Geophysics Comes of Age in North American Archaeology

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Abstract
For many years, geophysics has been a routine part of archaeological investigations outside North America, especially in Europe and Japan, largely because massive stone foundations and sarcophagi are easier to map than ephemeral prehistoric features commonly found in North America. Recent technological advances in geophysical hardware and software now allow detection of subtle anomalies over these archaeological features and can provide the archeologist with invaluable information, especially in the cultural resource management environment. This paper presents data from several prehistoric and historic sites demonstrating the merits of this technology under typical North American conditions.

Introduction
Geophysics is not a routine part of archaeological investigations in North America. A contributing factor for this situation is the subtlety of North American targets. Prehistoric peoples did not routinely leave massive stone foundations that have proved to be good geophysical targets in Europe and Japan, where geophysical studies are a routine part of archaeological investigations. For historic targets in North America, archaeologists often have access to contemporary maps that depict the location of structures of interest. Nevertheless, this is not always the case. Maps are not always available or reliable and some features, such as graves, are not always well documented. We will show that modern geophysical technology can be a powerful tool for the archaeologist, even in North American settings.

The starting point of a geophysical investigation must be basic physics. Geophysics will be effective only if a target of interest has a physical contrast with the surrounding ground. For example, a buried metal sword would be an easy target for a wide variety of techniques, but if adobe bricks are embedded in the same type of clay from which they were constructed, they might be hard to identify with geophysics. Another important consideration is if the geophysical contrast of the target can be distinguished from other features with similar contrasts — what geophysicists call the signal to noise ratio. A fire

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hearth might be easy to identify by its magnetic signal under ordinary conditions, but if it is sur-
rounded by scrap metal, it may not be possible to image the hearth. Notwithstanding the above
difficulties, examples of common archaeological targets include:

- Bricks, fire hearths - magnetic, high electrical resistivity
- Compacted earth floors, paths, roads - relatively high electrical resistivity
- Filled post holes - relatively low electrical resistivity
- Buried stone walls - possibly magnetic, high electrical resistivity
- Buried void space - high resistivity, low density
- Metal - magnetic if ferrous, low resistivity, strong dielectric contrast
- Soil layering - variable electrical and dielectrical properties
- Graves – dielectric contrasts make for good GPR reflections; sometimes electrical or mag-
netic contrasts
- Depth to bedrock - acoustic wave velocity contrast, possibly an electrical contrast

Commonly applied techniques include:

**DC Resistivity** - This method maps electrical variations in the ground. Traditional archaeological
application of this method has been to map lateral changes in shallow resistance, but recent ad-
vances in computer processing have allowed for the possibility of mapping the variations of elec-
trical properties as 2D profiles, or in 3D.

**Electromagnetic (EM) methods** – EM methods offer the possibility to rapidly measure variations
of soil electrical properties, as well as to delineate the distribution of metallic objects. EM meas-
urements are commonly applied to industrial “archaeology” with the goal of locating under-
ground tanks or pipes, but certain types of equipment are effective in mapping changes in shal-
low soil properties.

**Ground Penetrating Radar (GPR)** - GPR offers the highest resolution of any geophysical
method, but only when soil conditions are favorable. Typical applications include the mapping
of graves, middens, buried foundations, as well as industrial targets such as buried waste, USTs,
pipelines and other utilities.

**Magnetics** - Measurements of the magnetic field are good for mapping fire hearths or other fired
material and can also be sensitive to subtle variations of the ground where there has been distur-
bance. When two magnetic sensors are used at different heights from the ground, the difference
in response between the two sensors, the magnetic gradient, is especially sensitive to subtle near-
surface variations of magnetic properties and is often the preferred method for surveying at ar-
chaeological sites.

There are many other geophysical techniques, and some have specialized application at archaeo-
logical sites, such as paleomagnetic or radiometric measurements for age-dating, but the above
methods are by far the ones most commonly applied in archaeological mapping.

For many investigations, the best results are obtained when more than one technique is applied to
the problem. For example, a combination of magnetics and DC resistivity is often effective as a
means to map the limits of cultural resources in advance of excavations. Targets associated with metal are often best delineated with an EM method along with magnetics. Soil layering is frequently best delineated with GPR together with DC resistivity.

The physics of archaeological features hasn’t changed. Most geophysical techniques have been around for many years. Basic interpretation strategies also haven’t changed, as interpretations are based on an understanding of the physics involved. What has changed is the ability of the geophysicist to gather data rapidly. Also, better computers and improved software have revolutionized the means by which data can be processed and presented, resulting in improved interpretations. This paper presents three recent case histories where modern data acquisition and processing systems have been applied in North American settings.

Case Histories

Merritt Cemetery - Barboursville, West Virginia

The historic Merritt Cemetery, located in Barboursville, West Virginia about five miles east of Huntington, was located in the way of new road construction related to the development of a new regional jail facility. This cemetery, originally thought to include about 25 graves, was the burial ground of the Merritt family, prominent frontier settlers in the early 1800s upon whose land the town of Barboursville was established. The founding father William Merritt, who operated two gristmills in the village formerly known as Merritt’s Mill, was an officer in the Revolutionary War. While William Merritt is not thought to have been buried at the family cemetery, the site contained the graves of a number of descendants, as well as that of Revolutionary War veteran Malchor Strupe.

In October 1999, a crew from Horizon Research Consultants (HRC) began relocation of the Merritt family graves, none more recent than the 1850s. In order to photograph the area and accurately record the location of headstones and footstones, brush and several large trees were removed. After the area was cleared, 15 buried headstone bases and stone fragments were found, in addition to 25 visible headstones and 13 footstones. The fence surrounding the area had been constructed about 10 years earlier as an Eagle Scout project and their basis for defining the limits of the cemetery was unknown. The possibility that graves could exist outside of the Eagle Scout fence had to be considered. Rather than begin an excavation program of uncertain scope, geophysics was selected as a tool to identify the limits of the historic cemetery and to focus the archaeological field effort.
The geophysical survey was conducted in two field phases. The goal of the initial investigation in October 1999 was to determine if geophysics could prove a practical means to identify unmarked graves within and near the fenced portion of the cemetery. At the time of the first survey, it was not practical to survey east of the cemetery due to the presence of sheet metal in a collapsed building that precluded meaningful measurements. EM and resistivity measurements were made to determine if groups of graves could be identified on the basis of subsurface electrical properties. GPR was conducted to identify graves on the basis of disturbances to soil horizons and possibly to obtain images from the coffins, should they still be present. Of these techniques, GPR proved most effective in identifying graves. The initial survey established the distinct possibility of encountering graves north of the known cemetery.

After the first geophysical survey, archaeological excavations identified the presence of prehistoric artifacts. For this reason, a second geophysical survey was conducted in November 1999 with the goal of identifying in greater detail the extent of the historic cemetery, as well as to map prehistoric cultural resources, such as fire hearths, middens, dwelling locations, etc. A dense coverage with GPR, including areas not previously accessible, was used to define the extent of the historic cemetery. This dense GPR data was anticipated to be somewhat useful in delineating prehistoric features in the ground, but these features were expected to be very subtle and difficult to interpret from the GPR data alone. For this reason, two additional methods were applied to evaluate the prehistoric site: DC resistance and magnetic gradiometry.

The results of the second geophysical survey indicated that the subsurface of the Merritt Cemetery site is very complex, with geophysical anomalies produced by cultural features of multiple origins. Nevertheless, it was possible to determine that unmarked graves were probably within about 40 feet of the known cemetery, mainly towards...
the north. The geophysical survey also provided the archaeologists with specific targets for excavation.

After confirming with the West Virginia Division of Culture and History that additional excavation was needed to determine whether the site was eligible for the National Register, in January 2000, HRC began systematic excavation in the northern part of the cemetery. A third of the known cemetery was excavated with 35 five-foot-square units. Artifacts recovered from the site suggest that the area was inhabited as early as the Early Archaic period, although the majority of the prehistoric materials dated from the Woodland period. The artifacts came from disturbed contexts, however, probably because the site was plowed prior to its development as a cemetery. Accordingly, the intensive excavation for prehistoric artifacts ceased when it was understood that the site would not qualify for the National Register.

Unit excavations also identified grave shafts in locations not associated with tombstones. Not all of the grave shafts, however, had recoverable remains. Most of the contents of the graves were completely decayed due to high soil acidity. For the most part, all that remained were some teeth, an occasional button, some fabric, the soles of shoes and some coffin hardware. Once the detailed excavations were completed, a backhoe excavated the top two to three feet of soil over the remainder of the cemetery. Mapping from the detailed excavations provides the best correlation to the geophysical data.

The magnetic gradiometry results as measured with an EG&G Model G858G magnetometer/gradiometer show a significant variation in the magnetic gradient across the northern part of the known cemetery. The largest anomaly proved to be from a buried metal ammunition box that was found to contain human remains. Apparently, local residents recovered these remains from an eroding Fort Ancient site and reburied them in the cemetery in 1993. The fire hearths identified

DC resistance (red are highs/blues are lows) – the grave shafts are marked by resistance lows as measured by an RM15 instrument.

GPR profile obtained with a RAMAC2 system with 200 MHz antennas – this profile identifies an unmarked burial as a break in soil horizons.
proved to be located over the magnetic highs, as expected, but small amounts of disseminated metal apparently dominate much of the magnetic response. Graves tend to show up on magnetic lows, probably because the magnetic structure of the ground is disrupted. However, the response to metal interferes with the interpretation.

DC resistance was measured with a Geo-scan RM15 twin probe system and the ground containing graves is marked fairly clearly as a resistance low. The only areas where the graves are not clearly associated with a resistance low are where the ground contained trees or tree stumps, especially near the eastern fence.

The most effective technique for identifying burials proved to be GPR. Coffins were not preserved and metal coffins were not used, so the burials needed to be identified on the basis of soil disturbances. Distinguishing between graves as opposed to other types of soil disturbances such as refuse pits proved to be a challenging process and required a careful comparison of adjacent profiles, taken four feet apart. Discontinuities to soil horizons were mapped in terms of their interpretive clarity. Strong anomalies found on adjacent lines were interpreted to probably be graves and subsequent excavations verified this interpretation. Strong GPR anomalies associated with the resistance and magnetic lows in the western part of the known cemetery also may represent burials. Shafts were identified, but further excavation did not reveal any human remains associated with these features.

**Fort Buford, North Dakota**

The Fort Buford State Historic Site is located near the confluence of the Yellowstone and Missouri Rivers, about 20 miles southwest of Williston, North Dakota. The post was built in 1866 and over the years was home to six companies of infantry and cavalry including the 6th Infantry, Black 10th Cavalry and the 25th Infantry. Scouts Yellowstone Kelly and William B. Hazen were based at Fort Buford. Chiefs Sitting Bull, Joseph, Gall and Corn King were, at one time or another, imprisoned there. The fort was abandoned on October 1, 1895, after the surrounding area had been homesteaded.
Remaining today are a stone powder magazine, post cemetery and a large officers quarters. Although numerous other buildings were present, none show remains visible at the ground surface.

Development plans for this site include the reconstruction of barracks for public exhibition. To construct the buildings in their original positions it was first necessary to conduct an archaeological investigation supported by geophysical surveys. The early buildings at Fort Buford that were the targets of the investigation were constructed from adobe and it was anticipated that the original foundations would be from adobe, possibly with stone corners.

A magnetometer survey was conducted in May 2000 by the Midwest Archaeological Center in an attempt to locate the foundations and corners of an enlisted men's barracks. Unfortunately, a significant amount of metal (in the form of nails, parts of metal straps, and miscellaneous scraps) was present scattered across the area investigated. The response of this surface metal was significant enough to mask the weak magnetic anomalies of the foundations targeted by the survey.

An alternative survey that would not be strongly affected by the metallic debris, but which could also detect the foundations, was to measure soil resistance. Hemisphere Field Services (HFS) was contacted by Randy Kane, Chief Ranger at the Fort Union Trading Post, on behalf of the Friends of Fort Union/Fort Buford to conduct the resistance survey.

Resistance as measured with a Geoscan RM-15 at the barracks at Fort Buford, North Dakota – the goal was to map the barracks and excavations have confirmed the correctness of the interpretation. The survey also identified other structures, some which could be identified from existing maps and others that have yet to be identified.
The resistance data were collected with a Geoscan RM-15 system. Data were collected along east-west grid lines at intervals of 0.5 meter. The line spacing was 1 meter. The resulting data distribution – 0.5 meter separation east-west and 1 meter separation north-south – was chosen to provide the best resolution of features with a north-south orientation, specifically the long sides of the barracks known from historic maps.

Data were collected over grid blocks covering 20 by 20 meters. The survey covered 6 such grids, or a total of 40 meters by 60 meters. The ground was dry and very hard and it often took several attempts to drive the electrodes sufficiently into the ground to take a reading. This significantly slowed the rate of data collection. Five grids were completed on June 31 and the sixth was completed on August 1, 2000. The dry conditions, however, were favorable for the data quality, making it possible to meet the project objectives.

The interpretation of resistance data is based on the recognition of patterns of anomalies when plotted in a plan view. Patterns in the data are caused by variations in the electrical properties of the ground that result from natural conditions and cultural activities. The frequent difficulty is in determining which variations are related to cultural activities and which are not. The interpretation can be further complicated by the impact of site activities that occurred more recently than the targets of interest. When processed as a color image map, areas of low resistivity are represented by shades of blue and areas of high resistivity are shades of red. Foundations, where present, show up as resistivity highs.

The main target of the survey, a barracks, was identified from the resistance surveying and subsequently confirmed by excavations. Other structures produced anomalies that could be related to known structures from contemporary maps. The mess hall proved to be readily identifiable. Other anomalies relate to structures not yet confirmed by excavations. Nevertheless, it is not difficult to imagine that the long, linear anomaly in the back of a barracks would be the sink (lateral). The available maps show sinks in the backs of all but this barracks, but the geophysical data suggest that this barracks was not different from the others. Other apparent buildings and possible pits of unknown origin were also identified in the survey.

Confederate Stockade Cemetery, Johnson’s Island in Sandusky Bay in Lake Erie, Ohio

D’Appolonia Environmental Services, Inc. (D’Appolonia) conducted a GPR survey at the

Surveying at Johnson’s Island Confederate Stockade Cemetery with the RAMAC GPR system with 200 MHz bi-static antennas mounted in a sled with a trigger wheel to rapidly obtain continuous data.
Confederate Stockade Cemetery in Johnson’s Island in Sandusky Bay in Lake Erie on behalf of the Center for Historic and Military Archaeology (CHMA) of Heidelberg College, Tiffin, Ohio. The survey was conducted on May 26, 2000 and covered approximately 95 percent of the portion of the cemetery containing tombstones.

The scope of the investigation was to attempt to map grave locations within the cemetery. Based on information compiled by the Project Director, Dr. David Bush of CHMA, approximately 305 Confederate soldiers died while imprisoned at the Johnson’s Island stockade between 1862 and 1865, but only 206 tombstones are present. Records indicate that approximately 25 to 30 of the bodies were claimed by their families for burial elsewhere, which leaves approximately 70 soldiers whose burial location is unknown. Another question addressed by the survey was the relationship of graves to the tombstones. The initial markers were constructed of wood and the tombstones currently present at the cemetery were not installed until the United Daughters of the Confederacy restored the cemetery in 1890. Dr. Bush indicated that graves may have been lost prior to the restoration of the cemetery, which may also explain why some of the graves are marked as “unknown” and others have misspelled names. Available records indicate that the graves are shallow, no deeper

GPR Profile 18 in Block 1 – this line exhibits relatively little disturbance from graves and depicts a soil surface gently dipping towards the east. Disturbances to this horizon formed the basis for the identification of most of the graves.

GPR Profile 24 in Block 1 – this line exhibits a well-defined reflection from what is likely an air-filled or metallic coffin from a depth of approximately 0.8 meters – the other apparent graves are due to soil disturbances only definitively identified when looking at adjacent survey profiles.
than about three to four feet because of the presence of shallow limestone bedrock.

Graves often have complex GPR signatures. Coffins, especially when they are metallic or are air-filled, exhibit strong hyperbolic reflections. Where coffins are not present, however, graves are visible only as disturbances to natural soil horizons. This, of course, requires that undisturbed soil have a measurable, coherent stratification such that disturbances to natural layers are evident from the GPR reflections.

The first step in conducting the survey was to divide the cemetery into four survey blocks (Blocks 1 through 4 from west to east). These blocks were based on a previous survey and helped to minimize location errors that could have occurred if the survey profile lengths had exceeded a length of about 15 – 20 meters. The survey was conducted with the RAMAC GPR system using separate 200 MHz transmitter and receiver antennas (bi-static mode). With this system, measurements were made with a trigger from the trailing survey wheel every 0.2 feet along each profile line with a minimum of 16-fold stacking. 16-fold stacking means that at every measurement point, 16 readings were made and averaged to reduce the random noise. The profiles were all conducted in the same direction to facilitate a direct comparison of the parallel profiles.

Interpretation of graves at the Confederate Stockade Cemetery site proved to be challenging, as most indications of burials were evident only as disturbances to the natural soil. Within the natural soil, a horizon with a gentle dip towards the east was generally found to be present across the cemetery. The nature of this horizon is not known, although it appears to be somewhat shallower than the bedrock surface. Disturbances to this horizon formed the basis for interpreting most of the grave locations. Some well-defined hyperbolic reflections were interpreted to be from coffins or grave objects of unknown origin. The strongest reflections were assumed to be from an air-filled or possibly metallic coffin.

In general there is a poor correlation between interpreted graves and tombstones. It should also be noted that some of the apparent graves, in particular, the clusters of graves in the center and southern part of Block 2, are so close together that they could be mass burials. Another observation is that the burials in Block 4 are much more pronounced than in the other blocks, possibly indicative that more coffins were used in this area than in the others.

A total of 242 possible graves have been identified from the GPR survey. Fifteen are well defined and appear to be due to reflections from coffins. 101 possible graves are interpreted from fairly well defined disturbances to the soil horizon. Another 126 are identified on the basis of less well-defined soil disturbances. In some cases, a clear coffin reflection is observed on one line but the adjacent lines are marked only by a soil disturbance. It should also be noted that a basic assumption was made in the survey that the graves were laid out perpendicular to the line of tombstones. This appears to have been a reasonable assumption, although a few of the graves appear to be skewed from the prevailing apparent orientation.
If the small, unsurveyed portion of the cemetery covered by tombstones has the same density of apparent graves as found in the rest of the cemetery, the survey would have encountered approximately 260 graves. There could also be additional graves in the direction of the statue and still be within the borders of the cemetery. In any case, there appears to be significantly more graves than are marked by tombstones. This is not a definitive conclusion, as many factors could influence the nature of GPR reflections, including natural variations in the ground, but it would be an unusual coincidence that the number of GPR anomalies is close to the number assumed to be buried.

**Comments from a Geophysical Point of View**

The decision whether to use or not to use a specific geophysical technique in an archaeological exploration depends on its cost-effectiveness when compared to other technologies. Generally we have found that geophysics is usually cost-effective if there is reason to believe that a significant cultural resource is present. If the resource has an adequate physical contrast with the surrounding ground, it is usually beneficial to use geophysics as a tool for planning effective excavations.

Technological advances allow the geophysicist to obtain, process and present data in much less time than was required in the past. Geophysicists are thus able to obtain useful information in more of a cost-effective manner than used to be possible. At this point, however, it is necessary to raise a cautionary flag. The level of effort required for a good interpretation is a function of the physics of the site and is independent of the time it took to acquire and process the data.
Also, the interpretation needs to be a joint effort of the geophysicist working with the archaeologists. All too often, geophysical surveys are conducted and presented to archaeologist with minimal interpretation or with interpretations that do not account for the available archaeological information. The archaeologist ends up with a pretty map, but doesn’t know what to do with it.

A geophysical survey needs to be a multidisciplinary effort, where the necessary joint effort is dedicated to the interpretation. As excavations proceed, interaction between the geophysicist and the archaeologists needs to continue such that the geophysical anomalies can be re-interpreted in light of the realities of digging. In this manner, geophysics will continue to improve as a useful tool to archaeology, even in the difficult environments encountered at North American sites.