and can be a valuable adjunct, even when conditions are favorable to GPR. Resistance survey is most effective in clayey or silty soils, but can be employed under a wide range of conditions. It is the most widely effective of the methods discussed here, but it is also the slowest, which is its principal disadvantage.

In general, resistance data must be collected at a sample density of at least four samples per square meter

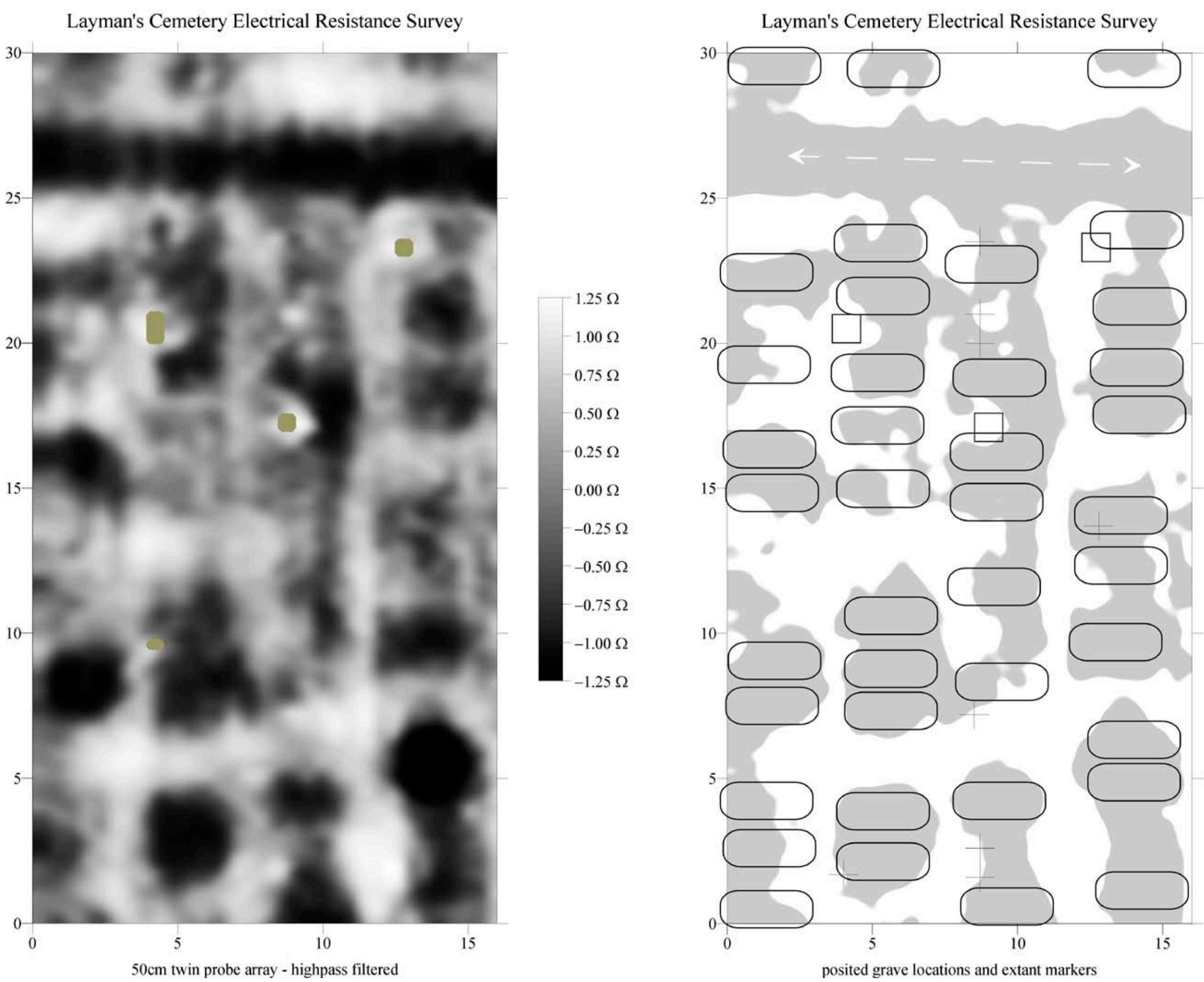

Figure 3. Resistance survey results and interpretations, Minneapolis Pioneers and Soldiers (Layman's) Cemetery. Rows of burials are readily apparent in this 19th-century cemetery. Although some individual graves are posited in the interpretation, a high density of burials obscures their individual expression. Grave markers are indicated as squares (family markers) and crosses (individual markers) on the interpretive map. There are clearly many unmarked graves in this area and throughout the rest of this 10-acre cemetery, which suffered many years of neglect. It is interesting to note that the few grave markers in this area do not appear well correlated with the rows of graves, suggesting that markers may not be in their original locations. The linear anomaly indicated by a white arrow may express a former path, landscaping element, or utility trench. It is unclear whether this feature might overlie or intrude into burials (Jones 2005).

to effectively resolve the patterning of individual graves. Sample patterning and instrument configuration should be adapted to the scale and geometry of cemetery patterning. Resolution is affected by soil moisture, and resistance survey should be avoided in excessively dry or saturated conditions. Resistance survey may not be possible in some extremely dry conditions.

Graveshafts may appear as either high-resistance or low-resistance anomalies, and within the same cemetery may appear as both. Small-scale variance and anisotropy (directional bias in resistance values) are also possible indicators of disturbed soils (Dalan and Bevan 2002). Figures 3 and 4 are typical examples of resistance surveys.

Magnetic Survey

Magnetometers can be very rapid and effective tools for mapping cemeteries under certain conditions, but must be used judiciously. In many cases, igneous rock and ferrous metal dominate the magnetic environment, obscuring subtler patterning. In other cases, highly magnetic materials are components of burials, rendering them highly detectable. Examples include steel or iron in caskets, coffins, or vaults; buried grave markers; and other monuments of stone or brick. Other materials may be mapped that give indirect evidence of grave patterning, including landscape elements such as paths and roads; metal debris from for-

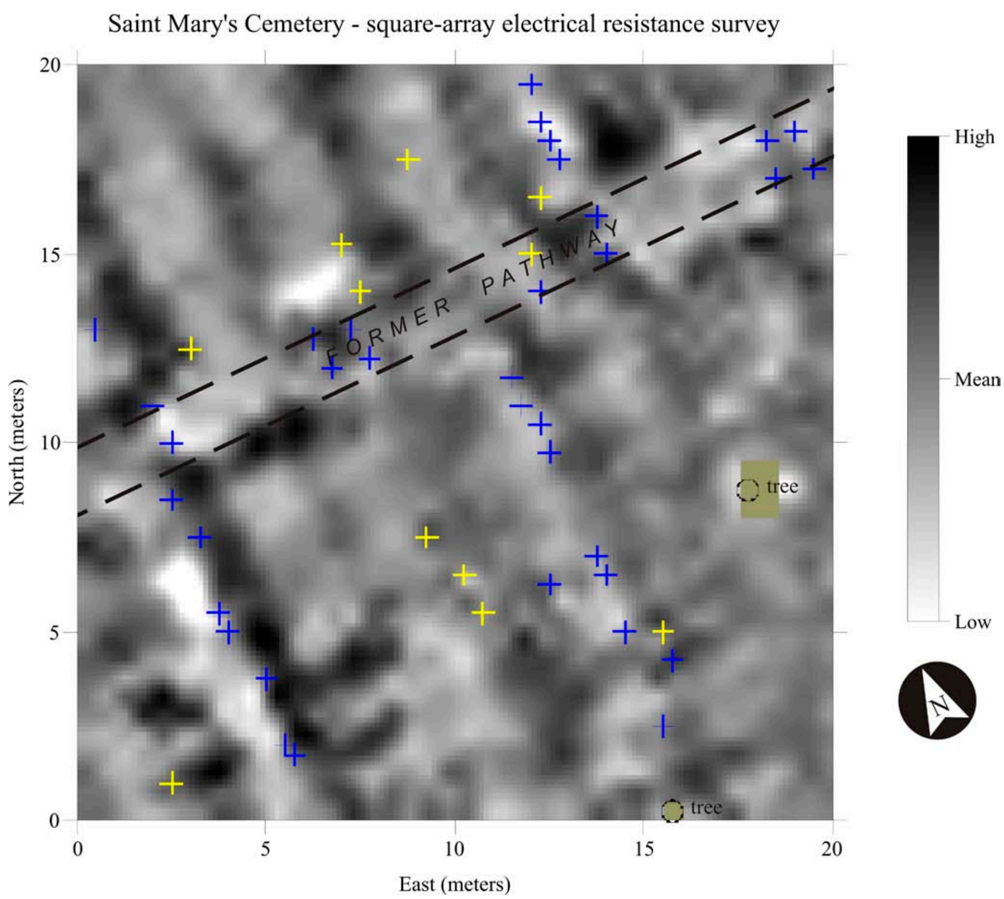

Figure 4. Resistance survey results, Saint Mary's Cemetery (Minneapolis, MN). Blue crosses indicate late-20th-century grave markers. Yellow crosses indicate older grave markers, mainly from the late 19th century. Grave markers (old and new) are mainly flush headstones. Many of the graves are infants and children. Resolution of individual graves is inconsistent, but rectilinear patterning associated with rows of graves is apparent. The former pathway was removed prior to 1960, and the space used for burial plots. Although this cemetery has been well maintained, it is clear that there are numerous unmarked graves, or graves whose markers have subsided and become buried. This dataset was collected with an experimental 50 x 50 cm square array, which can measure anisotropy as well as overall resistance (Clark 1995; Lane et al. 1995).

mer fences; and even plastic flowers that have degraded, leaving their wire stems.

Where igneous rock, metal, and brick are not present, magnetometers can detect more subtle anomalies caused by concrete, or organically enriched, disturbed, or compacted soils. In the absence of highly magnetic components, historic burials often appear as a weak magnetic low. A magnetic low may result from the replacement of topsoil (which typically has enhanced magnetic susceptibility) with subsoil or mixed soils in the filled graveshaft. It should be noted, however, that the organic components of graves can cause enhanced magnetic susceptibility (Linford 2004), but this effect is typically weak, and found at greater depths.

Due to differences in burial practices, burials within a single cemetery may have varying magnetic expressions. Graves may appear as both positive and negative anomalies within the same cemetery. The example in Figure 5 shows graves that appear as weak but distinctively patterned magnetic lows. Figures 6 and 7 show cemetery patterning with a variety of expressions within a single cemetery.

Other Methods

The great majority of geophysical surveys employ the methods already discussed, both in cemetery studies and in other archaeological contexts. Other methods have been used for cemetery survey, and emerging technologies may prove to be effective. The methods discussed below have achieved some degree of success in mapping cemetery patterning, although they have not been as extensively used as those already examined.

Electromagnetic (EM) conductivity instruments have a response that is comparable to that of resistance meters (conductivity being the inverse of resistance). EM instruments have not been widely used for cemetery survey, but some useful results have been obtained (Kvamme 2001).

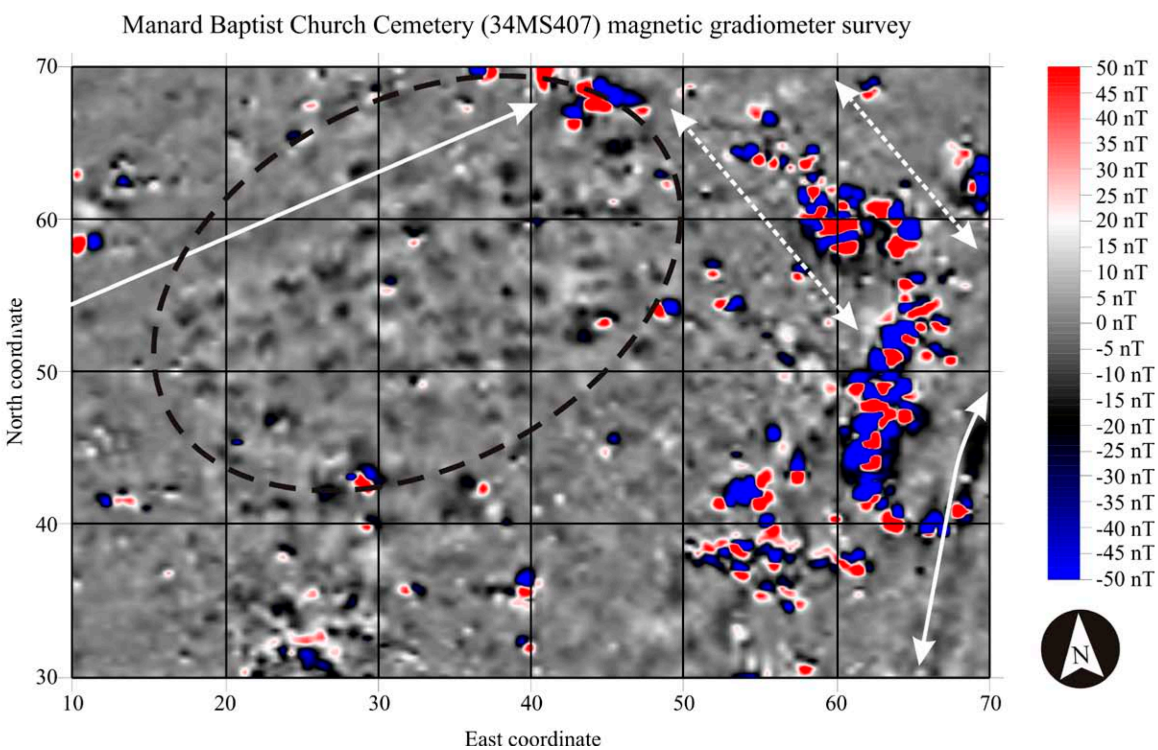

Figure 5. Manard Baptist Church Cemetery (Camp Gruber, OK) magnetic survey results. Strong magnetic anomalies (in the blue and red ranges of the color scale) are mainly caused by historic/modern ferrous metal, although igneous rock and brick are other possible sources. These permanently magnetized sources typically appear as bipolar anomalies, although sometimes only one pole is detected by the survey. Disturbed and compacted soils associated with graves and roads are expressed more subtly in the grayscale range of the color scale. A black outline indicates an area containing apparent cemetery patterning, expressed as weak magnetic lows. White lines indicate linear anomalies or trends in the magnetic data, thought to express former roads or other linear features (Jones 2007; Neel, Sundermeyer, and Jones 2007).

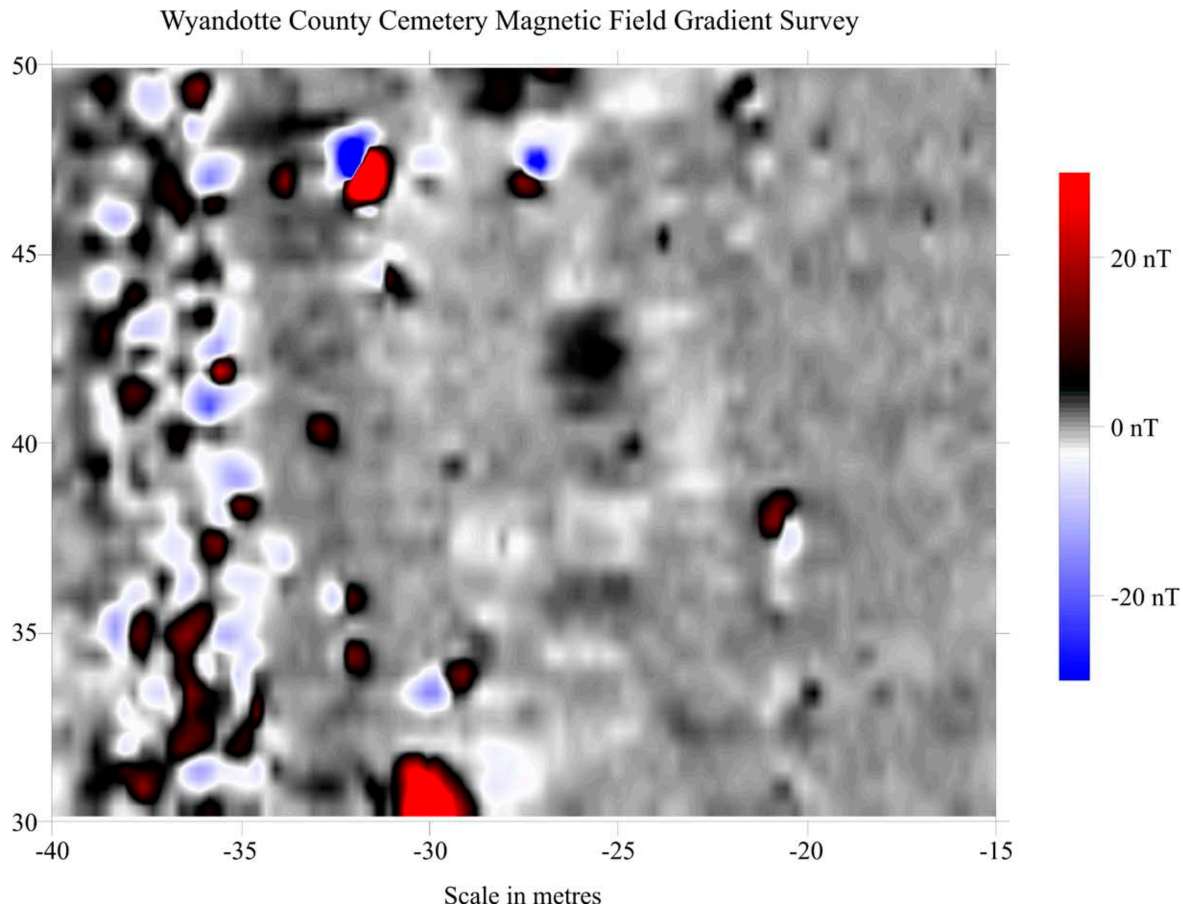

Figure 6. Wyandotte County Cemetery magnetic survey (detail). This data plot illustrates a variety of different magnetic expressions of graves (reflecting different burial practices) and other cemetery patterning. Specific interpretations are given in Figure 7. These data are part of a larger multi-method investigation as discussed in the case study.

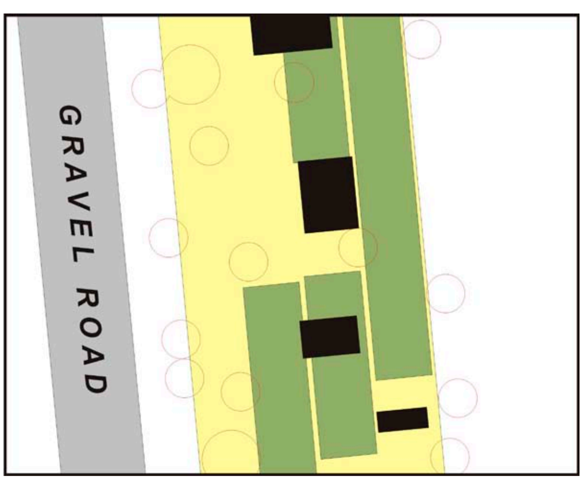

Figure 7. Interpretation of Wyandotte County Cemetery magnetic survey (detail). The yellow area on the interpretive map represents the extent of apparent cemetery patterning. Although suspected burials vary in the distinctness of their expression, the patterning and orientation of anomalies within this area is strongly diagnostic. Most suspected burials are expressed as weak magnetic lows (green), thought to result from soil disturbance. Similar patterning occurs throughout much of the yellow-tinted area but is not marked because it is weak or indistinct. Other suspected graves are expressed as moderately strong magnetic highs, thought to be associated with vaults or steel caskets. Red circles indicate discrete, mostly bipolar anomalies. These may be associated with ferrous metal objects, or with buried grave markers. While not distinctly patterned, their distribution coincides with the area of suspected cemetery patterning. To some extent these strong anomalies obscure the weaker expression of suspected burials. The gravel road is expressed as a concentration of small bipolar anomalies, due to igneous rock in the road gravel.

The instruments are generally less sensitive to the same phenomena than resistance meters, but they do have a number of unique properties. In particular, they may be used in some conditions that do not favor resistance instruments. They are also much more rapid than resistance meters.

Magnetic susceptibility is a property that is becoming increasingly important in archaeological studies. Variation in susceptibility is one of the phenomena that may be indirectly detected by magnetic surveys, but susceptibility may be more directly measured by susceptibility meters. Susceptibility data collected at high-sample density may be used to map disturbed soils in graveshafts. Some EM conductivity instruments are also capable of simultaneously measuring magnetic susceptibility (Kvamme 2001).

Thermal infrared (IR) imaging has provided some interesting results, but has not been widely applied in cemetery studies. The use of thermal IR in archaeology is very dependent on transient environmental factors. The effect of factors such as seasonality and daily temperature cycles must be thoroughly understood in order to use thermal IR methods effectively (Heitger 1991).

Penetrometers measure the resistance of soil to the insertion of a cone-tipped rod. The probe is not inserted deeply, but penetrometers are more intrusive than other geophysical instruments. Penetrometer testing has been found to be effective for locating graves (Trinkley and Hacker 1999). Although some instruments have digital data loggers, a very slow per-sample rate of testing makes penetrometers impractical for large-scale systematic survey. Penetrometers are not effective in rocky soils (Dalan and Bevan 2002).

Multiple-Method Investigations

In many settings it may be advantageous to use multiple geophysical methods. Not only does this increase the likelihood of success, but it can also greatly enhance interpretability. Because each geophysical method responds to different properties, multiple data sets are complementary rather than redundant. Even where multiple methods do not each yield unique, relevant information, correlation between multiple datasets can enhance the level of confidence of an interpretation—an important consideration when subsurface testing may not be performed.

Other Application Concerns

Site Conditions

Site conditions are a critical consideration in evaluating feasibility and designing a successful survey. Site reconnaissance is essential, and should include careful notation of soils and geology, surface features, vegetation, topography, subsequent use and disturbance, and other site conditions. Archival and literature research can give important insights into burial practices and cemetery patterning.

Sampling Strategy

The central issue in any meaningful consideration of survey design or budget is sample density. Appropriate sample densities vary with instrumentation and site conditions. As a generalization, transect intervals of a half meter or less, with multiple readings per linear meter along each transect, are usually required for good results. The patterning and orientation of sampling are also important, and should be adapted to the anticipated cemetery patterning.

Spatial Control

Accurate and repeatable spatial control is critical in both grid layout and data collection. The best means of assuring good spatial control is an accurate and permanently referenced survey grid system. The grid should be established using an instrument capable of decimeter-level accuracy, and permanently referenced by establishing two or more permanent datum points. Mapping of surface features is often done in conjunction with the staking of the survey grid.

Interpretation

Interpretations based on geophysical data alone may be considered hypothetical. With ongoing evaluation and testing, initial interpretations may be elaborated or revised. Cemetery studies must often rely on non-invasive means to verify or refute interpretations. Fortunately, the formal patterning within historic cemeteries is often diagnostic in itself. Interpretation may also be informed by complementary geophysical methods, and comparison with historical data and landscape features. If performed, subsurface testing can range from minimally invasive techniques such as coring or penetrometer testing, to surface stripping or complete excavation.

Case Study: Wyandotte County Cemetery

The Wyandotte County Cemetery (Kansas City, Kansas) was known to contain several hundred burials. Only two grave markers were present, and the locations of other burials and the limits of the cemetery were not precisely known. A program of archaeological research was undertaken to define the limits of the cemetery, integrating non-invasive geophysical techniques with conventional archaeological methods.

The geophysical investigation consisted of electrical resistance and magnetic gradiometer surveys of portions of the cemetery (Figures 7, 8, 9, and 10). GPR was not used because of the high conductivity of the soils. Geophysical survey interpretations were tested by limited excavation. Because of the large size of the cemetery, it was not surveyed in its entirety. The sampling strategy was designed to define the cemetery boundary at intervals that could be reasonably interpolated. The western boundary, which was adjacent to proposed road construction, was given more complete coverage.

While both methods were successful in detecting graves in portions of the cemetery, either method by itself would have given an incomplete or ambiguous picture. Resistance survey provided better resolution for identifying graves in the older part of the cemetery, while magnetic survey responded better to graves in the newer part of the cemetery. Limited excavation largely confirmed initial interpretations based on survey results. Graves exposed during excavation revealed shroud burials in the older part of the cemetery, coffin burials in the newer part, and an absence of burials outside the posited cemetery boundaries. This variety of burial practices is reflected in a range of different geophysical expressions. This illustrates the value of using multiple geophysical methods, especially where burial practices or other conditions may vary within the cemetery. The unsuitability of the soils at the site to GPR shows the importance of pre-survey reconnaissance, as well as underscoring the danger of reliance upon a single geophysical method.

Summary

Appropriately applied, geophysical methods can be an effective tool for the subsurface mapping of cemeteries. GPR, resistance, and magnetic methods are each adapted to a different set of environmental and archaeological conditions, and have all been used with success. Other established and emerging technologies have potential for cemetery investigations as well.

Ideally, geophysical methods should be part of an integrated program of research that considers historical, archaeological, environmental, and other available data. The shortcomings of geophysical survey results are mitigated, and their strengths complemented when used in conjunction with other archaeological and historical data sources.

Historic cemeteries can be very challenging subjects for geophysical survey. Different burial practices result in a variety of responses from different instruments, and older or ephemeral graves tend to have extremely subtle geophysical expressions. Fortunately, even where response to individual graves is very weak or indistinct, the larger-scale patterning of grave rows is often diagnostic of cemetery patterning.

Instrumentation, sampling strategy, and other survey design parameters must be adapted to unique site conditions and specific research goals. Research and reconnaissance is critical for good survey design and consistent success. As geophysical surveys become more common and more successful in archaeology, it is good practice to note relevant conditions even when geophysical survey is not immediately anticipated.

Analysis of geophysical data should integrate other available sources of data in generating initial interpretations. Where ground truthing may be performed, interpretation becomes an iterative process of hypothesis generation, testing, and refinement of initial interpretations. In the case of Wyandotte Cemetery, initial interpretations regarding the presence or absence of graves were confirmed by ground-truthing results. Comparison between exposed burials and geophysical data also informed further interpretation, allowing more specific inferences to be made regarding burial practices, age, and patterning in unexcavated portions of the site.

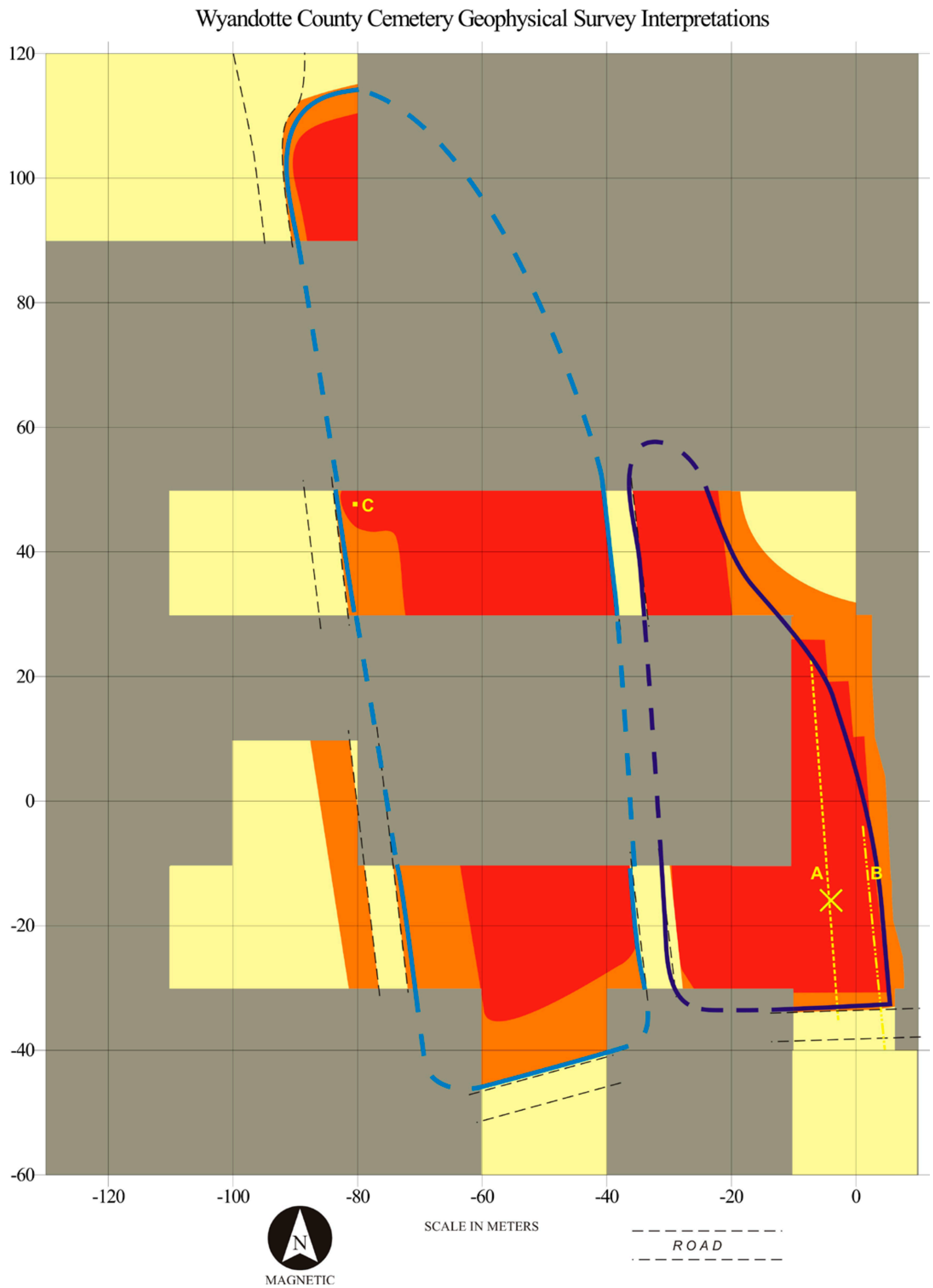

Figure 8. Wyandotte County Cemetery resistance survey. Resistance survey showed distinct patterning in the older portion of the cemetery (outlined in dark blue). Graves appear as north/south rows of low-resistance anomalies. Response in the newer part of the cemetery (outlined in light blue) is more ambiguous, showing linear patterning, but not clearly resolving individual graves. This large-scale linear patterning in the newer portion of the cemetery seems to be largely related to gentle terracing, although graves are apparent in the magnetic survey. The difference in response between the areas may be due to the terracing. Graves in the older portion are on a fairly level hilltop, and grave shafts may show greater contrast against undisturbed soils than in areas disturbed by terracing.

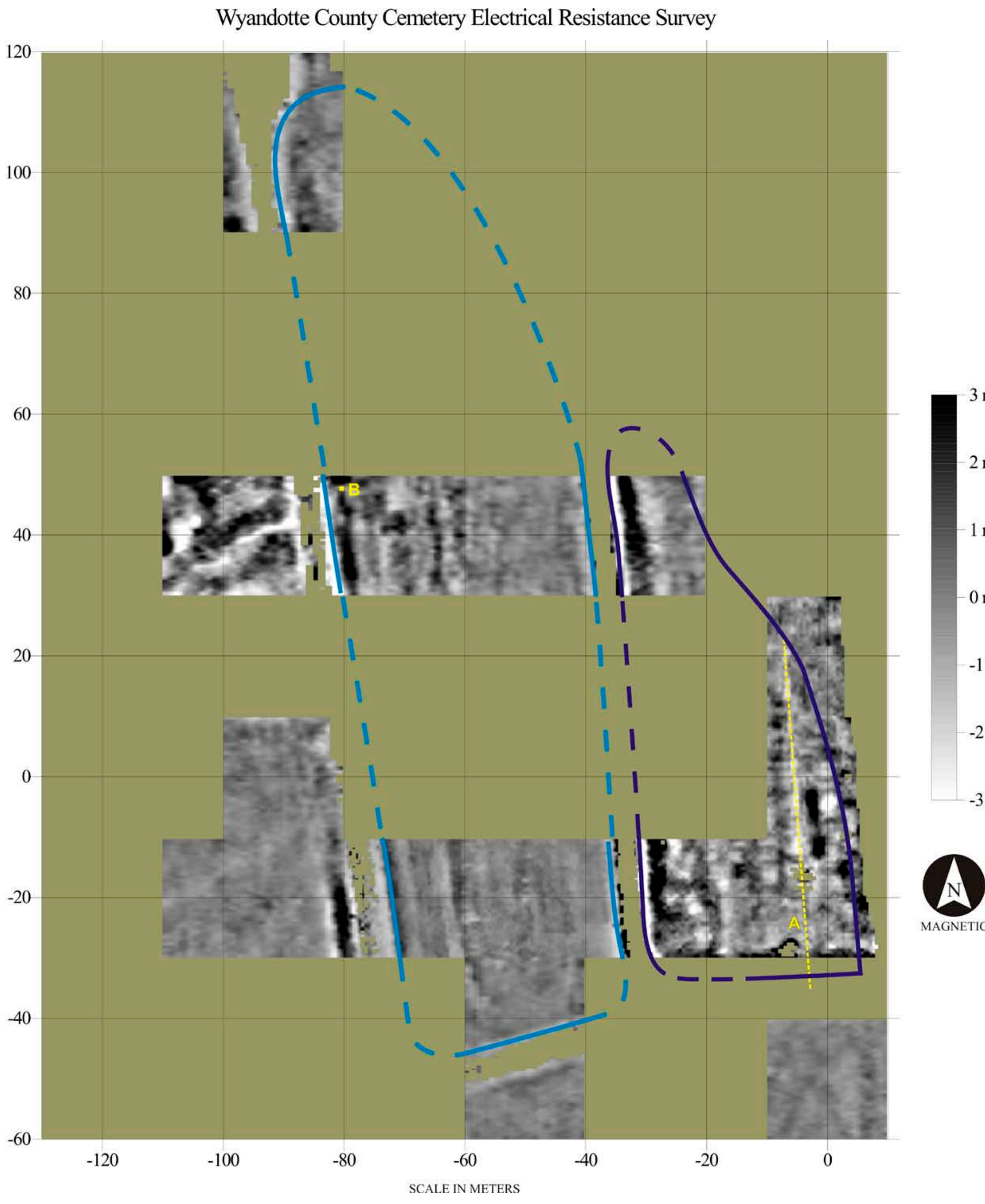

Figure 9. Wyandotte County Cemetery magnetic survey. In general, graves in the older part of the cemetery are expressed more subtly, mainly as faint magnetic lows. Graves in the newer part of the cemetery tend to be expressed as stronger magnetic highs—probably due to vaults or metal coffins—although a range of expressions is seen. Strong bipolar (having both positive and negative components) anomalies are likely to be caused by metal or igneous rock (possibly granite grave markers) near the surface. A gravel road and path (marked "A") are visible, as are more subtle anomalies caused by terracing and dirt roads. A single granite, grave marker near the surface is located at the point marked "B." The very strong linear anomaly is thought to be caused by a (posited) lightning strike on a former fence and on a nearby cross (marked with a yellow "X"). Laboratory testing of associated materials is pending.

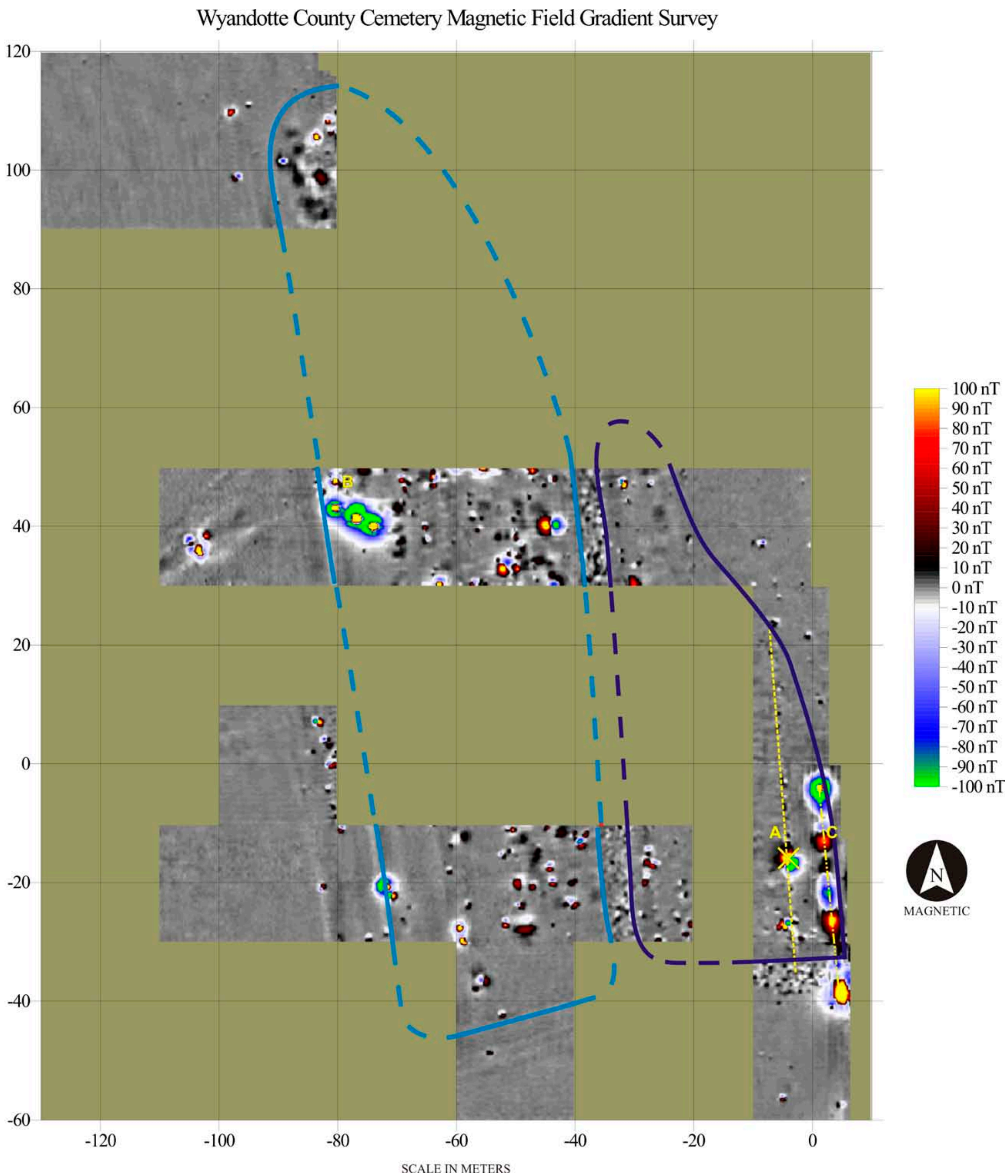

Figure 10. Wyandotte County Cemetery general interpretations. Areas thought to show positive evidence for the presence of burials are indicated in red. Orange indicates ambiguous or circumstantial evidence for cemetery patterning. Older and newer portions of the cemetery are outlined with dark and light blue outlines, respectively; these outlines are dashed where they are interpolated. Landscape features such as roads and topography were also considered in making these interpretations and in interpolating between survey areas.

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Geoffrey Jones
Archaeo-Physics, LLC
4150 Dight Avenue #110
Minneapolis, MN 55406