Geophysical Methodologies and Test Site for Battlefield Archaeology

Geophysical Methodologies and Test Site for Battlefield Archaeology

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts in Anthropology

By

Elsa Heckman, BA

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PROJECT ABSTRACT

This project rigorously examines a suite of commercial, off-the-shelf, geophysical instruments and various field methods to assess their suitability in effectively locating, and mapping, metallic battlefield artifacts. A collection of Civil War period artifacts, replicas, and other metallic artifacts were buried in mapped locations within a battlefield archaeology "test site" to examine a variety of instruments and field protocols. This test site will remain in-place for future research projects. The goal of this investigation is to determine which instruments and which field methods work best for detecting buried metallic battlefield artifacts. This objective was achieved through use of traditional metal detectors alongside more advanced geophysical instruments: the EM-38 electromagnetic induction meter and the FM-256 magnetic gradiometer. Success rates for each instrument were assessed by comparing detection probabilities for artifacts of various sizes, materials, and field methods. While the traditional metal detector out-performed both of the other instruments in percentages of artifacts recovered, mapping of finds is a separate and labor-intensive process. The EM-38 and the FM-256 have the advantage of generating maps as they are employed, making them useful for imaging larger metallic battlefield artifacts across broad areas, together with more traditional ground disturbances (e.g., trenches, graves).

This thesis is approved for recommendation to the Graduate Council

Thesis Director:

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Dr. Kenneth L. Kvamme

Thesis Committee:

____
Dr. Kirstin Erickson

____
Dr. Thomas J. Green

____
Dr. Kenneth L. Kvamme

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Editors Alexis Davis and Jason Herrmann, exact opposites in many ways, meshed beautifully in their criticism and encouragement of my sometimes "loose" writing style. While Jason toned it down and added professionalism, Alexis pushed the envelope and tried to make geophysics sound interesting to the everyman. Thank You.

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INTRODUCTION

Archaeologists and historians alike are desperately trying to curb the loss of important information as areas that were once the scene of military struggles that helped to shape our nation are destroyed by modern development. According to the Civil War Preservation Trust (2004), one acre of Civil War battlefield is lost to development every ten minutes and as much as twenty percent of all Civil War battlefield land has already been compromised in the United States. The Civil War Preservation Trust (CWPT) and the National Park Service's American Battlefield Protection Program (ABPP) are two non-profit organizations responsible for a large portion of formal battlefield investigations taking place in the United States. In some cases these agencies and others provide money for the acquisition of endangered battlefield land, and in certain circumstances they initiate and fund archaeological research for public interpretive development. Whether battlefield investigations are conducted by these types of organizations for public interpretation, or by private companies for section 106 compliance purposes, it is important that they use the most appropriate prospection methods available. This study will show which methods are the most efficient by comparing the performance of an array of instruments and field methods in detecting metallic battlefield artifacts that have been precisely mapped and buried in a controlled test site.

Archaeological surveys of battlefields have traditionally relied on the metal detector for the location of artifacts, mainly due to their low cost, ease of use, widespread availability and proven success in locating metallic artifacts buried close to the ground's surface. Connor and Scott (1998) outline the practical use of metal detectors in an archaeological context. They propose that metal detectors are most effectively implemented when survey is conducted systematically on a grid by experienced users. Metal detectors were most notably employed in an archaeological context by Scott and Fox (1987) to distinguish battlefield patterns at the Battle of Little Big Horn. Many archaeologists have followed suit. For example, metal detectors were employed on the Chickamauga Battlefield in Georgia (Cornelison 1995), the Newtonia Battlefield in Missouri (Cubbison et. al 1997), the Chalmette Battlefield, in Louisiana (Cornelison and Cooper 2002), and at the Lookout Mountain Battlefield in Chattanooga, Tennessee (Alexander and Heckman 2004a,b).

There is little doubt about the suitability and productiveness of conventional low-cost metal detectors for battlefield archaeology. Yet, a number of issues remain about metal detectors' capabilities and how they are employed in the field. Metal detector survey methods typically employ sweeps in parallel transects, separated by various distances (perhaps 3-10 m) depending on survey purpose and goals. Strict uniform coverage throughout a survey block is not easily maintained because metal detector operators tend to stray from their parallel transects disrupting the possibility of a constant spatial sampling. Large transect separations can also lead to missed artifacts, as can the density of individual sweep patterns, the speed of instrument passage, instrument coil size, ground cover, and the experience of the operator. Traditional metal detecting methodologies also require a multi-stage field survey design where a metal detecting team is employed to locate and flag potential artifact locations and a second team is then required to map and excavate their locations, adding to additional field time and costs (Connor and Scott 1998). Recent advances in GPS technology are greatly reducing the labor associated with mapping, however.

Investigating new and perhaps improved methods for locating and mapping artifacts associated with past conflicts is a worthwhile undertaking. This is especially true given ever-increasing losses of battlefield areas to development, including urban growth. Rapid, accurate, and reliable methods are necessary to map what lies in the ground to better understand actions that occurred in past battles and their material consequences.

While the metal detector has proven its effectiveness and worth on many battlefields, there are a host of other geophysical instruments that are extremely sensitive to buried metals whose capabilities warrant investigation. Many of these instruments generate data in the form of digital maps, and thus eliminate one of the time-consuming aspects of traditional metal detecting: recording and mapping each find by hand.

In recent years a number of geophysical technologies and instruments have come into being that hold potential for innovation in battlefield archaeology. These instruments are highly sensitive, and perhaps more sensitive, to buried metals than conventional metal detectors. Instruments included in this category are electromagnetic (EM) induction meters, initially designed for conventional soil conductivity survey or advanced metal locating (the conventional metal detector is a type of EM meter), magnetic gradiometers, and ground penetrating radars (GPR). These instruments' capabilities and potential for battlefield archaeology merit rigorous examination. Besides the possibility of *greater sensitivity*, which means detection of smaller and deeper metallic artifacts, they may offer other advantages.

Most geophysical instruments are passed over the ground in closely spaced transects, typically ranging from .125-1 m, therefore guaranteeing a *statistically uniform coverage* or sampling of a survey area. This may not be the case in some metal detector surveys with straying transects or variable sweep patterns. Furthermore, the use of an alternative metal detection unit, such as an advanced soil conductivity meter or magnetic gradiometer would *increase sampling densities* along survey transects: as low as 6 cm for magnetometers and 12.5 cm for electromagnetic meters such as the EM-38, an instrument used in this study. Finally, most of these geophysical technologies possess integrated data loggers that record the data in such a way that the *information can be downloaded in map form*, eliminating the need for a secondary mapping stage (grids to guide instrument passage are normally established prior to geophysical surveys, see Kvamme 2001).

INSTRUMENTATION

Magnetometers are most commonly employed in archaeology to locate buried earth features. Magnetometers successfully detect two types of magnetism: induced and remnant magnetism. When substances containing the iron compounds magnetite, maghemite, or hematite are introduced to a magnetic field they become temporarily magnetized and their magnetism is said to be "induced." When these same compounds are heated above the Curie point their ferromagnetic particles become aligned with the Earth's magnetic field, creating a permanent magnetic state (Bevan 1998; Clark 1990). It is easy to see why ferrous battlefield debris such as iron and steel would be easily detected using a magnetometer. It is essentially prospecting in a field of "tiny magnets."

An FM-256 fluxgate gradiometer was employed in this study rather than a traditional "total-field" magnetometer. The FM-256 gradiometer is a *type* of magnetometer that employs *two* sensors which are vertically oriented with a 50 cm separation. The top sensor measures primarily the Earth's magnetic field while the sensor that is closest to the ground also measures the Earth's magnetic field, but being closer, is more sensitive to magnetic soil deposits. The readings of the two sensors are simultaneously differenced in order to isolate the magnetism of the soil deposits below and cancel out temporal variations in the earth's field. With this "differencing" a certain amount of sub-surface feature expression is lost, but usually not enough to make a remarkable difference in anomaly detection. Larger magnetic objects are easier to detect as well as targets that are closer to the instrument's sensor. The time investment needed to do a gradiometer survey is greater than that of the traditional metal detector, but the coverage is statistically uniform. One person can comfortably survey approximately .59 acres or 2400 square meters in a single day using a .5 meter transect separation (these figures do not account for time invested in data processing).

Electromagnetic induction meters are also commonly used in archaeo-geophysics, but primarily to measure soil conductivity (how well soils conduct electricity), or for detecting large buried earth features (Bevan 1983). Transmitted radio energy induces eddy currents in the soil that are picked up by a receiver inside the instrument (and are proportional to soil conductivity). Conductivity is measured in units called siemens, or more commonly in archaeology, as millisiemens per meter (mS/m).

The Geonics Ltd. EM-38b, which is showcased in this study, is capable of surveying approximately .59 acres in a single day when using a .5 m transect separation, the same amount as can be covered by the FM-256 gradiometer. This instrument is also sensitive to highly conductive metals of any kind. The EM-38b is most popularly employed in archaeology, with sensing capabilities to a depth of 1.5 m with peak sensitivity at 0.4 m in the vertical dipole mode. It is also possible to place the instrument in a horizontal dipole mode, as was done in this project, where sensitivity peaks at the surface and decreases to the instrument's limit at about 0.75 m below instrument coils.

The EM-38b also has the capability of measuring an entirely separate geophysical property: magnetic susceptibility. As the instrument is passed over the ground measuring conductivity, it can simultaneously measure magnetic susceptibility. Magnetic susceptibility is essentially the potential for an object to become magnetized in the presence of a localized magnetic field. Like the magnetometer and gradiometer, this component of the EM-38b can only detect ferrous metals. Its capabilities were not examined in this study.

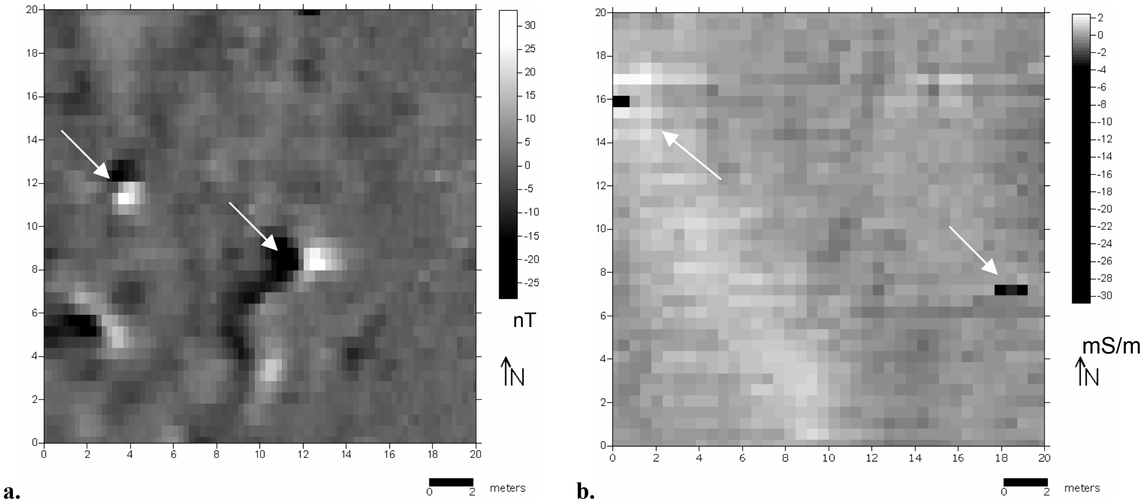
Metal detectors are technically EM induction devices, but are relatively simpler low-cost units for rapid field detection of metallic artifacts. Their performance is excellent and currently forms the backbone of battlefield archaeology. Metal detectors are inexpensive compared to the other geophysical instruments, and the technology behind them is quite straightforward. At their simplest, metal detectors measure how well an object conducts electricity. Most metal detectors consist of a search coil, handle, cable, a battery and a tuning apparatus that are contained in a metal box adjacent to the handle of the machine (Connor and Scott 1998). Many of the higher end models have a discrimination function that allows the operator to differentiate between different types of metal before excavating, although this feature's accuracy is questionable. The discrimination feature isn't essential to most traditional battlefield surveys because all objects detected are usually excavated regardless of their predicted metallic makeup**.** By implementing metal detectors and common archaeological field practices for metal detecting, an examination of detection probabilities and requisite sampling intervals is presented here.

Several studies have employed geophysical detection instruments besides conventional metal detectors on battlefield sites, although not specifically for detection of metallic artifacts. In 1999, a successful attempt was made at Tennessee's Shiloh National Military Park to integrate the use of GPR with metal detecting procedures; the metal detectors were used to locate individual Civil War era artifacts while GPR revealed the locations of past excavations as well as unknown graves (Anderson et al. 1999). Similarly, Kvamme (2003) conducted a GPR survey of the Bunker Hill National Monument in Massachusetts, but focused on evidence suggesting fortifications rather than the likely metallic anomalies that appeared in the data. More recently, Herrmann (2004) employed magnetic gradiometry, electrical resistance, and electromagnetic induction to investigate the former locations of historic buildings associated with Leetown hamlet on the Pea Ridge National Battlefield in Benton County, Arkansas. In short, archeological remote sensing *is* occasionally being conducted on battlefields, but overwhelmingly to prospect larger buried soil features - not individual artifacts.

Many Civil War period artifacts are composed of iron, including artillery projectiles and personal accoutrements. One of the few published studies that attempted mapping individual artifacts on a battlefield site using an instrument other than a conventional metal detector was conducted by Bruce Bevan (1998:27), who located and mapped numerous iron artifacts using a magnetometer at historic Fort Morton, on Virginia's Petersburg National Battlefield.

Bevan also performed conductivity tests on iron objects using EM meters. The electromagnetic induction meters employed in his conductivity study are the EM-38 and the EM-31, by Geonics Ltd., of Canada. Both the EM-38 and the EM-31 contain two hidden coils; one transmits while the other receives. The coils are spaced approximately 1 m apart in the EM-38 and nearly 4 m apart in the EM-31, where wider coil separation allows deeper prospecting, but less resolution or sensitivity to small objects. He tested the electromagnetic signatures of several metal objects using both the EM-31 and the EM-38. He found that a large iron artillery shell produced a strong negative response when passed under the coils of the EM-38, while smaller iron fragments produced only weak positive lows. He also notes that while both instruments are capable of detecting large metal objects, only the EM-38 can detect small metal objects.

Kvamme (2002) similarly mapped numerous iron artifacts at Pea Ridge National Military Park and at the Prairie Grove Battlefield State Park using magnetometry and electrical conductivity (Figures 1a and 1b). Both are Civil War battlefields in northwestern Arkansas where artillery was heavily employed. Note the strong dipolar anomalies present in the datasets below. A dipolar anomaly is a classic characteristic of buried metal and results when an object returns a strong positive magnetic signal adjacent to a strong negative signature. It is assumed that these stark anomalies represent buried metal objects or concentrations of metal, quite possibly artillery shell fragments deposited during the battle.



Figures 1 a. Magnetometry and **b.** Electrical Conductivity Data Sets from Pea Ridge National Military Park, (Kvamme, 2002).

CONTROLLED FIELD TEST

Given the relative dearth of scientific studies pertaining to the use of alternate prospection methods on America's battlefields, and the increasing necessity of efficient field methods for battlefield archaeology in the face of sweeping development, a study of available tools is essential. This report evaluates the advantages and disadvantages of using alternate remote sensing equipment to locate metal artifacts in a battlefield situation by presenting the results of several field tests.

An initial field test used the Geonics EM 38b meter to map the electromagnetic fields of two common metal battlefield artifacts in a controlled setting, without interference from ground effects. This above-ground electromagnetic experiment was conducted in an electromagnetically "quiet" area where the instrument was situated 1.5 m above the ground (beyond its sensitivity range) on a specially built, non-conductive frame. The objective of this procedure was to determine the maximum detection distance of metallic objects without considering the confounding effects of variable soil properties. Findings would also bear on the geophysical signatures expressed by similar objects when encountered during routine EM 38 survey in real field contexts.

I chose one iron object and one lead object to test in the above-ground electromagnetic field experiment. The first object was a Civil War period iron cannonball fragment that weighed 78 grams and had a volume of 11.14 cm^3 (Figure 2). The second object chosen was a .58 caliber lead minie bullet, also of Civil War period origin (Figure 2). The minie bullet was substantially smaller than the cannonball fragment, weighing only 26.7 grams and measuring 2.35 cm^3.

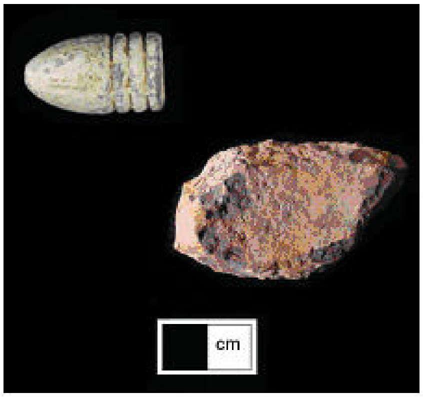
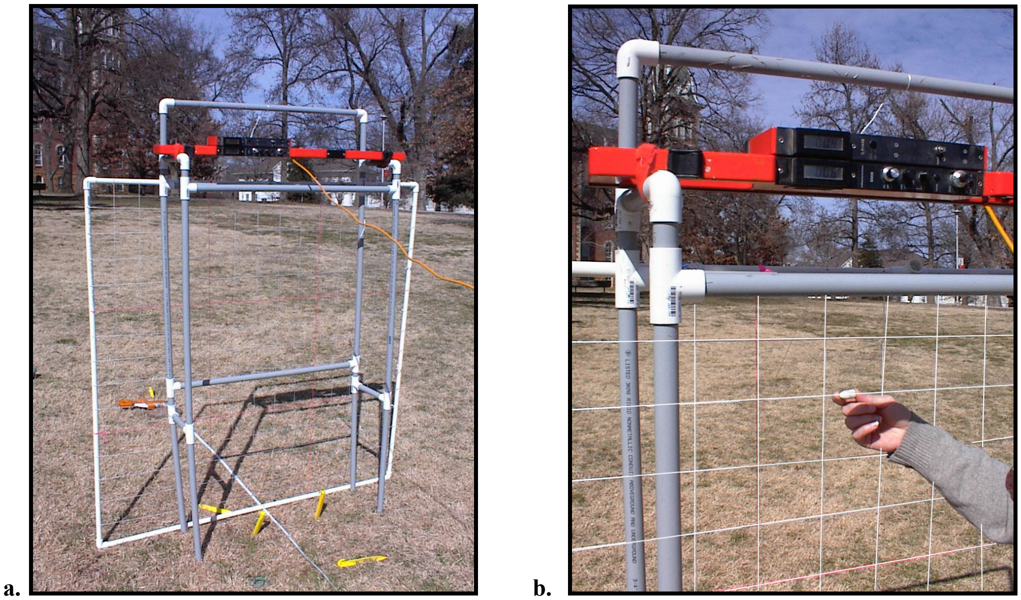


Figure 2. Minie Bullet and Cannonball Fragment.

The EM-38b can be operated in both horizontal and vertical dipole modes with different results. Horizontal dipole mode, with the instrument turned on its “side,” is appropriate for detecting features up to 75 cm below the instrument coils, whereas the vertical dipole mode can detect features as deep as 1.5 m with some loss of sensitivity, depending on the size of the target. In both phases of this project, the horizontal dipole mode was selected because it is more sensitive at shallow depths (where most Civil War battlefield prospecting would occur).

The objective of this experiment was to develop a three-dimensional map representing one quarter of the electromagnetic field that is created when the artifact reacts to an induced current. A special grid of strings placed 10 cm apart was constructed that acted as a guide for measuring sample locations in the cube or volume surrounding the artifact, and a series of profiles was generated as two researchers passed each metal artifact under the EM-38B, taking a conductivity reading every 10 cm in two directions (Figures 3a and 3b). Data collection was stopped when the machine no longer registered any change in the electromagnetic fields. The induced electromagnetic field was much larger for the iron cannonball fragment than the smaller lead minie bullet owing to the fact that iron is more conductive than lead and that artifact was much more massive.



Figures 3a and 3b. Controlled Experiment with the EM-38 in Horizontal Dipole Mode.

Iron Cannon Ball Fragment

The profile data from both the iron and the lead artifacts illustrate a “double peak” occurring in the upper portions of their respective electromagnetic fields – just under the transmitting and receiving coils (Figure 4).

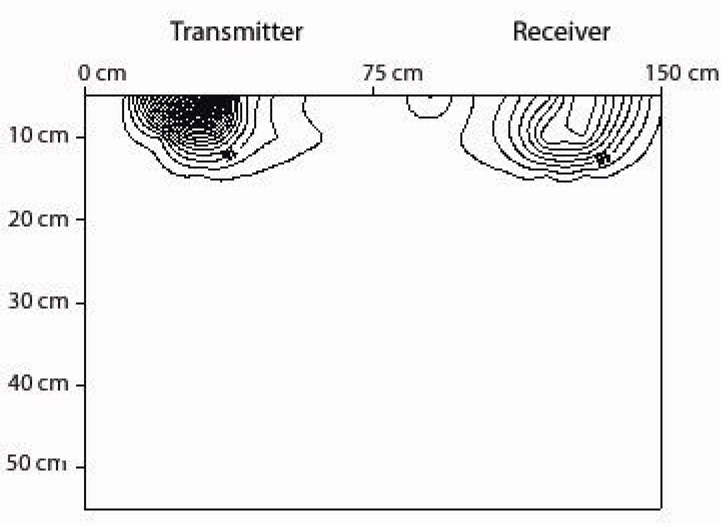


Figure 4. Electromagnetic Field of Iron Cannonball Fragment, Bisected.

Notice the reversal in the peaks from positive to negative in the first two panels of Figure 5. The first profile was generated directly underneath the EM-38B coils and exhibited a maximum high reading of + 130 mS/m and a minimum low reading of -5 mS/m. The second profile, which was offset 10 cm from the center of the coils, illustrated a drastic change in readings with a maximum reading of + 6 and a minimum low of – 44. We get our highest *and* lowest readings within 10 cm of the EM-38b coils. This pattern illustrates the well-known dipolar result produced by EM instruments in the vicinity of highly conductive metallic objects (Bevan 1998). Twenty centimeters from the instrument's centerline extreme negatives are still evident with very low maximum readings. The electromagnetic field for this iron cannonball fragment is still discernable at 30, 40, and 50 cm away from the EM-38B centerline – although it gets progressively weaker. This poses an important implication for practice. The instrument does not have to pass directly over a buried object in order to detect it, but the closer to the object that the machine passes, the easier it will be to detect and interpret it as a significant geophysical anomaly.

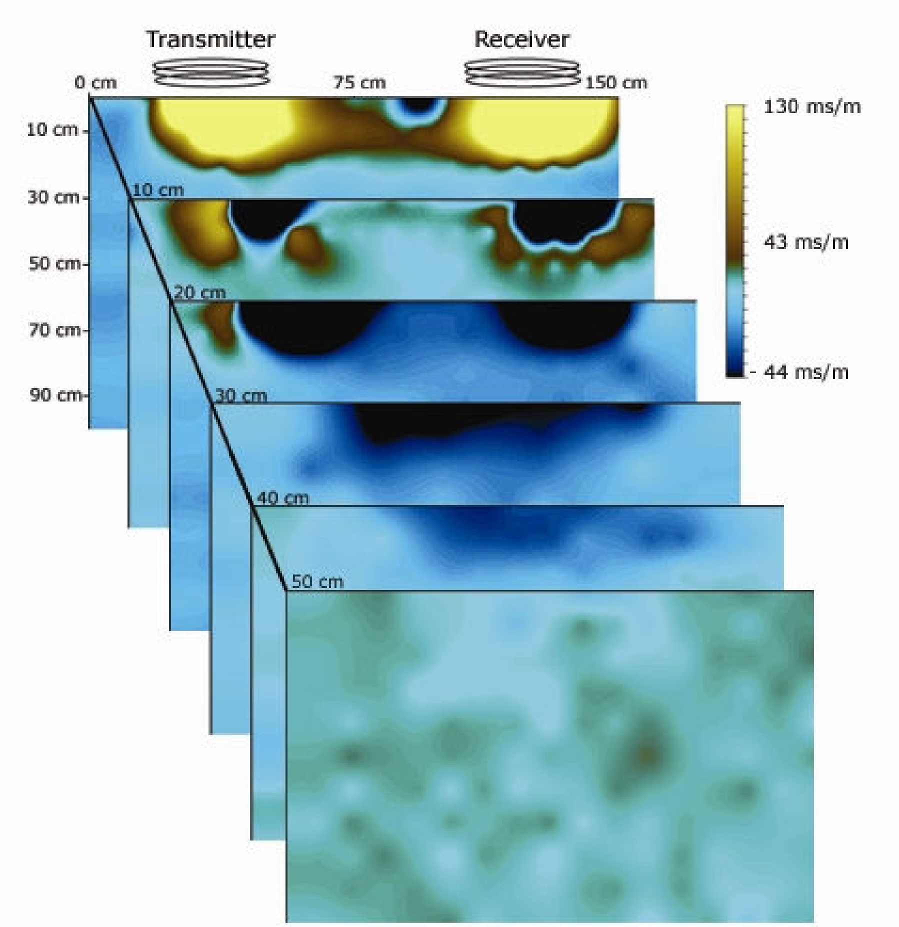


Figure 5. These panels illustrate the electromagnetic field generated by the iron cannonball fragment as it is moved in 10 centimeter increments going away from the center of the EM-38 coils.

As for the lateral results, along the length of the machine, where the two subsequent data "peaks" are so evident, it appears that the conductivity readings of the object are the most extreme directly under the transmitter and the receiver - showing little effect near the center of the machine. This strangely shaped electromagnetic field accounts for long linear anomalies that are evident in the battlefield test site plan view discussed later in this paper.

With the instrument on the ground, these depth results suggest that the iron fragment could be detected up to approximately 20 cm below the ground surface, but this result occurs with the artifact in non-conductive air. When placed in more conductive soil, it will be more difficult to discriminate its conductivity from that of the surrounding soil. Successful anomaly identification would fall off with increasing depth, just as detectable depth would increase with target artifact size.

Lead Minie Ball

The electromagnetic field generated by the lead minie bullet is very similar to that of the iron object – only weaker. It demonstrates the same “double peaking” under the transmitter and receiver but falls off at a quicker rate as the lead object moves away from the centerline of the EM-38b (Figure 6). With the lead minie ball, notice the same reversal from high positive to low negative within the first 10 cm of the centerline, as was evident in the preceding iron profiles. The electromagnetic field remains discernable up to at least 20 cm from the centerline and virtually disappears by 30 cm away from the centerline. The low strength of this result is due to the substantially smaller mass of the minie ball and the fact that lead is less conductive than iron.

Hypothetically, the electromagnetic field of the minie bullet is detectable up to a depth of 15 cm below the ground’s surface. However, during routine survey, it seems unlikely that this small lead object would be evident unless it was very shallow and was passed directly over, especially considering that soils are much more conductive than air.

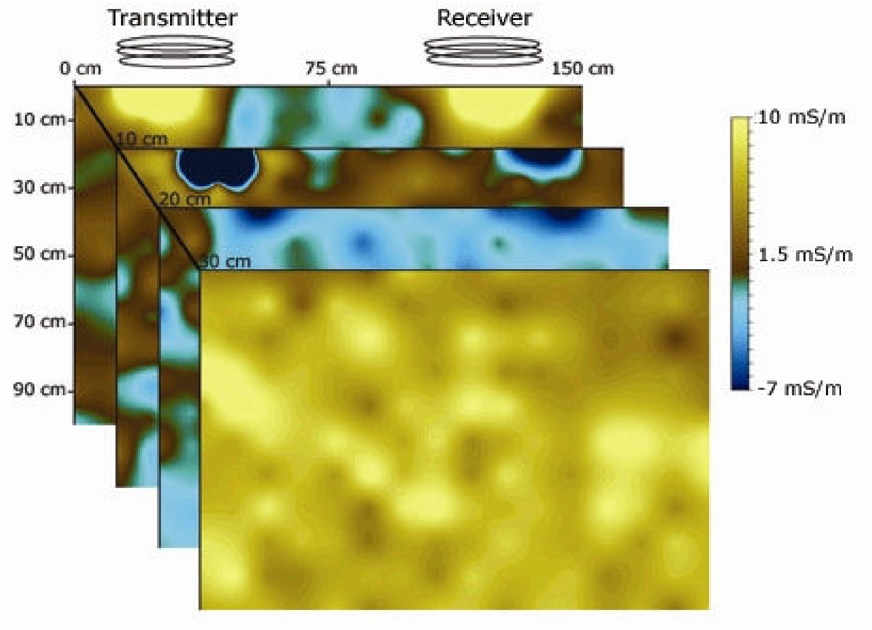


Figure 6. These panels illustrate the electromagnetic field generated by the lead minie bullet as it is moved in 10 centimeter increments going away from the center of the EM-38 coils.

There are many factors acting upon the EM-38b's ability to detect metal objects. These controlled electromagnetic experiments suggest that large, more massive objects are easier to detect, that iron is more conductive than lead, and that detection rates fall off with target depth (Table 1). These conclusions are supported by the battlefield test site data that show a bias towards larger iron objects. The element of size within material grouping was not accounted for in these experiments but will be discussed at greater length in the following sections.

Table 1. A Comparison between the Electromagnetic Fields of the Lead Minie Ball and the Iron Cannonball Fragment.

Variables	**Iron**	**Lead**
Cm^3	11.14	2.35
Maximum mS/m	130	10
Minimum mS/m	-44	-7.6
Max Depth Detectable	20 cmbs	15cmbs
Max diameter of entire field	100 cm	50 cm

This experiment shed some light onto realistic detection expectations for small objects like the lead minie bullet. The recovery rate for objects of that size and composition will no doubt be low during routine EM-38 survey situations. It was reassuring, however, that if moderate to large iron artifacts are encountered in an EM survey, they should be easily recognized given the unique "double peaked" signature (Bevan 1998). This "double peak" signature leads to the most informative finding resulting from this experiment — the fact that the EM-38 registers strong values at *both* the receiving and transmitting ends. During routine survey, any given metal object is measured at least twice with an approximately 75cm separation between its strongest peaks. When the tails of the object's electromagnetic fields are factored in, strong linear anomalies become apparent.

TEST SITE CONSTRUCTION

A battlefield archaeology "test site" was created to provide a facility where geophysical instruments and methods for the identification and mapping of metallic objects can be tested. The test plot, measuring 10 x 10 m (100 m^2), is located on the University of Arkansas experimental "farm," in Fayetteville, Arkansas, not far from the main campus. The test site was first screened for extant metallic artifacts using metal detectors, and all detectable metal was then removed. After "cleaning" the site of debris that could interfere with future experiments, the area was surveyed with an EM-38b electromagnetic induction meter, the FM-256 magnetic gradiometer, the RM 15 resistance meter, and a standard metal detector, to map the background geophysical signature of this plot of land. These methods indicated that all but the most insignificant fragments of metal had been successfully removed.

Following the metal clearing phase, 88 historic and modern metal artifacts of various types, many from the American Civil War period (bullets, casings, buckles, nails, and hardware) representing a variety of metals (iron, lead, brass, steel, copper, pewter, and aluminum), were selected for burial in the test site. Objects of like material types were grouped together within the test grid to more easily see how they would be detected as a group. A separate portion of the grid was also reserved for a mixture of all material types to see how the deposition of various metals in close proximity to each other would affect detection probabilities. Each artifact was given randomly-generated x-axis and y-axis coordinates within its respective plot (Figure 7). These positions were then accurately located by transit survey and tape measures. The spatial coordinates were employed to create an accurate map database of the locations of each of the artifacts.

All artifacts were uniformly buried to a depth of 10 cm. For small artifacts this was accomplished by using a dowel rod and hammer to “punch” them into the ground; a small excavation was required to bury larger artifacts. Since depth of find is rarely, if ever, documented during traditional metal detector surveys, this study relied on the personal experience of other battlefield archeologists in the field to make an educated approximation of a standard depth below surface. Ten centimeters was chosen to mimic an approximate average depth for metal artifacts on most Civil War period battlefields (Personal Communication: John Cornelison, Lawrence Alexander, Charlie Harris).

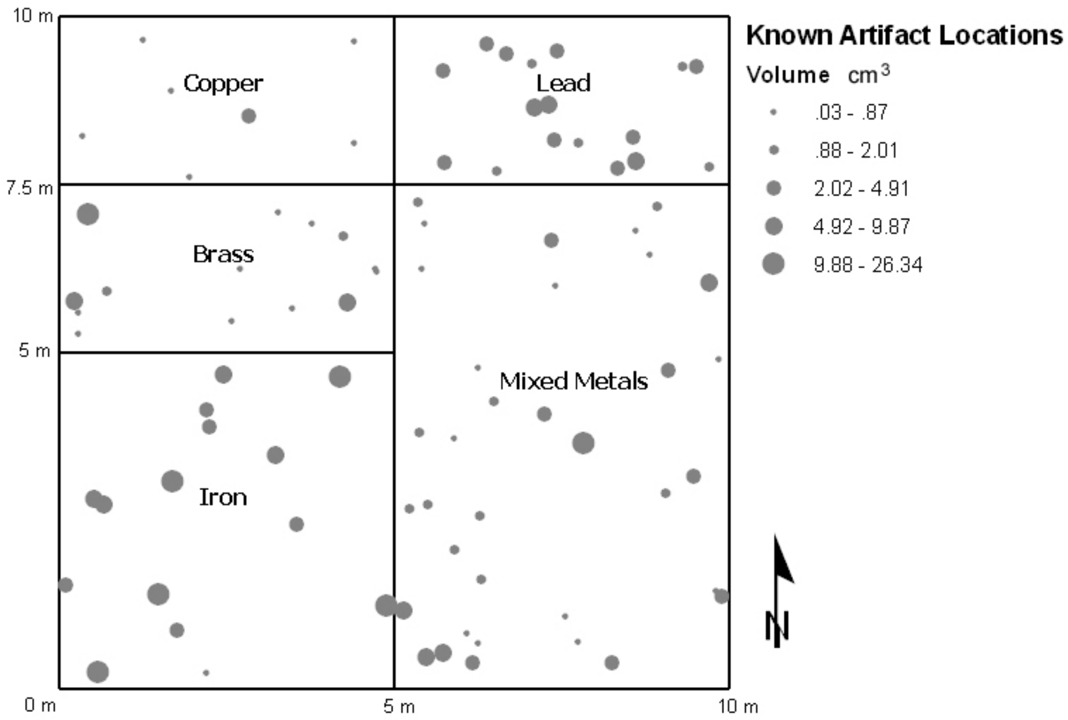


Figure 7. Metal Placement within the Test Site.

GEOPHYSICAL SURVEYS

Following the completion of test site construction, including the interment of the sample artifacts, a series of geophysical surveys was conducted over the test plot with conventional metal detectors, the EM-38b, and the FM-256 gradiometer. Survey method varied for the EM-38b to examine different sampling densities (measurements/m^2). Results of these surveys will be discussed in detail in the following sections.

Analysis

The data from the EM-38b and the FM-256 were processed using the zero mean traverse algorithm which subtracts the mean of each transect from the values of the individual measurements, leaving only the variation and thus standardizing anomalous values. The images were then geographically registered to the survey grid by GIS methods, allowing correlation of instrument results with the base map of actual artifact locations. The data from each instrument and field method combination were analyzed to calculate detection rates for the known sizes and material types of the artifacts. These data have been synthesized to rank the various instruments and methods according to their suitability for detecting and mapping battlefield artifacts. Based on the findings, a series of recommendations and field protocols are developed.

Variation attributed to artifact depth was neutralized by burying all of the objects at a standard 10 cm depth. Each material type was tracked and treated separately. Variation due to size differences in artifacts proved important to detection rates and will be specifically addressed. Size was initially broken down according to measurements of mass, density, and longest side, but mass *and* density were later combined in a measure of volume in cubic centimeters (cm^3). The variables of mass versus longest side were then charted and compared to establish which dimension was a more significant determinant of successful detection.

The following scatter-plot graphs, based only on objects from the “iron” category, indicate that “volume” is a more significant factor than “length” in all three surveys: metal detector, EM-38b, and the FM-256 (Figures 8, 9, and 10). The scatter-plots show that iron objects larger than 10 cm^3 in volume are detected one hundred percent of the time, while the positive detection rate based on length shows much less predictability. This data set shows that the number of longer artifacts that *were* consistently detected shared the characteristic of greater volume, but that length, itself, is a less useful predictor. For the sake of simplicity, this study used only artifact volume (cm^3) in all of the comparative tests involving size.

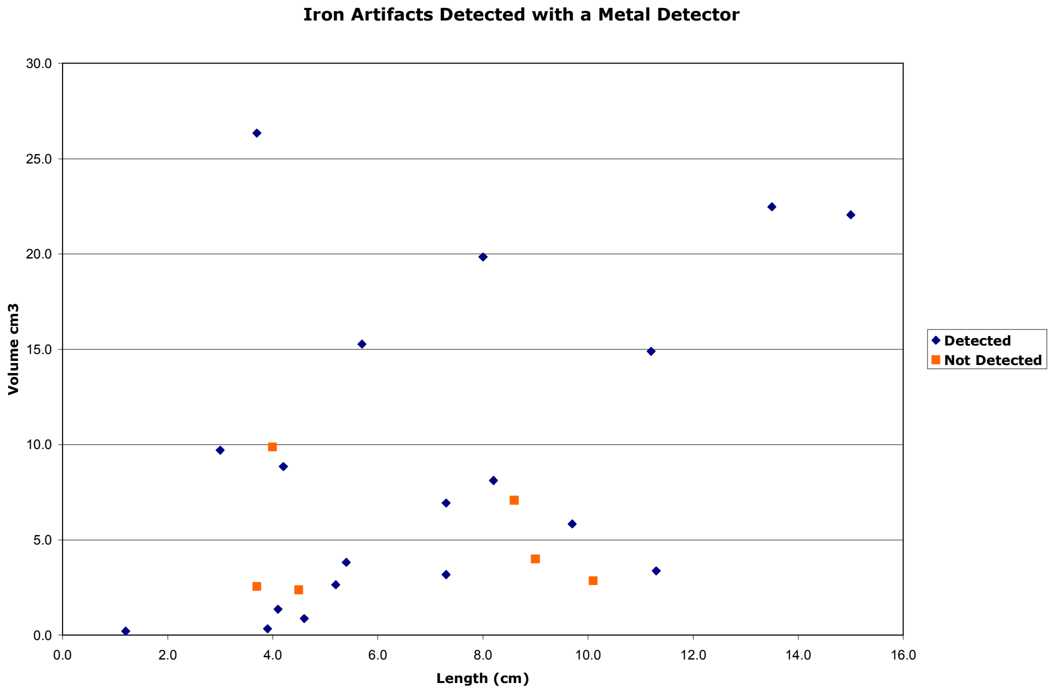


Figure 8. Scatter Plot Comparing the Variables of Volume and Length as Detected by the Metal Detector.

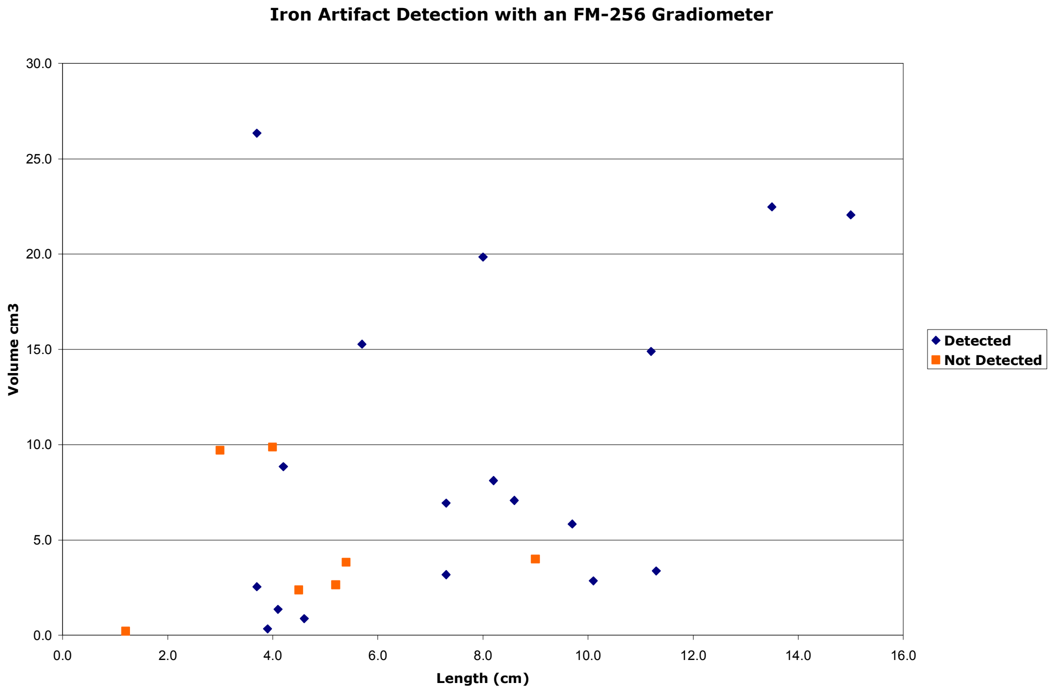


Figure 9. Scatter Plot Comparing the Variables of Volume and Length as Detected by the FM-256 Gradiometer.

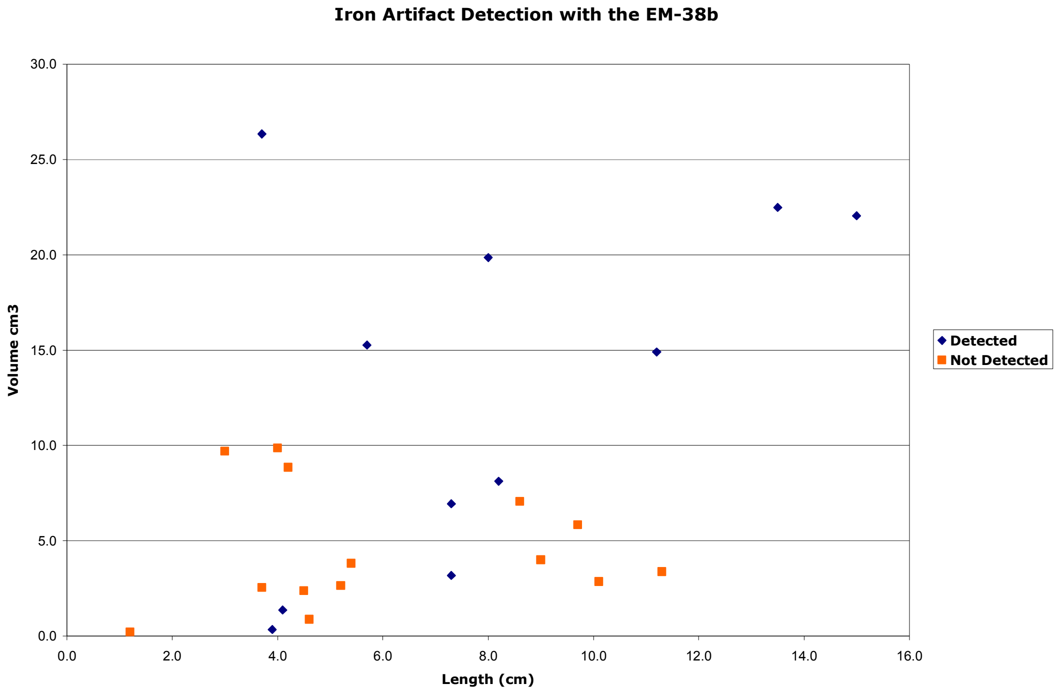


Figure 10. Scatter Plot Comparing the Variables of Volume and Length as Detected by the EM-38b.

Each buried object was placed into a size class based on its volume using the Jenks "Natural Breaks" Classification system. Jenks Classification utilizes a statistical formula to reveal patterns in a data set by minimizing the variance within each class; thereby grouping data into "natural clusters" (Kennedy, 2001). The size classes for this study are as follows: Class 1 (.03 - .87 cm^3), Class 2 (.88 - 2.01 cm^3), Class 3 (2.02 - 4.91 cm^3), Class 4 (4.92 - 9.87 cm^3), and Class 5 (9.88 - 26.34 cm^3). From here on, the object sizes will be referred to by their "Volume Class".

Magnetometer Survey

A high sampling density of 64 measurements per square meter, or 8 readings per meter on both x- and y- axes, (12.5 cm transect separation) was employed on the test site in order to obtain "saturation" coverage by the FM-256 gradiometer (Figure 11). At this extremely tight transect interval, 20 of 88 objects were correctly located, a 23 percent success rate (Figure 11 and Table 2); it must be realized, however, that magnetometers are only sensitive to ferrous metals (iron and steel). Considering *only* ferrous metals, the success rate becomes 69 percent, or 20 of 29 ferrous objects successfully detected. The gradiometer success rates were also examined within the context of specific material type and object volume.

Eighteen of twenty five (72 percent) buried iron objects were recovered, whereas two of four (50 percent) steel objects were located, albeit with a small sample size (Table 2). The positive detection rates by volume for the FM-256 including only iron and steel objects are as follows: Class 1 (.03 - .87 cm^3), 50 percent; Class 2 (.88 - 2.01 cm^3), 100 percent; Class 3 (2.02 - 4.91 cm^3), 44 percent; Class 4 (4.92 - 9.87 cm^3), 86 percent; Class 5, (9.88 - 26.34 cm^3) 86 percent (Table 2). Probability of detection clearly increases as object size and sample size increases.

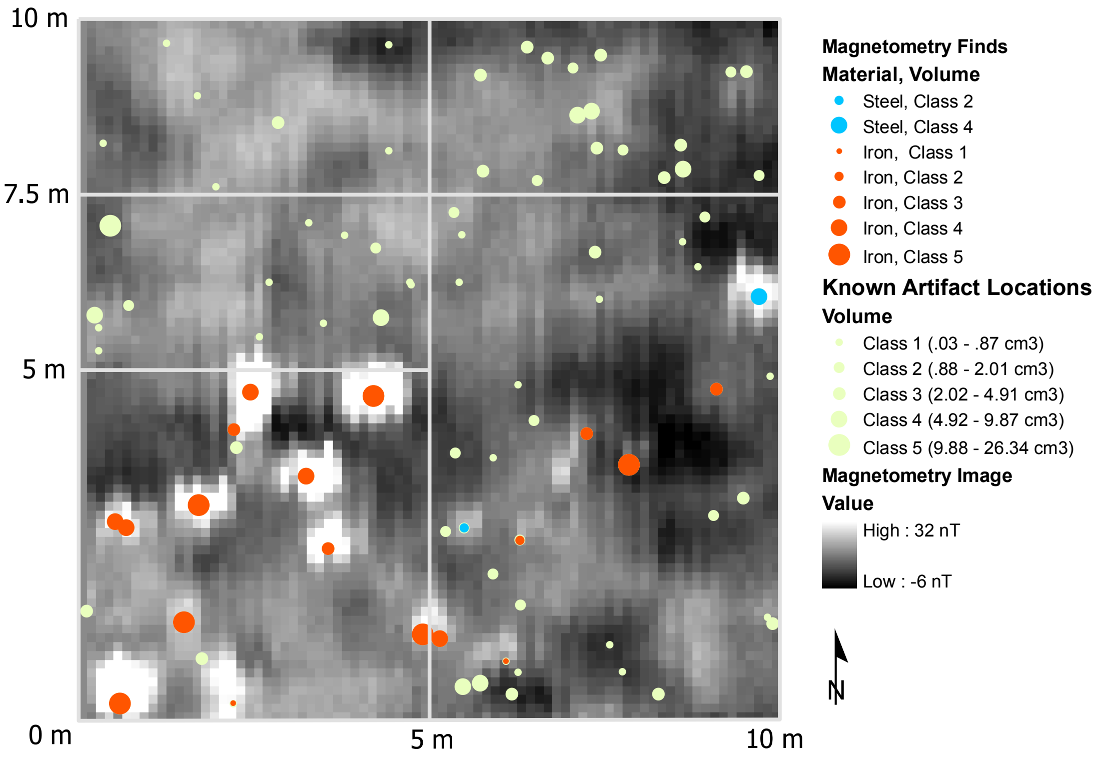


Figure 11. FM-256 Survey of Battlefield Test Site with Detected Objects Plotted.

Table 2. Artifact Detection Rates for the FM - 256

FM-256 Detection Rates for Objects of Different Material Types (12.5 cm sampling interval)			
Material Type	**# Objects Detected**	**Total Objects**	**Percentage Detected %**
Aluminum	0	1	**0%**
Brass	0	20	**0%**
Copper	0	11	**0%**
Iron	18	25	**72%**
Lead	0	25	**0%**
Pewter	0	1	**0%**
Steel	2	4	**50%**
Tin	0	1	**0%**
TOTAL	**20**	**88**	**23%**

FM-256 Detection Rates for Objects of Different Volume Classes (ferrous metal only)			
Volume Class	**# Objects Detected**	**Total Objects**	**Percentage Detected %**
Class 1 (.03 -.87 cm3)	2	4	**50%**
Class 2 (.88 - 2.01cm3)	2	2	**100%**
Class 3 (2.02 - 4.91 cm3)	4	9	**44%**
Class 4 (4.92 - 9.87 cm3)	6	7	**86%**
Class 5 (9.88 -26.34 cm3)	6	7	**86%**
TOTAL	**20**	**29**	**69%**

The capabilities of the FM-256 gradiometer lend themselves to battlefield prospection only when shallowly buried, moderate to large iron or ferrous metals are the target of research *or* for the detection and imaging of subsurface soil disturbances such as trenches, graves, and earthworks, which is not addressed at length in this study. Over a broad battlefield landscape magnetic signatures of exploded artillery shells and concentrations of incidental iron would easily be revealed. This includes concentrations of iron nails and personal accoutrements which are often found in and around Civil War Period encampments (Geier, C.R., Jr. and Winter, 1994). The FM-256 and other magnetometers are incapable of locating non-ferrous metals, so would not be a viable method to use when prospecting for other common battle field metals such as brass, lead, and copper.

Electromagnetic Induction Survey

The EM-38b is capable of detecting any metal as long as the target is large enough for the instrument to “see.” The larger pieces of metal successfully detected reveal themselves as linear “double peaked” anomalies (Figure 12), as was evident in the above ground controlled experiment. The double peaks result when both the transmitting and the receiving coils of the EM-38b pass over a single metal object and, in essence, register each metal object twice. To the untrained eye, these anomalies would suggest the sub-surface presence of long, linear features rather than the diminutive objects that they actually are. It should be noted that pewter, aluminum, and tin all suffered from insignificant sample sizes of one artifact each, therefore meaningful statements about their detectability can only be made in cases of positive detection. The aluminum and pewter objects were not detected by any of the instruments used in this study.

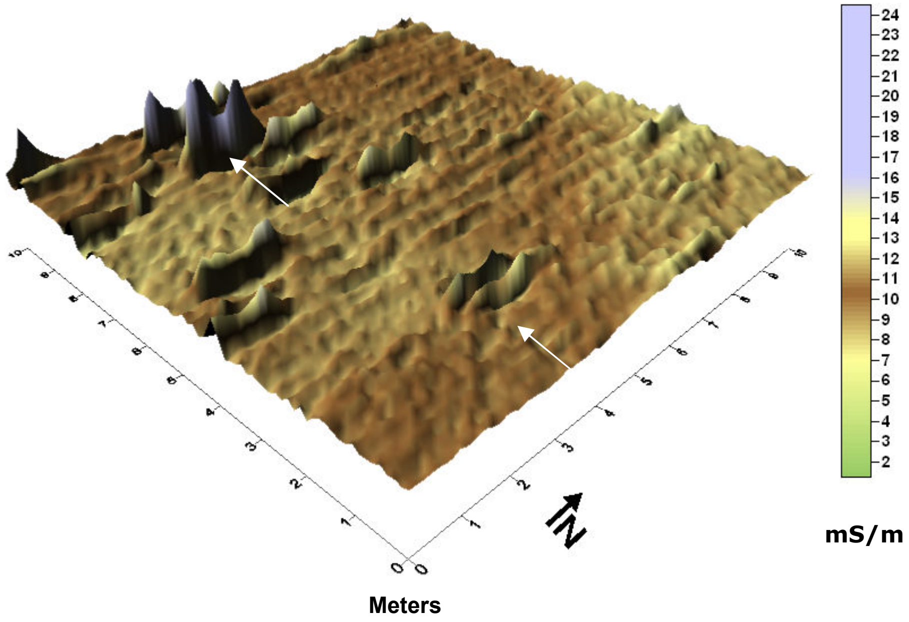


Figure 12. Surface Map of the Electrical Conductivity Survey on the Battlefield Test Site Illustrating "Double Peaked" Geophysical Anomalies (arrows).

At its tightest sampling interval of 12.5 cm (64 readings per m^2) – which is close to maximum coverage for this instrument, the EM-38b successfully detected only 23 percent of the buried metal objects (Table 3 and Figure 13). Twenty seven percent (3 of 11) of all copper artifacts were detected, 44 percent (11 of 25) of iron, 8 percent (2 of 25) of lead, 75 percent (3 of 4) of steel, and the single tin object that was buried was also successfully located. As with the FM-256, size, again, seems to play a significant role in whether or not an object is detected by the EM-38b. The success rate approaches 86 percent for objects larger than approximately 10 cm^3 (Class 5), but declines severely as object size decreases. The positive detection rates by size classification for the smaller objects break down as follows: Class 4 (4.92 - 9.87 cm^3), 31 percent; Class 3 (2.02 - 4.91 cm^3), 18 percent; Class 2 (.88 - 2.01 cm^3), 18 percent; Class 1 (.03 - .87 cm^3), 10 percent.

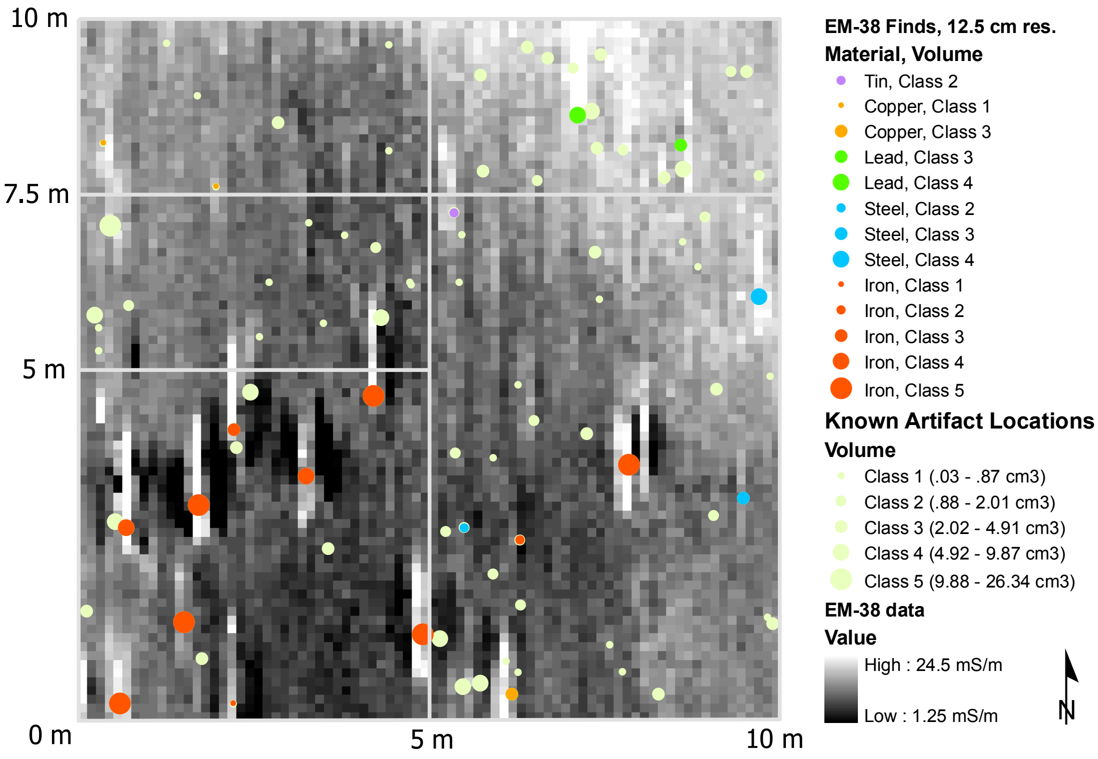


Figure 13. EM-38b Survey of Battlefield Test Site with Detected Objects Plotted.

Table 3. Artifact Detection Rates for the EM-38b.

EM-38b Detection Rates for Objects of Different Material Types (12.5cm sampling interval)			
Material Type	**# Objects Detected**	**Total Objects**	**Percentage Detected %**
Aluminum	0	1	**0%**
Brass	0	20	**0%**
Copper	3	11	**27%**
Iron	11	25	**44%**
Lead	2	25	**8%**
Pewter	0	1	**0%**
Steel	3	4	**75%**
Tin	1	1	**100%**
TOTAL	**20**	**88**	**23%**

EM-38b Detection Rates for Objects of Different Volume Classes (12.5cm sampling interval)			
Volume Class	**# Objects Detected**	**Total Objects**	**Percentage Detected %**
Class 1 (.03 -.87 cm3)	3	29	**10%**
Class 2 (.88 - 2.01cm3)	3	17	**18%**
Class 3 (2.02 - 4.91 cm3)	4	22	**18%**
Class 4 (4.92 - 9.87 cm3)	4	13	**31%**
Class 5 (9.88 -26.34 cm3)	6	7	**86%**
TOTAL	**20**	**88**	**23%**

The data set was manually thinned in the laboratory to 25 cm, 50 cm and 100 cm transect intervals to see how less coverage would affect recovery rate. For all of these sampling rates a constant 12.5 cm sampling interval along the y- axis (or 8 samples per meter) was preserved. The success rate generally declined as the number of transects per meter declined. The results are as follow. The 25 cm transect separation successfully located 22 of 88 artifacts or 25 percent. A 50 cm transect separation yielded 14 of 88 artifacts; 16 percent. And at a 100 cm transect separation a total of 10 out of 88 objects were successfully identified for a total of 11 percent. Essentially, the maximum recovery rate for metallic battlefield objects for this study using the EM-38b approaches 25 percent for artifacts of all size grades. There is no significant difference in recovery rates between 12.5 cm and 25 cm transect separations, making the 25 cm transect separation the clear choice for reasons of speed and time between the two for field survey. These numbers suggest that using a transect interval as high as 50 and 100 cm for the purposes of locating metallic artifacts would not be worth the meager return; and the time investment needed for tighter sampling is not justified by the low recovery rate unless specifically looking for concentrations of large metal pieces in a localize area.

Although not employed in this study, the magnetic susceptibility component of the EM-38b may shed light on anomaly makeup in real world applications. With its ability to detect only ferrous metals, it would be possible to compare magnetic susceptibility results with conductivity datasets of the same area and see which anomalies were detected by both. If an object is detected by both components of the instrument then ferrous vs. non-ferrous anomalies could be predicted.

Although it performed poorly in locating small battle-related debris like lead minie bullets and brass percussion caps, the EM-38 could still be a viable tool in situations where heavy artillery was employed. “Ground burst” artillery patterns could certainly be detected over a battlefield and would aid interpretation of troop and firing positions. With its powerful mapping capabilities over large areas, the EM-38 may be a good candidate for battlefield surveys where the imaging of broad subsurface patterns is the goal, rather than interpretation through excavation of individual artifacts.

Metal Detector Survey

The metal detector survey of the battlefield test site was conducted by a local volunteer, Stephen Burgess, who has twenty one years of experience in metal detection and has done volunteer survey for the National Park Service under Dr. Doug Scott as well as for the Arkansas Archaeological Survey. Mr. Burgess' metal detector of choice for the experiment was the *White's 6000 Pro XL* model. To avoid biasing his detection to the small test site, he was instructed to locate and flag all metallic objects within a 30 m x 30 m survey area while operating at a standard 3 m transect interval (Figure14). The 10m x 10m battlefield test site was imbedded within this square without his prior knowledge of where it was. The grass covering the survey area was waist high during this experiment so he had to switch to a smaller than usual coil. After he felt confident that he had surveyed the entire block, his "location flags" were precisely mapped using a tape measure.

Comparisons were made between the map of known artifact locations and the map of positive metal detector hits to obtain the conventional metal detector success rate. Its performance was superior to all other instruments tested, with a 50 percent accuracy rate (Table 4). The hit rate would have likely increased if the grass was shorter and the metal detector operator was excavating artifacts as he went along. Often artifacts that are close in proximity to each other will seem like a single object until they are excavated and the immediate area is re-swept. Numerous metal objects are found this way during regular battlefield surveys.

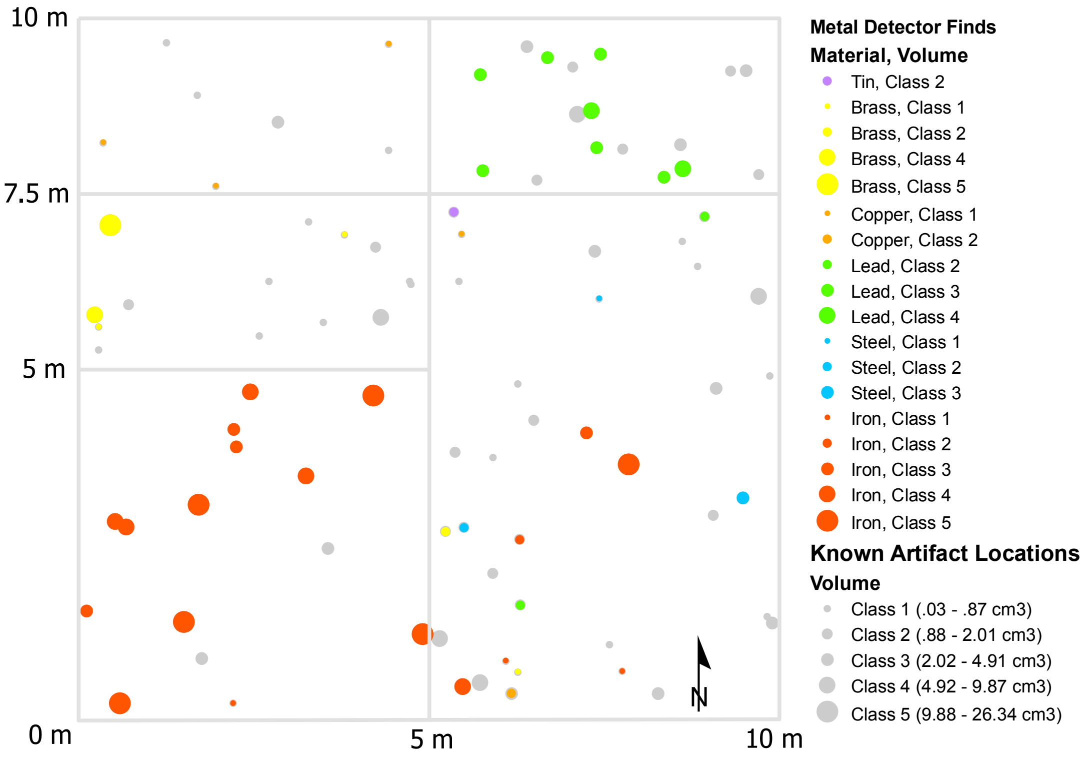


Figure 14. Metal Detector Survey of Battlefield Test Site with Detected Objects Plotted.

Table 4. Artifact Detection Rates for the Conventional Metal Detector.

Metal Detector Detection Rates for Objects of Different Material Types.			
Material Type	**# Objects Detected**	**Total Objects**	**Percentage Detected %**
Aluminum	0	1	**0%**
Brass	6	20	**30%**
Copper	5	11	**45%**
Iron	19	25	**76%**
Lead	10	25	**40%**
Pewter	0	1	**0%**
Steel	3	4	**75%**
Tin	1	1	**100%**
TOTAL	**44**	**88**	**50%**

Metal Detector Detection Rates for Objects of Different Volume Classes			
Volume Class	**# Objects Detected**	**Total Objects**	**Percentage Detected %**
Class 1 (.03 -.87 cm3)	11	29	**38%**
Class 2 (.88 - 2.01cm3)	6	17	**35%**
Class 3 (2.02 - 4.91 cm3)	12	22	**55%**
Class 4 (4.92 - 9.87 cm3)	8	13	**62%**
Class 5 (9.88 -26.34 cm3)	7	7	**100%**
TOTAL	**44**	**88**	**50%**

Given a large enough sample size for particular materials, the metal detector did not appear to have any true deficiency in locating specific *types* of metal. The metal detector successfully located 30 percent of the brass artifacts, 45 percent of copper, 76 percent of iron, 40 percent of lead, 75 percent of steel, and was successful in detecting the single tin object (Table 4). High rates of recovery were also observed for *all* volume classes when the metal detector was employed: Class 1, 38 percent; Class 2, 35 percent; Class 3, 55 percent; Class 4, 62 percent; Class 5, 100 percent (Table 4).

These results suggest that the traditional metal detector is still the best option for high yield metal artifact detection. It must also be stressed, however, that even within these tight survey parameters the metal detector's maximum artifact recovery was only 50%. Since this figure was obtained through controlled testing – it can be useful in stating maximum recovery probabilities for surveys where a metal detector is the primary means of prospection.

Unlike the magnetometer, the traditional metal detector can detect any type of metal, and it is also not limited by object size as much as the EM-38b. The metal detector can be implemented effectively in almost any realm of battlefield prospection ranging from combat sites to troop encampments. Unlike the alternative geophysical methods tested in this study, metal detectors can be employed on steep slopes and wooded areas. The most glaring drawback of the conventional metal detector is its inability to create visual maps of the geophysical properties as it detects, as the other instruments can. There are also legitimate concerns about uniformity of ground coverage and the real possibility of recovery biases.

CONCLUSIONS AND RECOMMENDATIONS

The EM-38b conductivity meter and the FM-256 magnetic gradiometer were designed to map near-surface patterns in the Earth's surface that might suggest former human activity manifested in disturbances to the ground. The targets throughout the majority of this project, commonly referred to as small metal “data spikes”, are what most archaeo-geophysicists “process out” of their data sets in order to make soil and deposit changes in the geophysical background more easily discernable. It is known that incidental metal appears in almost all ground-based remote sensing data sets, but is largely ignored on the basis that it is not the target anomaly. The potential for these sensitive instruments to reveal the identity of these data spikes, generally regarded as interference, warranted further examination. As valuable data, these data spikes would invert the traditional mindset by examining the exception, rather than the rule.

While it is clear that the EM-38b and FM-256 offer powerful mapping capabilities, the comparisons in this research demonstrate that these technologies cannot compete with the tried and true metal detector when it comes strictly to metallic artifact detection rates. Now we know, to some extent, the limits of these advanced technologies when metals *are* the target, as these instruments are not specifically designed for detecting metals.

While the metal detector had the highest accuracy rate, the widely accepted field technique in which it is implemented can certainly be improved upon. On the vast majority of battlefields where archaeology is being performed, the metal detector is employed to find metal artifacts which are then excavated. Why must they be excavated? The alternative methods examined here are generally non-invasive, meaning that the “finds” are not meant to be excavated – only mapped. I propose that the metal detector can be implemented in a similar manner as the two other instruments examined in this study.

Although, current metal detectors do not have the automatic mapping capabilities that the EM-38 and the FM-256 have, the metal finds can still be hand mapped and placed into a GIS without excavation. A tighter, more controlled sampling procedure can also be followed that will increase uniform survey coverage. With current trends towards non-invasive archaeology, EM technology is well on its way to producing highly sensitive metal detectors with advanced mapping capacities that will hopefully succeed in merging the positive aspects of each of these alternative technologies.

As this study shows, the artifact recovery rate for a traditional metal detector only approaches 50 percent, a rate higher than other instruments, but is it yet high enough to justify the systematic dismantlement of our Nation's battlefields? By extrapolating the recovery figures derived from this study, as much as half or more of metallic artifacts are left on the battlefield following a formal metal detector survey. This figure should be heartening for those who are concerned with saving cultural deposits for future generations. In many cases it would be a superior option to leave the artifacts in the ground, saving these sacred sites for future generations when technology has advanced past its current stage. For those interested in harvesting as many artifacts as possible from a battlefield, it may just make them look a little harder.

In the meantime, a compromise can be made. Most metal detectors utilized in these battlefield surveys have a discrimination feature that allows the metal detector operator to discern what type of metal they are probably sensing. With this capability, distribution maps of material types and concentrations can be made with some degree of certainty without destroying the integrity of the battlefield. If a non-invasive investigation is warranted, this could be a viable method to implement.

When artifact excavation *is* necessary, a tighter transect interval should be used and enforced. Since no major detection deficiencies were noted for particular materials or sizes it is assumed that most of what the metal detector operator failed to locate on the battlefield test site was due to uneven coverage of the area. This has potential for greatly increasing the artifact recovery rate for traditional metal detector surveys.

The EM-38 and the FM-256 would be perfectly suitable for use in situations where heavy artillery fire has occurred and the modern landscape is relatively flat and grassy. These instruments would be especially suited if conducted in landscape-wide surveys designed to uniformly image the geophysical signatures of large iron fragments on a battlefield. Considering recovery rates and time investment, the most practical sampling interval for this type of undertaking would be either 25cm or 50 cm transect separation, although it would still be time consuming.

After rigorously examining the capabilities of these three instruments, it is clear that they each have strengths and weaknesses when employed in a battlefield situation. Metal detectors successfully detect all metal types large and small but are unable to create geophysical images of the soil as they survey. The EM-38b will create subsurface image maps as it moves along a grid and can detect all metal types as long as they are large. In areas where heavy iron content is expected, and subsurface mapping is desired, the FM-256 would work well. The EM-38 and the FM-256 would be clear choices when prospecting for trenches, earthworks, graves, and various other buried battlefield features. It can be said with certainty that none of these methods is appropriate in every battlefield archaeology situation, but these tests will help the battlefield archaeologist better understand their available tool kit.

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