MAC/NCPTT Memorandum of Agreement; MAC/MSUM Cooperative Agreement HG115050086

IDENTIFICATION OF UNMARKED GRAVES

Applicant Institution:
Minnesota State University Moorhead (MSUM) under a Cooperative Agreement with the National Park Service, Midwest Archeological Center (MAC)

Co-Principal Investigators:

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December 20, 2007

ADMINISTRATIVE SUMMARY REPORT

1. Institution/Organization: Minnesota State University Moorhead (MSUM) under a Cooperative Agreement with the National Park Service, Midwest Archeological Center (MAC)

2. Project Title: Identification of Unmarked Graves

3. Grant Number: MAC/NCPTT Memorandum of Agreement; MAC/MSUM Cooperative Agreement HG115050086

4. An amendment to the original grant agreement was requested to extend the duration of the grant to December 31, 2007. No additional funds were requested. This request was approved on November 22, 2006.

5. Grant products include: 1) a final project report that presents the results of studies at three cemeteries directed toward advancing techniques for the location and identification of unmarked graves by integrating innovative down-hole geophysical techniques and soil magnetic studies with near-surface geophysical surveys; 2) color digital images of project activities; and 3) an approximately 400-word article appropriate for a general audience.

6. Differences between planned and actual work costs include greater than expected salaries due to increased student salaries, and a decrease in travel expenses. Salaries increased $2905 in funds for student labor. This was offset by savings in travel expenses, including travel to the Institute for Rock Magnetism (IRM) at the University of Minnesota and Clay's travel to the Terrill cemetery. Planned and actual work costs in all other budget categories were closely matched.

7. Final budget breakdown:

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PROPOSED AND ACTUAL BUDGET*				
Budget Item	***Proposed NCPTT***	***Proposed Match***	***Actual NCPTT***	***Actual Match***
Contracted Travel & Per Diem				
Dalan/Students travel	6803		4456	
Clay travel	947		87	
Supplies	100		403	
Contractual Fees				
Dalan, release	19950	0	19950	2122
Student Workers	2400		5305	

Clay		5009		5009
Total Budget	**30200**	5009	**30201**	7131

* Budget breakdown addresses only those costs listed on the MOA and does not include any salaries, payroll expenses, or travel costs incurred by De Vore of the MWAC.

8. Differences between planned and actual work costs in the various budget categories resulted from the need for increased student labor to organize, process, analyze, and present the greater than planned quantity of field data and laboratory samples that were generated. These costs were offset by lower than estimated travel costs. As capabilities at MSUM's Geophysics and Soil Magnetism Lab had increased since this project had been proposed, less travel to the IRM was required. In addition, we were able to accomplish some of the research at the IRM as part of an internship agreement.

9. This project has advanced techniques for identifying unmarked graves that combine new technology in down-hole geophysical capabilities with laboratory soil magnetic techniques. This cost-effective, efficient, and relatively non-invasive approach has the potential to improve results gained through near-surface geophysical surveys alone.

10. A publication will be developed for submission to a professional journal. Upon publication, copies will be forwarded to the NCPTT.

Signed: Date:

Rinita A. Dalan, Ph.D.
Professor, Department of Anthropology and Earth Science
Minnesota State University Moorhead

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EXECUTIVE SUMMARY

Near-surface geophysical techniques, including ground-penetrating radar, magnetometry, electrical resistivity, and electromagnetic conductivity, have become primary tools in the detection of unmarked human interments. The main advantages of these techniques are that, unlike archaeological excavation, they are relatively rapid and do not involve grave disturbance. Disadvantages are that most surveys do not offer foolproof detection of all or even most graves, and the absolute identification of these anomalies as interments is rarely positive and often requires additional invasive archeological fieldwork. Stripping, excavation, or other invasive tests, however, are not acceptable to many Native American tribes and other groups.

This project has explored techniques of down-hole magnetic susceptibility and soil magnetism as a means of improving the detection of unmarked graves. These relatively non-destructive techniques were tested at two historic Native American family cemeteries located in Kansas and Nebraska and at an Anglo-American cemetery in Kentucky that was being excavated in advance of development. Down-hole tests explored geophysical anomalies and grave shafts at each of these cemeteries, comparing these to tests of undisturbed ground in the search for distinctive magnetic characteristics of grave shafts that could be used in the evaluation of geophysical anomalies. At select locations, soil samples were collected when making the hole for the down-hole sensor and these samples were analyzed in the laboratory using a number of magnetic techniques in order to understand the origin of observed magnetic contrasts. Magnetic characteristics of the burials themselves, which might be useful for grave identification in certain contexts, were investigated only at the cemetery that was being excavated.

Results indicated distinctive magnetic characteristics of both shafts and interments related to the burial process and transformation of the interment over time. Grave shafts, per unit volume, tended to be less magnetic, apparently as a result of soils that are less-compact than surrounding undisturbed ground. Compaction information provided by penetrometer studies did not consistently identify grave shafts, although this failure is probably related to the insufficient depth sampled by the pentrometer. Soil magnetic studies showed a patterned magnetic enhancement of interments useful for burial identification during excavation when grave goods and skeletal remains are lacking. The magnetic signatures documented were not invariable, but by combining near-surface geophysical, down-hole magnetic susceptibility, and soil magnetic techniques, there is a potential for improved capabilities in the identification, evaluation, and thus the preservation of unmarked human burials.

INTRODUCTION

A major concern in the evaluation of cemeteries and the detection of unmarked graves, especially with Native American tribes, is the development of non-invasive techniques. Near-surface geophysical techniques (e.g., ground-penetrating radar, magnetometry, resistivity, and electromagnetic conductivity) have become central in the search for unmarked human interments because, in contrast to conventional archaeological field techniques, they do not disturb the grave. Near-surface geophysical techniques, however, do not allow the identification of all or even most graves.

To detect a grave, there must be sufficient contrast between it and the surrounding soil in the physical property being measured. For example, there may be iron objects such as coffin hardware that are detectable through a magnetometer survey or perhaps even burial vaults or iron coffins. More often, however, graves are located through contrasts between the grave shaft and surrounding soils produced as a result of the excavation and refilling of the grave and attendant disturbance and mixing of soil horizons and changes in porosity and permeability. Detecting and identifying grave shafts may be challenging, as soil contrasts are often weak and can easily be confused with signatures due to other causes. Multiple-method geophysical surveys have been employed as one means of improving grave detection (Heimmer and De Vore 1995, 2000). These methods are fairly rapid with survey coverage of between one to two hectares per day.

Depending on site conditions and survey methods, variable percentages of these unmarked graves will be detected. In examining the effectiveness of geophysical techniques for finding graves, Bevan (1991) concluded, after reporting unambiguous detection at only one site, that "These surveys have found no guarantee of success." In most cases, some graves were detected while others showed no clear signature.

Subsequent to the detection of geophysical anomalies, an interpretation must be made identifying which anomalies represent interments. Not only are many graves not detected during geophysical surveys, but geophysical surveys often indicate that there were graves where there were none (Bevan 1991). An estimated average prediction rate for unmarked graves using geophysics is 30%.

For this reason, near-surface geophysical surveys are traditionally followed by excavation where positive identification is required. Initial near-surface geophysical surveys can usefully narrow down the area to be excavated without the invasiveness of other techniques (e.g. topsoil stripping), yet they are not considered sufficient in most cases for positive identification. In many cases, however, excavation is not preferable, and in certain cases, it may be unacceptable.

Our project addressed the issue of the identification of geophysical anomalies as graves. Our goal was to provide an approach with limited invasiveness that would allow these culturally sensitive resources to be better evaluated, preserved and managed. This approach added a second geophysical component, down-hole magnetic susceptibility, to evaluate geophysical anomalies identified through near-surface surveys. Down-hole surveys were tested as a means of improving grave identification before moving immediately into excavation.

At three cemeteries that were first surveyed using various near-surface geophysical techniques, we conducted down-hole magnetic susceptibility surveys to see if there were distinctive characteristics of grave shafts that could be used in the evaluation of geophysical anomalies. Soil penetrometers were also tested at two of these cemeteries as an additional method for anomaly evaluation.

The cemeteries chosen for this project include two Native American family cemeteries in southeastern Nebraska and northeastern Kansas dating to the late 19th century as well as a 19th century Euro-American family cemetery in east central Kentucky (Figure 1). Site 25RH122 is a multiple family cemetery located on the Sac and Fox of Missouri reservation in Richardson County, Nebraska (De Vore 2004a; De Vore and Nickel 2007; Nickel 2003) and Site 14BN111 (the Campbell Cemetery) is a family cemetery located on a private in holding within the Iowa Tribe of Kansas and Nebraska reservation in Brown County, Kansas (De Vore 2004b, 2007). Site 15MA424 (the Terrill Cemetery), located in Madison County, Kentucky, was being excavated by archaeologists from the Kentucky Archaeological Survey (KAS) in preparation for future development and expansion of an existing industrial park (Favret In prep.). The Terrill Cemetery provided an opportunity to test down-hole magnetic susceptibility techniques in a controlled situation where we could securely locate these tests both within and outside of known graves.

The general location of the Sac and Fox family cemetery was identified from maps and oral accounts but no markers are currently visible (Figure 2). According to oral histories of tribal members, the Sac and Fox family cemetery contained the burials of individuals from at least three families. A 1907 photo taken of the Sac and Fox family cemetery (Figure 2; on file at the Sac and Fox of Missouri Tribal Museum in Reserve, Kansas), shows six spirit houses in the foreground of the photograph as well as what appears to be a recent interment near the center of the left side of the photograph. This interment consists of a mound of earth surrounded by planking. The traditional style burials were expected to differ from those at the other two cemeteries; perhaps not extending as deep into the ground and lacking coffins. But shaft graves with coffins may also be present at this cemetery, based on reports of family members who had uncovered a grave stone in the field where the cemetery is located. Edmore Green of the tribal council (Edmore Green, personal communication, March 10, 2006) indicated that the traditional interments may be seated and shallow. He also mentioned that 18 inches (45 cm) of flood deposits covered the cemetery area in a 1993 flood

The Campbell Cemetery of the Iowa Tribe of Kansas and Nebraska is a burial plot for members of the Campbell and Dupuis families that is located in a small tree grove surrounded by agricultural fields. This cemetery contains a series of headstones and footstone in a rough north-south line through the center of a historic tree grove (Figure 3). Based on the inscriptions on the headstones and the additional number of bases, a minimum of eight individuals were buried here (Figure 4). If the three footstones are not associated with the same individuals, then a minimum of 11 individuals were interred at this cemetery. Headstones indicate that the cemetery was in use between 1875 and 1901. Site 14BN111 contains this late 1800s cemetery as well as a prehistoric component.

The Terrill Cemetery was located within a large pasture on a ridge overlooking a small tributary stream. The surrounding field had been plowed to within 2 m of the cemetery. The cemetery was encircled by trees but these were cut down prior to surface geophysical surveys and excavation (Figure 5). Nine graves with sandstone markers were apparent on the surface, dating from 1831 to 1866. Archival records together with coffin styles and recovered artifacts, however, suggest that the cemetery dates from 1804-1880. The western portion of the cemetery appears to be earlier than the eastern, as Burials 5-11 were interred in caskets with hand wrought nails while burials with machine-cut nails were located exclusively in the eastern half of the cemetery.

The Terrill Cemetery was excavated by KAS archaeologists during the period from March 12-23, 2007 (Favret In Prep.). Prior to excavation, a backhoe was employed to remove approximately 50 cm of overburden from the area as an aid in identifying unmarked graves and cemetery limits. In total, 23 potential grave shafts were identified on the stripped surface in addition to eight fence post and two gate post locations. Of these 23 potential grave shafts, seven were later identified to be probable tree root disturbance and not burials and two burials (6 and 8) turned out to consist of two graves each with a second grave shaft found during excavation (Figure 6). In total, 18 individuals were interred at the Terrill Cemetery, all within their own graves and each oriented with the head pointing to the west. The majority (12) were of fetal/infant to adolescent in age. Remains recovered from the cemetery were in very poor condition. The majority of the burials had no remains or the remains were too badly decomposed for identification and analysis. Only Burial 19 was in fair condition. The single burial (Burial 18) in the sealed iron coffin was not opened.

Down-hole magnetic susceptibility tests explored the magnetic characteristics of probable grave shafts at each of these three cemeteries and compared these characteristics to those observed for undisturbed ground adjacent to the grave shafts and elsewhere within the cemetery. Because our investigations at the Terrill Cemetery took place during KAS excavations of the graves, we were able to securely position our down-hole tests within and outside of burials at this cemetery. At the Campbell Cemetery, we had the locations of headstones, bases, and footstones to guide us in placing our down-hole tests (although some of these may have been moved), as well as the location of geophysical anomalies identified during near-surface geophysical surveys. At the Sac and Fox family cemetery, where no markers were apparent, we had only anomalies identified through geophysics that potentially represented graves. These anomalies and areas outside but adjacent to the anomalies were tested. At both the Campbell and Sac and Fox family cemeteries, penetrometer tests were employed at each of the down-hole locations.

Down-hole susceptibility studies required a 22-25 mm hole in order to introduce the sensor into the ground. A hand-held push-tube corer was used to make this hole. At select locations, soil samples from these cores were collected and brought back to the laboratory for the measurement of magnetic susceptibility and other magnetic properties. These laboratory investigations were used to confirm magnetic susceptibility data gathered in the field, but more importantly, to also investigate the nature of the contrasts in magnetic susceptibility documented between graves and surrounding areas. Soil magnetic studies in the laboratory explored the mineralogy, grain size, and concentration of the magnetic carrier within these samples, parameters helpful for understanding the cause of the observed magnetic contrasts.

Our investigations focused on the search for distinctive magnetic signatures of grave shafts. This approach would be less intrusive than techniques which required testing of the interments. Avoiding any disturbance of the burial itself, even the 22-25 mm diameter hole required for the down-hole susceptibility sensor, was preferred. The grave shafts were also more accessible as they could be studied from the surface downward. Because the graves at the Terrill Cemetery were being excavated, however, we also explored, in a limited fashion, whether there were distinctive magnetic signatures associated with the burials themselves. KAS staff mapped the variation in susceptibility over the surface of two graves at the level of the interment. They also collected soil samples for magnetic analyses from two other graves.

Our studies indicated magnetic contrasts between grave shafts and surrounding soils that could be used to identify unmarked graves. At the Terrill Cemetery, where we had an opportunity to confirm grave locations through excavation, lower average volume susceptibilities measured with the down-hole sensor characterized grave shafts. This signature was not site-specific, but was seen also at the Campbell Cemetery. The explanation for this signature, based on magnetic analyses in the laboratory on collected samples, is that the lower susceptibilities are largely the result of differences in soil compaction. Although not a foolproof method for anomaly evaluation, down-hole methods do appear to have potential for evaluating near-surface geophysical anomalies and finding unmarked graves. Penetrometer studies were generally not successful, in our opinion because they did not extend deep enough in the soil column. We were unable to document a magnetic signature for graves at the Sac and Fox family cemetery, possibly our tests of anomalies there did not consistently locate grave shafts or perhaps the magnetic signature documented at the Terrill and Campbell cemeteries will not hold for other burial styles such as the traditional burials at the Sac and Fox family cemetery. Magnetic studies of soils within interments, made possible because of excavations at the Terrill cemetery, suggested the burials themselves may be magnetically enhanced, though these high susceptibility zones are spatially discontinuous. The source of this patterning is not well understood.

METHODS

Potential grave locations were identified through surface geophysical surveys, grave markers, and, in the case of the Terrill Cemetery, through removal of the topsoil to identify the footprint of the grave shaft. Locations both inside and outside graves were then investigated using a down-hole magnetic susceptibility sensor and soil penetrometer. Representative soils samples were brought back to the laboratory for magnetic analyses.

Surface Geophysics

Multiple method near-surface geophysical surveys were completed at each of the three cemeteries prior to down-hole susceptibility tests. In all cases, it appears that surface geophysical surveys were not sufficient for the location and identification of all or even most graves. The surface geophysical data from the two Native American family cemeteries in Kansas and Nebraska has been previously presented, analyzed, and interpreted (De Vore 2004a, 2004b, 2007; De Vore and Nickel 2007; Nickel 2003) and hence will only be briefly summarized here. Two near-surface geophysical methods, magnetometery and ground-penetrating radar (GPR) were applied at the Terrill Cemetery. The GPR survey is reported on in Favret (In prep.) but the results of the magnetometer survey, conducted by Clay, are presented below.

Sac and Fox Family Cemetery

Near-surface geophysical surveys at the Sac and Fox family cemetery were conducted by the National Park Service (NPS), Midwest Archeological Center (MWAC) in response to a request by the Sac and Fox Nation of Missouri tribal council. The tribal council wished to have the extent of the cemetery identified and hoped to gain evidence of grave locations and an accurate count of graves within the cemetery. The geophysical surveys were completed in 2003 by De Vore and a private consultant.

Three complete and one partial 20 x 20 m grid units were surveyed at the Sac and Fox cemetery. The geophysical survey of the cemetery site included a magnetic survey with a fluxgate gradiometer, a conductivity survey with a ground conductivity meter, and a ground-penetrating radar survey with a GPR cart and 250 mHz (megahertz) antenna.

The geophysical survey indicated the presence of several geophysical anomalies including a number of linear anomalies that corresponded to historic fence lines and more recent agricultural related metal objects. Due to their orientation and alignment, a group of magnetic and conductivity anomalies to the west of a north-south fence line were interpreted as possible grave locations as seen in the 1907 photograph of the spirit houses at the cemetery (Figure 2). The gradiometer results with the locations of linear and dipolar anomalies are depicted in Figure 7.

Campbell Cemetery

Near-surface geophysical investigations at the Campbell Cemetery were initiated at the request of the Iowa Tribe of Kansas and Nebraska who wanted to identify the extent of the cemetery but were also hoping for identification of individual graves within the cemetery. The geophysical surveys were done De Vore in March and April of 2004.

A 20 x 20 m grid was surveyed at the Campbell Cemetery. The geophysical survey included a magnetic survey with a fluxgate gradiometer, a conductivity survey with a ground conductivity meter, a resistivity survey with a resistance meter and twin probe array, and a ground-penetrating radar survey with a GPR cart and 400 mHz antenna.

Geophysical surveys identified several small magnetic gradient, conductivity, resistance, and ground-penetrating radar anomalies. Some of these anomalies were suggestive of graves but the most prominent geophysical anomalies were linear anomalies in all four data sets that corresponded to the remnants of a 1970s cemetery fence that surrounded the graves.

Terrill Cemetery

Near-surface geophysical surveys at the Terrill Cemetery were conducted within a 40 x 40 m grid laid out by the KAS that extended beyond the boundaries of the cemetery. These surveys were conducted after the cemetery had been cleared of trees and other vegetation, but prior to surface stripping.

A GPR survey was conducted by Edward Henry and Phillip Mink (KAS) using a Ramac GPR CU II Geo System with a 500 MHz antenna along transects spaced at 0.5 m intervals. This survey detected 20 possible anomalies in the 2-4 nanosecond (ns) map while 25 were detected in the deeper 4-6 ns map. Some anomalies were located in both maps, some only in one or the other. Some anomalies corresponded to visible headstones and others did not. A cluster of anomalies corresponded to the location of several large trees. As of the writing of this report, a final reconciliation of anomalies and grave locations has not been completed.

A magnetometer survey was conducted by Clay of the same 40 x 40 m area using duplexed FM256 Geoscan Research fluxgate gradiometers. Readings were taken at 0.125 meter intervals along transects 0.5 meter apart for a total of 25,600 values for the entire area. Data were transferred to Geoplot (Geoscan Resesarch) for processing, then to Surfer 8 (Golden Software) for the development of presentation graphics (Figure 8). Data processing dealt with the major magnetometer overloads caused by iron targets (search and replace high values), secondarily with survey matters (de-stagger and zero-mean traverse), and finally with display (interpolation of values).

The survey results were dominated by the effects of major iron targets. In Figure 8 these have been "blanked out" with dummy values so that they do not affect the remaining values in the survey. The major iron target, located approximately in the center of the surveyed area, although unknown at the time of the survey, was an iron casket. Other high value targets, which probably also represent iron, were also located. These may primarily be fragments of woven wire fencing, attachments (fence staples), and gate fixtures (hinges and latches).

The background of the surveyed area exhibits a mottled, low contrast variation in magnetic values which probably reflects the nature of the upland soil at the site and, possibly, variations in its mineral content. On the margins of the surveyed area, in areas which were clearly outside what had been the fenced Terrill Cemetery, this mottling is somewhat reduced. These exterior areas had been heavily cultivated and in fact were lower in elevation, due to sheet erosion, than the cemetery itself. Mottling perhaps increases in the cemetery because it had not been plowed (thus it retained more topsoil) and possibly due to the presence of the grave shafts.

It is difficult, however, to even suggest possible grave shaft locations from these data. A major disturbance in the SW corner of the cemetery (Figure 8) may represent a burned tree stump, perhaps with iron wire fragments suggesting that it may have supported wire fencing at one time. The magnetic features most suggestive of grave shafts are areas of low value reflecting, in theory, disturbance of the topsoil in the course of grave excavation. These have been indicated in Figure 8. At the time of this writing, the geophysical grid and the plan map of the cemetery had not been reconciled and hence we are unable to comment on the locations of these four anomalies with respect to known graves.

Down-hole Susceptibility

Magnetic susceptibility provides a measure of a material's ability to be magnetized. This parameter quantifies the induced magnetization of a sample in a weak magnetic field (i.e., 5-100 μT) on the order of the Earth's magnetic field. Also called low field magnetic susceptibility, this property measures the degree to which a substance can be magnetized; it is defined by the ratio of the magnetization induced in a sample to the magnetizing field. Since this magnetizing field is low, the method is essentially non-destructive and there is little or no change to the sample.

In the SI system of units (i.e., International System of Units, abbreviated from the French "Le Système International d'Unités"), volume magnetic susceptibility (κ) is dimensionless. Mass magnetic susceptibility (χ), which is normalized by the density of the sample, is expressed in units of m^3/kg.

As applied to a soil profile, the term "magnetic enhancement" refers to changes in the magnetic mineralogy of upper soil layers, resulting in higher susceptibility values in the surface horizons as compared to the subsoil. These magnetic changes are the result of firing (which may have a natural or a human origin) and/or pedogenic processes. Pedogenic enhancement occurs as part of soil development both through low-temperature chemical reactions (i.e., inorganically) as well as organically via magnetotactic bacteria, iron-reducing bacteria, and bacterial-induced chemical reactions (Evans and Heller 2003). Typically, it is a very fine-grained magnetite or maghemite that is produced within these surface soil layers. These would be magnetic grains in the superparamagnetic to stable single-domain size range (i.e., smaller than 0.1 μm) (Hunt et al. 1995).

Our assumption in undertaking this research was that disturbance of the soil profile resulting from the excavation of the grave shaft would result in an altered soil, and thus soil magnetic, profile. Our goal was to ascertain if newly developed instruments, specifically sensors capable of measuring magnetic susceptibility down small-diameter core-holes, might be useful for identifying alterations in profiles resulting from the digging and filling of graves. We felt that this approach offered a minimally invasive means of documenting spatial changes in susceptibility associated with inhumations.

The hole needed to introduce the sensor was made with two different hand corers, a JMC backsaver push-tube probe and an Oakfield push tube corer (Figure 9). At the Sac and Fox and Campbell cemeteries, both types of corers were employed. At the Terrill Cemetery, only the Oakfield corer was employed. These corers make a hole in the ground just under 25 mm in diameter.

A Bartington Instruments MS2 susceptibility meter and MS2H susceptibility sensor were used for the down-hole tests (Figure 10). Using this system, we were able to rapidly document (ca. one sec./reading) fine scale vertical changes in susceptibility down each of the core holes. The

Multisus FieldPro (v1.0.1) database program was used to record all measurements and other information about these tests.

Two kinds of down-hole tests, timed and manual, were accomplished at each location. A timed test is a rapid reconnaissance of subsurface susceptibility accomplished by first zeroing the MS2H sensor in air, taking readings automatically at approximately one-second intervals as the sensor is lowered at 2-cm increments down the core hole, and concluding with a final reading in air at the end of the test. The difference between the initial zero reading in air and the final air reading measures temperature-induced drift, which tends to be minimal due to the short amount of time elapsed. Drift is distributed linearly along the readings down the hole. A manual test, accomplished by taking measurements manually as the sensor is positioned at 2-cm increments down the hole, provides tighter depth control. Drift may be checked and corrected for at any interval; for these studies drift was checked and corrected for at the end of each test and also from one to two times during each test, depending on how deep the test extended. In general, this resulted in drift correction at intervals of every 50-70 cm. Down-hole measurements commenced at 10 cm below the surface (bs) to avoid edge effects. Values were recorded using a sensitivity setting of 1.0. Values were multiplied by 1.7 E-5 to arrive at SI susceptibility, a calibration factor suggested by Bartington Instruments for 25 mm holes and confirmed through comparison with collected samples.

Sac and Fox and Campbell Cemeteries

Fieldwork at the Sac and Fox and Iowa (Campbell) family cemeteries was conducted by Dalan, De Vore, and three MSUM undergraduate research assistants, Elizabeth Kalinowski, Jennifer Krutsinger, and Maraigh Leitch, during the period from March 10 through 16, 2006. After a review of the geophysical anomalies identified at the Sac and Fox family cemetery, eleven magnetic, conductivity, and ground penetrating radar anomalies (Anomalies 6-11, 17-19, and radar 1 and 2) were selected for down-hole magnetic susceptibility survey (Figures 7 and 11). Down-hole tests were positioned north of the anomaly peak by about one-third the source-to-sensor distance. Source-to-sensor distances were estimated using the full width of the profile at half maximum. An additional seven areas outside of these anomalies were also selected for tests (Outside 6, 7-9, 10-11, 17, 18, 19, and radar anomaly 1) to compare to the magnetic susceptibility measurements inside the geophysical anomalies (Figure 11). At the Campbell Cemetery, down-hole susceptibility studies were conducted at 30 different locations (numbered 1-26, and 3b, 8b, 10b, and 19b). A three-dimensional plot of these down-hole tests is provided in Figure 12. These 30 locations were chosen in relation to existing monuments on the property, surface geophysical anomalies, and for the purpose of sampling different portions of the study area. A plan map showing these locations in relation to existing surface features is presented in Figure 13.

Terrill Cemetery

Down-hole investigations at the Terrill Cemetery were conducted by Dalan, Clay, and KAS staff over the period from March 12 through 15, 2007. Down-hole tests were placed inside and outside the footprints of grave shafts identified after stripping surface soils. Exposed soils within grave shafts were described by excavators as dark brown to black silty clay loams while the surrounding soils were described as dark yellow brown consolidated clays (as shown in Figure 10). Coffin outlines were demarcated by dark brown silty clay loams and coffin nails and screws.

Down-hole susceptibility tests were completed at 19 locations, 11 inside seven graves and eight outside identified grave shafts but within cemetery limits (Figure 14). While surface stripping did provide greater control in placing down-hole tests, one location (Burial 14) was tested that later was revealed to be a probable tree root disturbance.

Penetrometer

Since the detection of graves poses a serious test of the various geophysical instruments' capabilities, the present project also incorporated the use of a digital compaction meter or cone penetrometer to attempt to identify graves. This instrument has been used to located clandestine graves sites in criminal investigations (Davenport 2003). The assumption in using a penetrometer is that the fill matrix within the graves ends up being less consolidated than the surrounding natural soil matrix and that this is revealed as areas of low compaction. Although not part of the original proposal for this grant, we investigated whether penetrometer findings would correlate with the susceptibility data and/or grave locations.

A Spectrum Technologies Investigator soil compaction meter was applied during down-hole surveys at the Sac and Fox family cemetery (23RH122) and the Campbell Cemetery (14BN111) (Figure 15). Soil compaction measurements were taken immediately adjacent to the down-hole locations. No soil compaction data was collected at the Terrill Cemetery.

Soil depth measurements are determined by internal shaft sensors and the external magnetic collar. As the cone and shaft are inserted into the ground, the instrument records the compaction values when the magnetic collar triggers one of the load cell sensors in the shaft of the instrument. The reading is held in the memory of the instrument. The instrument is capable of recording the pounds per square inch (0-1000 PSI) or kilopascal (0-7000 kPa/cm) of compaction at 2 inch (approximately 5 cm) increments from 0 to 18 inches (0-45 cm) below the surface (bs).

The penetrometer was calibrated by balancing the instrument on it cone tip on the bumper of the field vehicle. The instrument was zeroed according to the automatic calibrations instructions provided by the manufacturer (Spectrum Technologies). The start button on the compaction meter was pushed to start the data collection. After the LCD display indicated 0 for depth, the probe was slowly inserted into the ground to a depth of 18 inches. The display beeped when the magnetic collar passed the internal shaft sensor at each 2-inch increment. The measurements were recorded in the compaction meter. The probe was slowly removed and the memory of the meter was reviewed for the measurement data which was hand-recorded in a field notebook. The memory of the meter was cleared and the process was repeated at the next survey station. Care was taken not to push the instrument too fast into the ground which caused an alarm to go off and required repeating data collection.

Soil Magnetic Studies

Soil samples from select down-hole locations were collected for magnetic measurements in the laboratory. In general, these were collected as part of push-tube coring to make the hole for the down-hole sensor (Figure 16), although this procedure was altered at the Terrill Cemetery as described below. The soil cores were cut into 5-cm segments, with each segment placed in a separate labeled plastic bag. Seven of the 21 down-hole test locations at the Sac and Fox family cemetery were sampled in this manner. These sampling locations included four geophysical anomalies (8, 11, 17, and 18) and three locations outside these anomalies (outside 7-9, 10-11, and 17) (Figures 7 and 11). In addition, spot samples were collected from Anomaly 19 (4 samples) and Radar Anomaly 1 (1 sample). Seven of the down-hole locations at the Campbell Cemetery (1, 3, 5, 10b, 13, 19, and 26) were sampled (Figure 13) using this same procedure. In the laboratory, samples from each bag were homogenized and packed into Althor P15 plastic (nonmagnetic) boxes (5.28 cc volume) and labeled. A total of 385 samples were collected from the Sac and Fox and Campbell cemeteries.

At the Terrill cemetery, samples were collected from outside two graves in this same fashion (Outside 19 and Outside 20 Test 2) (Figure 14). Samples within two grave shafts (Burial 13 and 19) were collected by KAS staff at 5 cm depth increments as part of their excavations (Figure 14). For one of these graves (Burial 13), excavators did not start to collect samples until 40 cm below the stripped surface. At a depth of 90 cm where the internment was encountered, three spatially separated samples were collected. Two sets of Althor P15 boxes were packed from the Burial 19 samples to look at variability. A wall was cut back to the east from Burial 7 to sample undisturbed soils in the region between Burials 7and 14. Down this wall, soil samples were collected using an aluminum sampler. The aluminum sampler was pounded into the vertical exposure with a rubber mallet and samples were then directly extruded from the sampler into Althor P15 boxes and labeled. One hundred and one samples were collected from grave shafts and areas outside these shafts at the Terrill Cemetery. Including the two sets of boxes packed from the Inside 19 test, this yielded a total of 117 sample boxes from the Terrill Cemetery for magnetic measurement.

Excavations at the Terrill Cemetery provided an opportunity for tests that were not possible at the other two cemeteries. Another Bartington sensor, the MS2K, a hand-held susceptibility sensor designed for use on moderately smooth surfaces, was used on the exposed section that was sampled between Burials 7 and 14. The MS2K sensor was also employed to measure a surface transect that cut across the footprint of Burial 8, exposed when the soils across the cemetery were stripped prior to excavation, as well as two east/west transects across Burial 13 at burial level. Work with the MS2K was continued by KAS staff after Dalan finished her fieldwork. Two grid maps of susceptibility, with measurements spaced at 10 cm increments, were completed across the tops of Burials 13 and 19 at the burial level. KAS staff also collected samples from two burials (Burials 1 and 20) for magnetic analyses. These were collected from the area of the head, pelvis, and between the legs at three different depths (157, 163, and 167 cm) for Burial 1 (yielding a total of 9 samples) and at two depths (72 and 76 cm) for Burial 20 (yielding a total of 6 samples). Together with the previously mentioned 117 samples, this brought the total samples from Terrill to 132.

Reconnaissance-level soil magnetic measurements of mass magnetic susceptibility and the frequency dependence of susceptibility were completed for all collected samples on equipment located in the geophysics and soil magnetism lab at MSUM. These measurements were accomplished using a Bartington Instruments MS2B lab sensor with a counter and computer interface designed by James Marvin of the Institute for Rock Magnetism at the University of Minnesota. The frequency dependence of susceptibility (χ_{fd}) is the percent difference in susceptibility measured at two frequencies (approximately 460 Hz and 4600 Hz). Measurement of χ_{fd} is used to investigate the contribution of superparmagnetic (SP, i.e., ultrafine) magnetic grains as these show the most pronounced frequency dependence of susceptibility (due to their delayed response to the magnetizing field). An increase in frequency dependence suggests an increase in the percentage of these ultrafine magnetic grains and potentially the presence of a developed soil.

Other soil magnetic measurements were applied only to a representative number of the collected samples to understand the contribution of magnetic mineralogy, concentration, and grain size to the susceptibility signal. These measurements included anhysteretic remanent magnetization (ARM; an artificial remanence produced in the laboratory during the smooth decay of an alternating field to zero in the presence of a weak steady field), Saturation Isothermal Remanent Magnetization (SIRM), S values (the degree of loss of remanence on a previously saturated sample at selected reverse fields) and hysteresis loops (which allowed measurement of saturation magnetization (Ms), saturation remanent magnetization (Mrs), coercivity (Bc), and the coercivity of remanence (Bcr)) (Banerjee 1981; King and Channel 1991; Evans and Heller 2003). These tests were completed both at MSUM and at the Institute for Rock Magnetism (IRM) at the

University of Minnesota. Hysteresis loops were only completed for the samples from the Terrill Cemetery.

At MSUM, ARMs were produced on a Magnon International AFD 300 alternating field demagnetizer with an ARM coil using a peak field of 99 mT and a steady field of 0.1 m and measured using an AGICO JR-6 Dual Speed Spinner Magnetometer. At the IRM, ARMs were imparted using a D-Tech Alternating-Field (AF) Demagnetizer and measured on a 2G Superconducting Rock Magnetometer. For S values, samples were saturated in a strong magnetic field (2 T at MSUM using an ASC Model IM-10-30 Impulse Magnetizer and 1.45 T using a Princeton Measurements Vibrating Sample Magnetometer at the IRM). The resulting SIRMs were measured using either an AGICO JR-6 Dual Speed Spinner Magnetometer (MSUM) or a 2G Magnetometer (IRM). The samples were then placed in a reversed field of 300 mT and remeasured. S values were calculated by dividing the absolute value of the magnetization produced in the backfield by the SIRM. Hysteresis loops were measured with a Princeton Measurements Vibrating Sample Magnetomter.

For the Sac and Fox family cemetery, ARM was measured on all samples from three anomalies (11, 17, and 18) and two locations outside anomalies (outside 10-11and outside 17). SIRM and S values were completed for samples only from two locations (Anomaly 11 and outside Anomalies 10-11). At the Campbell Cemetery, ARM was measured on the samples collected from 6 of the 7 locations (locations 1, 3, 5, 10b, 13, and 26). SIRM and S values were measured on samples from 4 of these locations (5, 10b, 13 and 26). As we could be certain about the provenience of the Terrill samples in relation to graves, ARM, SIRM, and S values were measured for all collected samples. Hysteresis loops were measured on all samples but those collected from inside Burial 19.

More specialized studies, which included low-temperature investigations and Mössbauer spectroscopy, were conducted on only a small number of samples from the Terrill Cemetery. These were completed at the IRM. Low temperature investigations were conducted using a Quantum Designs Magnetic Properties Measurement System (MSPMS) and a Lakeshore Susceptometer. These investigations focused on several samples from the two burials (1 and 20) that were sampled by KAS staff. In addition, a few of the core samples at a similar depth from the second test outside Burial 20 were used as a comparison. Susceptibilities were measured at five frequencies (1, 3.2, 10, 31.6, 99 Hz on the MSPMS and 40, 140, 400, 1000, 4000 Hz using the Lakeshore Susceptometer) from 20-300 K. Mössbauer work was restricted to two samples drawn from the two burials, one from Burial 1 and the other from Burial 20.

RESULTS AND DISCUSSION

Investigations employing the down-hole susceptibility sensor focused on a comparison of disturbed soils within grave shafts to undisturbed soils located outside the grave shafts. It was expected that the interruption and mixing of developed horizons that would occur as a result of the excavation and refilling of the grave shaft, together with accompanying changes in soil properties such as porosity, permeability, and compaction, would affect soil magnetic properties and the appearance of the soil magnetic profile.

A distinctive magnetic profile characteristic of grave shafts was identified at the Terrill Cemetery where the most secure association of down-hole tests and grave shafts was achieved. Down-hole tests were accomplished following the removal of the topsoil from the cemetery when the discoloration associated with grave shaft fill was clearly visible as a darker color than the surrounding soil matrix. In several cases, however, graves defined by these soil contrasts turned out to be other forms of disturbance, such as tree root disturbance. Only one of these tree root disturbance areas initially misidentified as a grave (Grave 14, Figure 14) was investigated using the down-hole sensor.

One of the first tests at Terrill was the east/west trending transect of MS2K measurements conducted on the ground surface exposed by stripping. Measurements were recorded at 5 cm increments across and extending beyond the Burial 8 shaft footprint (Figure 17). This test indicated that soils at the Terrill Cemetery were quite variable in magnetic susceptibility as expected given the common occurrence of redoximorphic features, iron staining, and manganese concretions.

Soils in the project area have been mapped as Nicholson silt loams, 2-6% slopes, formed in a loess mantle underlain by a residuum of limestone, calcareous shale, and siltstone on upland ridges (http://www2.ftw.nrcs.usda.gov/osd/dat/N/NICHOLSON.html). In a typical pedon, the surface Ap (0-20 cm) and Bt1 (20-60 cm) horizons are a silt loam, Bt2 (60-71 cm) and Btx (71-97 cm) horizons are a silty clay loam, and the underlying 2Bt3 (97-127 cm) is a silty clay. Magnanese concretions increase in numbers with depth as do iron and clay depletions as silt coatings and masses as iron accumulations. The 2C horizon is a massive clay, also with common iron depletions. Permeability is moderate above the fragipan (Btx) and slow or very slow in the fragipan. Horizons range from slightly acid (Ap) to strongly acid (Bt1 and 2).

Smoothing the data collected across the Burial 8 shaft footprint using a 5-point running average suggested that the soils in the shaft might be of lower susceptibility than the soils outside the shaft (Figure 17). This was confirmed by the down-hole susceptibility tests, which also indicated a pattern of lower susceptibility inside the grave shafts versus outside. This tendency toward relatively low susceptibility became clearer with depth. For the down-hole data, lower magnetic susceptibility values were either concentrated in a defined segment of the profile or apparent as a lower average magnetic susceptibility for the whole profile or both of these patterns were observed. In addition, magnetic stratigraphy observed outside the shaft was interrupted within the shaft. These findings are exemplified in the down-hole tests inside and outside three of the defined graves (Figure 18).

A plot of the mean down-hole values versus standard deviation for all tests at the Terrill Cemetery shows that this pattern held for most locations tested at the Terrill Cemetery. Statistics were generated for the top 60 cm (taking into account the approximately 50 cm of soil that was machine stripped from the surface, this would correspond to depths of 50-110 cm bs). Tests within grave shafts are characterized by lower mean susceptibilities and are more homogeneous in value than tests outside grave shafts. In the latter, not only were higher mean susceptibilities recorded, but values were more variable. This variability derives from the common occurrence of redoximorphic features and manganese nodules in the undisturbed soils.

Using these two parameters, mean down-hole susceptibility and standard deviation, however, did not provide a clear separation of tests inside and outside grave shafts in all cases. Burial 19 was relatively low in susceptibility and the average value of readings in the test outside Burial 19 was relatively high, but susceptibility values at depths below 60 cm for the test outside Burial 19 were actually lower than those measured inside Burial 19. It may be that this test outside of Burial 19 penetrated an area disturbed by the construction of a fence around the cemetery (Figure 14). Additionally, not all the tests inside and outside Burials 8 and 8A fit the general pattern (Figures 14 and 19). Inside 8 Test 2 was clearly low in susceptibility and both tests outside 8 were clearly high in susceptibility. The first test inside 8 was intermediate in value, but the odd test was that which was conducted inside Burial 8A which exhibited a relatively high average susceptibility. Disturbance associated with the re-excavation of a second grave at this location may be the cause for departure from the general pattern at this location. Burial 14, which was ultimately revealed to be an area of tree root disturbance and not a grave, did fit the general pattern. Therefore, it is clear that anomalously low susceptibilities defined disturbed areas in general, not just disturbance associated with graves.

The general pattern documented at the Terrill Cemetery, of lower magnetic susceptibility characterizing the grave shafts, was reinforced by our findings at the Campbell Cemetery as illustrated in Figures 20, 21 and 22. At the Campbell Cemetery, we could not be entirely sure if our tests were placed within grave shafts or not. But there are a number of locations that we strongly suspect are either graves or disturbed areas based on their proximity to gravestones, their correlation with geophysical anomalies (Table 1), and soil characteristics encountered when coring to make the hole for the down-hole test. This is not to say that we have identified all graves but those that we have identified may serve as models. There are also a number of locations, that due to their locations and soil characteristics encountered when coring, that we can be relatively sure represent undisturbed ground. Figure 20 presents the data from some of these locations. As at the Terrill Cemetery, distinctive low susceptibility regions within the magnetic profile and/or a lower average susceptibility are characteristic of the down-hole tests within grave shafts at the Campbell Cemetery. In Figure 21, an average magnetic profile produced from several tests indicates the same pattern. In particular, this figure distinguishes a bulge in susceptibility between 40-80 cm bs for tests in undisturbed areas that is not apparent for tests within grave shafts. This zone of high susceptibility most certainly has resulted from magnetic enhancement associated with soil development and, as expected, it is not seen in areas where these soil horizons have been disturbed and mixed.

Figure 22 plots mean down-hole values versus standard deviation for all tests at the Campbell Cemetery. At this cemetery, the hard and dry surface soils often cracked when coring, which left a wide opening at the surface of the core hole and resulted in erratic down-hole values. For this reason, the down-hole statistics were computed on measurements recorded from depths below 40 cm. We used depths of 40 to 100 cm bs as this would compare well with the 60 cm section we used at the Terrill cemetery. Tests that we strongly suspect represent grave shafts or disturbed areas are highlighted in red and these tests exhibit the same pattern of low average susceptibility values that was observed at the Terrill Cemetery. In contrast to our findings at the Terrill Cemetery, however, it is the magnetic profiles from the grave shafts that tend to exhibit the largest standard deviations. The undisturbed soils at the Campbell Cemetery are more magnetically homogenous than the soils at the Terrill Cemetery.

The abundance of redoximorphic features that contributed to the high magnetic variability of the soils at the Terrill Cemetery is not characteristic of soils at the Campbell Cemetery. The Campbell Cemetery lies within the Marshall-Morrill soils association of “very deep, gently sloping to strongly sloping, well-drained soils that have a silty or loamy subsoil; on uplands (Palmer et al. 1998a). The soil mapped within the project area is a Reading silt loam, moderately wet, rarely flooded (Palmer et al. 1998a and b). Reading soils formed in alluvium within loess hills. They are characterized by moderately slow permeability, slow surface runoff, high available water capacity and moderate organic matter content. Soil pH is moderately acid to slightly acid in the upper section of the pedon and slightly alkaline in the C horizon. In a typical pedon within a cultivated field, there is a deep (36 cm) silty clay loam mollic epipedon (AP and A horizons), below which is found a thick sequence (36-142 cm) of silty clay loam argillic horizons (Bt1, Bt2, Bt3), underlain by a dark yellowish brown silty clay loam C horizon extending from 142-203 cm (http://www2.ftw.nrcs.usda.gov/osd/dat/R/Reading.html).

Interpretation of results at the Sac and Fox family cemetery is made difficult by a lack of secure identification of grave shaft locations; we had only the locations of geophysical anomalies to use in positioning our tests. Comparing results from inside to outside anomalies, no consistent pattern in susceptibility values was observed (Figure 23). Statistics were calculated on readings from 20 cm to 120 cm in depth (as near surface anomaly sources appeared shallow but it had also been suggested that significant deposition of sediments had occurred recently during flooding). The lack of agreement with results gained from the other two cemeteries may be due to the different character of the traditional graves at this cemetery or perhaps our test locations have not actually compared grave shafts to undisturbed ground. It is not certain that these geophysical anomalies are associated with graves. Perhaps some are and others are not. Some of the anomalies were interpreted to be associated with iron based metal and others with non-metal magnetic materials (De Vore and Nickel 2004). They all appear to have relatively shallow sources (40 cm or less). Perhaps the metal was associated with the spirit houses, but by using such anomalies to position our down-hole tests, we have missed the grave shaft itself.

It is unlikely that differences in soils are major factors in this lack of agreement. Though soils at the Sac and Fox family cemetery are not as strongly developed as soils at the Campbell Cemetery, both formed in alluvium and are characterized by similar textures and magnetic properties. The Sac and Fox family cemetery lies within the Kennebec-Judson-Wabash soil association (Sautter and Kuhl 1974) of deep soils found in Nemaha River bottom land and foot slope positions. Soils in the project area are described as silty alluvial land and they consist of floodplain soils (0 to 1% slopes) found on narrow tracts of land adjacent to meandering streams. The project area lies are within floodplain of the channelized Noharts Creek, a tributary of the Big Nemaha River, and would be expected to be subject to periodic flooding. A comparison map unit would be the Nodaway series soils which are very deep, moderately well drained soils formed in alluvium. In a typical pedon of the Nodaway series, the Ap horizon is a very dark grayish brown silt loam approximately 18 cm thick that overlies silt loam and silty clay loam C1, C2, and C3 horizons (http://www2.ftw.nrcs.usda.gov/osd/dat/N/NODAWAY.html). A competing series would be the Eitzen series, very deep, well drained, and moderately well-drained soils that formed in a mantle of recent silty alluvial sediments overlying a buried soil (http://orthos/ftw.nrcs.gov/osd/dat/E/EITZEN.html).

In addition to searching for distinctive magnetic characteristics of grave shafts, we also evaluated the reproducibility of our down-hole magnetic susceptibility data and its agreement with normalized mass magnetic susceptibilities measured in the laboratory. The reproducibility of the down-hole tests, as assessed by comparing the timed and manual tests at each location, was excellent at all three cemeteries. As an example, we present one of these comparisons for the test outside Anomalies 10 and 11 at the Sac and Fox family cemetery (Figure 24). To compare down-hole magnetic susceptibility values and those measured in the lab on samples collected while coring to make the hole for the down-hole sensor, we created graphs using two X axes, one for volume susceptibility measured during down-hole tests and one for the mass magnetic susceptibilities measured using the samples packed in Althor P15 boxes. We then shifted these two axes to compare the shape of the two magnetic profiles (e.g., Figure 25). In general, the down-hole tests and measurements on collected samples compared well at all three cemeteries. The down-hole tests provided more information on soil variability, however, as they recorded susceptibility every 2 cm as opposed to the boxes packed from the soils homogenized over 5 cm increments.

What surprised us, however, was that even though the general shape of the curve tended to be the same for the down-hole and the collected sample readings, when comparing mean susceptibility values for the collected sample locations, the magnitude shift between undisturbed areas and grave shafts disappeared and, in fact, for the collected samples the grave shafts locations had a tendency toward higher, not lower, average susceptibilities. It is true that we have a relatively small number of locations from which we collected samples. The fact that this pattern was apparent at the Terrill Cemetery (Figure 26), where we had secure placement of our tests within grave shafts and undisturbed locations, and also at the Campbell Cemetery (Figure 27), however, suggests that this reversal is not simply the result of sampling error. (As with the down-hole data, no pattern was apparent in the collected sample data from the Sac and Fox family cemetery as shown in Figure 28.)

Magnetic measurements of the collected samples were used to investigate why the grave shafts did not exhibit higher mean mass susceptibilities in keeping with the pattern documented by the down-hole tests. These magnetic measurements also provided an opportunity to see if soil magnetic parameters other then susceptibility would be useful for distinguishing graves shafts from undisturbed areas. We discuss these tests in most detail for the Terrill Cemetery where we had the greatest control on actual grave locations.

As part of the basic reconnaissance efforts involving all samples, we measured not only magnetic susceptibility but also the frequency dependence of susceptibility (χ_{fd}), which tracks the proportion of ultra-fine magnetic grains. At the Terrill Cemetery, variations in χ_{fd} did not appear to clearly distinguish grave shafts from other areas. In general, percentages were relatively high, ca. 7-8%, throughout and across tests. A comparison of suspected grave shaft locations to other locations at the other two cemeteries also failed to reveal a distinctive pattern using this parameter. Frequency dependence data, therefore, suggested that there was not a significant difference in magnetic grain size, at least on the finer end of the spectrum, between grave shafts and undisturbed areas.

For selected locations from each of the cemeteries, we also measured ARM, SIRM, and S values. ARM and SIRM, like susceptibility, track the concentration of magnetic minerals. Like susceptibility, these parameters are not independent of magnetic grain size. ARM and SIRM are often used in ratios and bivariate plots to investigate magnetic grain size independent of concentration. S values are quite useful for investigating magnetic mineralogy. A comparison of locations within and outside grave shafts did not reveal distinctive signatures in any of these parameters that would be useful for identifying grave shaft locations at any of the three cemeteries. Even though magnetic changes with depth were observed, a distinction between shaft areas and undisturbed ground, other than in the interruption of magnetic stratigraphy in some cases, was not apparent.

Because we could be certain which samples were collected from inside and outside grave shafts, and because we also had information on the depths of the interments, we decided to measure ARM, SIRM, and S values on all collected samples from the Terrill Cemetery. In addition, we were able to measure hysteresis loops for all but the grave 19 samples. A decrease in magnetic concentration with depth was consistently indicated by χ, ARM, SIRM, and M_s versus depth plots. This decrease occurred from 55-90 cm below the stripped surface and corresponded to a lighter colored, more compact and clayier soil noted during coring and also by excavators. Figure 29 presents saturation magnetization (M_s) data, which is the only one of these parameters not also influenced by magnetic grain size. Locations both inside and outside grave shafts show a similar decrease with depth, with the exception of samples from outside Burial 19, which had anomalously low concentrations at depth. As mentioned previously, the outside Burial 19 location is one of the odd locations that we tested, where down-hole susceptibility readings at depth were actually less than those inside the Burial 19 grave shaft. The outside Burial 19 samples also showed an anomalous grain size shift at depth. This area may have been disturbed as part of the construction of a fence around the cemetery (Figure 14). At other locations from which samples were drawn, there was no consistent indication of a mineralogy (based on S values) or grain size (based on bivariate plots and ratios to normalize concentration) change at this level.

Bivariate plots employing multiple magnetic parameters allow a separation of changes in magnetic mineral concentration and grain size. For example, both χ_{arm} (ARM susceptibility, i.e., mass normalized ARM per unit bias field) and χ are dependent on magnetic concentration but χ_{arm} preferentially responds to SD particles and χ is relatively sensitive to larger PSD and MD grains (King et al. 1982). Thus, plotting χ_{arm} against χ provides a rapid means of characterizing the relative grain sizes and concentrations of magnetic minerals contained with the measured samples (Banerjee et al. 1981). Changes in the slope of a line fit to the plotted samples correspond to variations in relative grain while increasing distance out from the origin along this line represents an increase in concentration. Increasing slope (i.e., higher ARM) indicates finer magnetic grains while decreasing slope indicates larger grain sizes.

An χ_{arm} versus χ plot of all samples from the Terrill Cemetery (Figure 30) indicates variation in magnetic concentration but little variation in magnetic grain size. With the exception of a few outliers, almost all samples plot along the same concentration line. Again, it should be noted that our samples were collected from below the stripped surface so that we do not have enhanced surface soils represented on this plot. A plot of M_s versus χ_{arm} (Figure 31) presents essentially the same picture but on this plot the Outside 19 samples do separate out as finer grained. Average saturation magnetization (M_s) values for each location (Table 2), agree with findings from average χ values for collected samples. All locations, whether inside or outside grave shafts, have average values in the same range, from 0.04 to 0.06 Am^2/kg. The average value for the samples collected within the Burial 13 shaft is at the high end of the range (0.06 Am^2/kg), but, because of differences in depths reached and because we only have hysteresis parameters for one grave shaft (we did not complete hysteresis loops for the Burial 19 grave shaft), we cannot conclude that grave shafts have a higher average susceptibility. All we can say is that we seem to have the same range of magnetic concentrations and grain sizes inside and outside grave shafts, based on the normalized collected samples, a pattern different than that documented through down-hole studies.

So let us consider why magnetic concentration is lower within grave shafts and surrounding soils in the down-hole data but not for our measurements of collected samples. Soil descriptions recorded when excavating, coring, and also from packed samples are helpful in explaining these differences and in correlating magnetic patterns with soil changes. These descriptions address issues of soil variability and compaction. At the Terrill Cemetery, reddened areas within the soil column correspond to localized susceptibility highs or spikes while the presence of manganese nodules results in localized low susceptibility values. Even though excavators described undisturbed areas outside grave shafts as more homogeneous and grave shafts as less homogeneous, they were referring to macro-scale areas of soil mottling within grave shafts produced from soil mixing when infilling and not to micro-scale redoximorphic features. Within grave shafts, a narrower range of browner toned soils was observed. The micro-scale redoximorphic features, the iron masses and manganese nodules, were found to be much more prevalent in the undisturbed areas. And it is these micro-scale features that produce the extreme variability recorded in the 2 cm down-hole measurements and hence result in a generally higher standard deviation for measurements taken in the undisturbed areas (e.g., Figure 19). Looser and less compact soils within grave shafts versus harder and dryer soils in undisturbed areas suggest an explanation for observed contrasts in susceptibility values. Because the down-hole sensor is responding to a volume of soil, if soils are not as compacted within grave shafts then they would contain by volume less magnetic material and be recorded as having a lower susceptibility. When these same soils are disaggregated, brought into the lab, packed into boxes, and normalized by density, this difference then disappears.

Changes in porosity and permeability within the grave shaft might also result in differences in the production and selective dissolution of magnetic minerals and contribute to the anomalously low susceptibility of the grave shaft. Because we did not see any distinctive magnetic grain size or mineralogy contrasts between the grave shafts and undisturbed areas, however, we feel that this is unlikely. As the difference is one of magnetic concentration, and as this concentration differential disappears when we pack the samples, this suggests that changes in soil density or compaction are the chief contributing factor. If anything, analysis of collected samples suggests that the soils from the shaft may be slightly more magnetic although, again, we do not believe that we have a large enough sample to securely test this. In addition to differences in compaction, it appears that localized areas of low susceptibility within the grave shaft may also result from localized soil mixing and reversals, perhaps incorporating the deeper, weakly magnetic soils higher up into the soil column.

It is interesting that magnetic measurements suggest that our ability to identify grave shafts rests on differences in compaction, with soils in grave shafts being less consolidated than surrounding soils, yet when we compare the mean down-hole mean susceptibility data with the soil compaction data there does not seem to be a consistent correlation between the two methods (Figures 32-34). Penetrometers have been successfully used to locate grave sites in criminal and other investigations, yet we did not have success with the method. Unfortunately, we do not have penetrometer data for the Terrill Cemetery where we could securely correlate results with grave locations. Our evaluation of the method is based only upon studies at the Sac and Fox and Campbell family cemeteries. At the Campbell Cemetery, certain locations characterized by low mean susceptibilities do correlate with low average penetrometer readings, but others do not and in fact show an opposite pattern. Figure 32 depicts mean penetrometer and down-hole susceptibility values for each of the 30 locations tested at this cemetery. In Figure 33, that plots mean down-hole values against penetrometer values, if there was a clear correlation between the two measures we would expect to see the data points form a more or less straight line. This is not the case. A lack of correlation with anomaly locations was also apparent in the penetrometer data from the Sac and Fox family cemetery (Figure 34), although we should again emphasize that we are uncertain whether anomaly locations indeed correlate with grave locations.

We suspect that the lack of correlation between penetrometer data and grave locations, and between penetrometer and down-hole susceptibility data, has less to do with the assumptions of the penetrometer method itself (i.e., that the fill within the shaft is less consolidated than the surrounding natural soil matrix) and more to do with the depths investigated in our studies. For the down-hole data at the Campbell Cemetery, contrasts between grave shaft and surrounding soils were most apparent below 40 cm. At the Terrill Cemetery, though we do not have penetrometer data, localized susceptibility lows in the magnetic profiles of the grave shafts also occurred more often in the lower sections while values were more similar in the upper sections. Therefore, a penetrometer that was capable of measuring compaction to depths of at least 1 meter (the instrument that we employed went only to 45 cm) would be preferable.

Soil magnetic studies conducted on the interments themselves, possible only at the Terrill Cemetery because these graves were being excavated, did provide some interesting results that support the suggestion of a magnetically distinctive signature of graves based on studies by Linford (2004). Linford explored mineral magnetic contrasts between inhumations and surrounding ground for both Roman and Anglo-Saxon graves. A susceptibility contrast, with localized magnetic enhancement in the grave, was demonstrated in each case, suggesting that inhumations themselves, apart from the grave shaft, might be identifiable by their magnetic signature. Linford conducted various soil magnetic studies to understand the origin of this magnetic contrast. Possible contributors are iron deriving from the human body, localized concentrations of organic material and nutrients from the human body providing a fertile site for magnetic enhancement through various organic and inorganic processes, and metal associated with the burials. While not conclusive, Linford's studies suggest a biogenic source, i.e., microbial colonization of the organic remains and subsequent alteration and production of iron minerals.

Linford conducted a topsoil magnetic susceptibility survey over the stripped surface of an Anglo-Saxon grave prior to full excavation (2004:Plate 1). As a comparison, we present susceptibility maps recorded with a Bartington MS2K sensor at burial level at 10 cm intervals over the surface of two interments (Burials 13 and 19) at the Terrill Cemetery. Unlike Linford's survey, these maps do not extend significantly outside the coffin (they were constrained by the limits of the excavated area), yet some interesting similarities between Linford's data and ours are apparent.

Burial 13 was that of Mary Hudson, a 32 years old woman who died in 1866. Excavations revealed the decomposed remains of a wood coffin (the outline of the burial was apparent but no wood was recovered), together with late cut nails and screws. Skeletal remains consisted only of small fragments of a cranium and limb bones as well as four teeth fragments. Other remains included buttons, eye and hook fasteners, a vulcanized rubber comb around the skull area, and leather and cotton fragments. Grave fill was recorded as a 10YR6/8 yellow brown clay loam mottled with a 10YR4/3 brown clay loam. Dark stains (dark brown 10YR3/3 clay loam) were associated with skeletal remains. The subsoil was a 10YR6/8 brownish yellow clay. The susceptibility map was accomplished at a depth of 98 cm below the stripped surface. Burial 19 was that of Zerelda E. Terrill, a 14 years old girl who died in 1845. Again, remains were in poor condition, including a coffin outline, teeth fragments, and fragments of limb bones, a pair of gold plated hoop earrings, a slate pencil, and fabric from a dress. Grave fill included mottled 10YR

6/8, 10YR 4/3, and 10 YR 3/3 clay loams, as observed in Burial 13. The susceptibility map was accomplished at a depth of 91 cm bs.

Excavators noted that the burials were darker and more organic than surrounding soils. Dark stains marked the former locations of bones, with the center of the grave area, corresponding to the center of the body, the brownest. Susceptibility maps (Figures 35 and 36) reflect this patterning in soil color, indicating relatively high susceptibility soils in the area of the body which contrasted with lower susceptibility surrounding soils. This pattern is most apparent for Burial 19. Unlike Linford's study, we were unable to compare soils well outside the coffin to those within the coffin as excavations were confined only to the coffin area.

In keeping with Lindford's results, the susceptibility plan maps for Burials 13 and 19 indicate significant variation in susceptibility within the area of the body rather than a consistent high susceptibility signature across the grave. The highest susceptibilities, with the exception of single- point susceptibility highs associated with coffin nails and screws, were observed for both burials in a broad diagonally oriented area across the middle of each grave. This high susceptibility area seems to resolve itself into three distinct clusters of high susceptibility soils. Depending on the burial, high susceptibility areas were also indicated near the head and/or feet. Spikes in susceptibility associated with nails were a particular problem for Burial 13, and these single point anomalies were replaced with a local average. Down-hole tests in Burial 13 appear to have extended into one of these high susceptibility areas. Susceptibilities began to increase as we approached 90 cm bs, nearing the coffin area (Figure 18).

We find it fascinating that our susceptibility plan maps are very similar to Linford's map of the Anglo-Saxon grave. In Linford's map, significant variation in susceptibility within the grave was also indicated including a diagonally-oriented cluster of susceptibility highs across the center of the body. We don't want to make too much of this, but it is interesting that a similar patterning within the grave was observed on burials so different in time and context and possibly this relates to a distribution of iron-containing human tissues and organs such as the heart, spleen and liver. Human brain tissue is also an area where magnetite or maghemite is concentrated.

As noted by KAS excavators at the Terrill Cemetery, mottled soils were observed within these burials. Soil mixing alone might explain the variation in susceptibility observed. The fact that the brownest, high susceptibility soils were observed in the center of both graves as well as in the burial investigated by Linford, however, makes us doubt this simple explanation.

Unfortunately we do not have corresponding soil samples from the level at which the susceptibility maps were made for Burials 13 and 19 and so we are unable to investigate the magnetic characteristics of the different soils within these graves. This would have been the optimal situation, to have sampled from the various susceptibility zones defined by the MS2K survey within each grave. We hope that we will have the opportunity to do this at another cemetery in the future and to also study well-controlled samples at the same depth from outside the grave for comparison.

Although we don't have samples from Burials 13 and 19, KAS staff did collect samples from two other graves, Burials 1 and 20, that we have been able to study (Figures 14 and 37). Burial 1 is located in the southern portion of cemetery and was oriented NW/SE in contrast to the west facing orientations of most other graves. This burial contained the remains of a 12-20 year old individual and hexagonal coffin. Nails and screws were recovered although the outline of this coffin was just barely visible. Skeletal remains recovered included just a few teeth and small portions of a few limb bones. A few buttons were also recovered. Three depth samples were collected by KAS staff from each of three areas within the grave. These areas were near the head, near the center of the body, and in the lower body area between the legs. The depths sampled within each area were 157, 163, and 167 cm bs, moving from the top to the bottom of the burial. Burial 20 was located in the eastern portion of cemetery, and this was a grave that we had conducted down-hole studies both within and outside of. Burial 20 was the grave of William Towels Terrill, Jr. In this grave, excavators found the remains of a hexagonal wood coffin, screws, escutcheons, nails, tacks, and viewing plate glass. Although a number of bones were mapped in the field, because of the poor condition of the bones, only small cranial and unidentifiable dental fragments were recovered. Other remains included cast iron buttons (possibly from pants), porcelain buttons (possibly from an overcoat), a buckle or clip (probably for pants), fabric (from a jacket and vest), and leather fragments (from shoes). The same three areas were sampled as within Burial 1 (near the head, near the center of the body, and between the legs) but at two depths only (72 and 76 cm bs).

As documented by saturation magnetization values, the two burials are very different in terms of magnetic concentration (Table 2). Average Ms values are very low for Burial 1 (0.01 Am^2/kg) and very high (0.09 Am^2/kg) for Burial 20 compared to the average profile values (0.04-0.06 Am^2/kg) obtained for samples collected within the grave shafts and areas outside the grave shafts. Burial 20 was shallow (samples collected at 72 and76 cm) compared to Burial 1 (samples collected from 157-167 cm bs). Burial 20 was in fair condition, as opposed to very poor to poor condition of all other burials. Burial 1 samples were notably fibrous and full of roots. Burial 20 soils were redder in color than those from Burial 1. Burial 20 samples are relatively high in susceptibility in comparison to other soil samples at that depth. Mass susceptibilities of the Burial 20 samples range in magnitude from 1-2.7E-6m^3/kg. In contrast, soils collected from depths greater than 60 cm do not in general exceed 2E-6 m^3/kg. We do not have samples from greater than 150 cm bs to compare against the Burial 1 samples.

Inspection of χ_{fd}, S values, and bivariate plots and parameters for the samples from these two burials did not suggest any distinctive characteristics in grain size and mineralogy. We reviewed the samples for distinctive patterns that might correspond with changes in depth or location within the grave and also for any distinctive contrasts between the burial soils and soils collected outside graves. In keeping with the susceptibility surface maps of Burials 13 and 19, samples from Burials 1 and 20 indicated significant variation in magnetic concentration but no consistent patterns that correlated either with depth or location or that distinguished grave soils from those below or outside these graves.

On Day plots (Day et al. 1977), which characterize magnetic grain size, rectangular zones of single domain (SD), pseudo-single domain (PSD), and multidomain (MD) behavior are defined using ratios of Mrs/Ms against Hcr/Hc. Recent work by Dunlop (2002a and b) has suggested modification of the boundaries of these rectangular zones. For environmental samples containing mixtures of grains of different domain states, the Day plot will indicate a mean grain size (Jackson et al. 1990). As shown on a Day plot of all collected samples (Figure 38), the samples from Burials 1 and 20 are similar in mean grain size to all other samples at Terrill. Most cluster within the area defined as PSD behavior, although there are some outliers. Several Burial 1 samples are found beyond the high (head area at 157 cm bs and between the legs at 167 cm) and low (pelvis area at 167 cm bs, the strongest sample) ends of the cluster. The Burial 1 samples were magnetically weak, however, and noticeably more rooty and fibrous than the other samples.

Figure 39, an χ_{arm} vs χ plot comparable to Figure 30 but with the addition of the Burial 1 and 20 samples, does not indicate significant contrasts in magnetic grain size for the Burial 1 samples. Burial 1 samples fall in the main along the concentration gradient established by the other samples, but plot close to the origin and hence indicate relatively low magnetic concentrations. Of the Burial 1 samples, those from the pelvic area at 157 and 167 cm bs are magnetically the strongest. This was not true for the Burial 20 samples where the center of the body samples were lower in susceptibility. Burial 20 samples from the area of the feet and the head at 76 cm bs plot above and below the concentration line, but the remaining four samples look much like the other samples collected at the Terrill Cemetery. Most obvious from this plot is the contrast in magnetic concentration, with Burial 1 samples low in concentration as opposed to the higher concentrations observed for the Burial 20 samples.

Figure 40 is a logarithmic biplot of χ_{arm}/χ_{fd} versus χ_{arm}/χ that has been suggested (Oldfield 1999) as the basis for a preliminary assessment of whether fine grained magnetic particles are detrital or bacterial in origin. Defined areas of typical behavior are indicated on the plot. As shown in Figure 40, Burial 1 and 20 samples plot within a detrital source. Linford's (2004) research suggested a bacterial source; ours does not suggest this for the Terrill burials although we do not know if the Burial 1 and 20 samples were collected within high susceptibility areas of these graves.

Low temperature and Mössbauer studies on samples from the Terrill Cemetery indicate mixed grain assemblages with varying concentrations of paramagnetic, ferromagnetic, and antiferromagnetic minerals. Analysis is ongoing but so far has not provided an indication of distinctive characteristics of soils from the burials.

SUMMARY AND CONCLUSION

The goal of this project was to advance techniques for the location and identification of unmarked graves by integrating innovative down-hole geophysical techniques and soil magnetic studies with near-surface geophysical surveys. We chose these techniques because they promised to provide a relatively non-invasive and efficient means of determining whether anomalies detected through near-surface geophysical surveys corresponded to graves. Additionally, these techniques could be used in a targeted fashion to locate other graves that might not be detected by at-surface surveys.

Our project tested these techniques at three North American cemeteries. These cemeteries included two Native American cemeteries in southeastern Nebraska and northeastern Kansas dating to the late 19th century (family cemeteries of the Sac and Fox Nation of Missouri and the Iowa Tribe of Kansas and Nebraska), one of which included traditional spirit house burials. An Anglo-American family cemetery in Kentucky, dating from approximately 1800-1880 that was being excavated by the Kentucky Archaeological Survey, provided another opportunity to test these techniques.

Multiple-method near-surface geophysical surveys were completed in advance of our down-hole tests at each of the three cemeteries. Near-surface geophysical results were not conclusive at any of these cemeteries, identifying only variable percentages of the graves present, although in most cases they were quite successful in their identification of fences and other features associated with cemetery boundaries. Certain methods worked better than others and the application of multiple methods aided in maximizing unmarked grave predications. For example, the magnetometer survey at the Terrill Cemetery was compromised by the effects of a large iron casket near the center of the survey area, thus making it difficult to suggest possible grave shaft locations. The GPR survey did not have this problem. In no case, however, was it apparent that geophysical surveys had identified 100% of the graves present, although in each case anomalies suggestive of graves were identified. These results underscore the need for improvements in our ability to locate unmarked graves.

To investigate whether down-hole susceptibility studies could be used to improve grave prediction rates, we conducted down-hole susceptibility and soil magnetic tests on soils both within and outside of grave shafts to ascertain whether there was a diagnostic magnetic signature of grave shafts that might aid in their identification. Our studies demonstrated a consistent, but not invariable, magnetic signature of grave shafts. In general, the down-hole sensor indicated that grave shafts soils were less magnetic, per unit volume, than undisturbed soils outside the shaft. This relative shift in susceptibility was variously expressed as a lower average down-hole susceptibility or as an anomalously low susceptibility region at depth (compared to high susceptibility soils at comparable depths outside the shaft) or even both of these patterns. Depending on soil horizonation, an interruption of stratigraphy was sometimes also observed in the magnetic data. At the Terrill Cemetery, because excavators had removed approximately the top 50 cm of the soil prior to our studies, we did not have the opportunity to compare grave shafts to surrounding areas in terms of properties of magnetically-enhanced surface layers. At the Campbell Cemetery, we found that susceptibilities of surface soils did not clearly distinguish grave shafts; down-hole averages provided a better distinction of grave shafts if we looked at values below 40 cm bs.

It definitely surprised us that a similar magnetic signature for grave shafts was indicated at both the Terrill and Campbell cemeteries. (Again, the lack of any control on grave locations precludes our ability to draw conclusions about diagnostic signatures at the Sac and Fox family cemetery.) Because magnetic properties of soil are environmentally sensitive, we had assumed that we might find a unique diagnostic signature in each environmental setting. Therefore, the fact that we found a similar signature across two cemeteries located in very different soil environments was a significant discovery. This discovery suggested that similar methods of digging and refilling graves produced this common signature, not potentially unique processes of magnetic enhancement and dissolution proceeding in each soil environment after the grave shaft was refilled. Our comparison of down-hole and soil magnetic data confirmed that the main factor producing the low susceptibility signature of the grave shafts was differential soil compaction.

Although a similar pattern was observed at both the Terrill Cemetery and the Campbell Cemetery, this pattern was not invariable. A small number of tests did not match the expected pattern and there were other tests that fell in an overlap zone and could not be clearly classified. This variability probably relates to the different ways that graves are dug, with most, but not all, following a particular pattern, and also to the effects of other sources of disturbance (for example the excavation of subsequent graves or other cultural activities that disturb areas outside the grave shaft). At the Terrill Cemetery, graves that were deeply excavated often incorporated low susceptibility soils found at depth into the fill just above the coffin level and this produced a distinctive localized susceptibility low in the magnetic profile. In other cases, only a subtle effect of on-average lower susceptibility values over the length of the shaft was observed, and in these cases it was more difficult to identify the grave shaft. Either characteristic would not be expected to produce a large magnetometer anomaly, explaining why magnetometer surveys were not particularly successful at these cemeteries. Due to its sensitivity to these subtle changes and its ability to investigate susceptibility at depth, the down-hole sensor was able to distinguish differences in magnetic concentration resulting from differences in compaction.

As indicated by our studies at the Terrill Cemetery, tree root disturbance can mimic the pattern observed for grave shafts, producing a localized susceptibility low. This has been observed for near-surface magnetometer surveys of cemeteries and it also appears true for measurements of down-hole susceptibility. In general, our down-hole tests did not discriminate between the two, although tests at the Campbell Cemetery suggested that extremely low susceptibility values (near 0) are produced in areas with extreme disturbance from tree roots and these then would serve as an indicator that this was not a soil-filled shaft .

Thus, down-hole susceptibly is not a magic bullet that will determine in each and every instance whether a geophysical anomaly represents an unmarked grave, but they can be employed, in conjunction with near-surface surveys and other techniques, to improve the accuracy of geophysical predictions. Additionally, they may add other interpretive details such as information on the depth of the grave. When coring to make the hole for the down-hole sensor, information on soil properties and stratification may also be gathered. The down-hole tests themselves are rapid, efficient, and provide reliable and reproducible results. Their application appears to be limited mainly by the difficulty in coring in certain environments.

Magnetic analyses of soil samples allowed us to understand why the grave shafts were characterized by low susceptibilities. Various hypotheses were generated to explain this pattern, including: 1) dilution of higher susceptibility soils during shaft infilling with lower susceptibility soils garnered from deeper in the profile; 2) differences in the production and/or dissolution of magnetic minerals between grave shafts and undisturbed areas; and 3) differences in the compaction of soils within grave shafts and undisturbed areas. Our soil magnetic studies indicated that although dilution could and did appear to produce localized susceptibility lows in the soil column within the shaft, dilution would not suffice as a general explanation because mass susceptibilities inside grave shafts were not less than mass susceptibilities outside grave shafts. It also did not appear likely that alterations in factors such as porosity, permeability, and hence drainage had significant impacts in terms of magnetic diagenesis as no significant contrasts in magnetic grain size or mineralogy were noted between grave shafts and undisturbed areas. Soil magnetic results indicated variation only in magnetic concentration.

Changes in magnetic concentration with depth were observed over a similar range both inside and outside grave shafts. Down-hole tests, however, indicated lower average susceptibilities within grave shafts. In contrast, average mass magnetic susceptibilities measured on collected samples were essentially the same for locations inside and outside grave shafts. The main determinant of these differences appears to be soil compaction. The down-hole sensor, which measures the susceptibility of a radial volume out from the core hole, documents the higher concentrations of magnetic materials in the compacted, undisturbed soils outside the grave shaft and the lower concentrations of magnetic minerals in the less-compacted grave shafts. Notes made when coring the holes for the down-hole sensor, which indicate that in general the grave shafts were softer and easier to core, support this explanation.

Given these findings, it would seem reasonable to use instruments that measure compaction to assess near-surface geophysical anomalies rather than the down-hole susceptibility sensor. And this has been done in many cases. But based on our tests at the Campbell Cemetery and the Sac and Fox family cemetery, soil penetrometer studies did not clearly distinguish grave locations and indeed appear to have been distinctly less successful than the down-hole studies. Unfortunately, we did not have the opportunity to collect penetrometer data at the Terrill Cemetery. Our lack of success with the penetrometer could be due to a number of factors, one of which is noise introduced by disturbance from other cultural activities and tree roots. We suspect, however, that a larger problem was the depth to which we were able to sample. If soil compaction data could be collected for depths greater than the 45 cm that we were able to sample, we think the results would be improved. Based on the regions where we saw the most consistent differences between grave shafts and surrounding soils using the down-hole sensor, this would be the region between approximately 40 and 100 or 120 cm below the surface. Even so, it is likely that the penetrometer would also have difficulty distinguishing grave shafts from other forms of disturbance such as tree roots.

We have focused on techniques applied to grave shafts to aid in the identification of unmarked graves because they are more accessible and tests focused on the shaft would avoid disturbance to the burial itself. It has been suggested (Linford 2004), however, that there may also be a distinctive soil magnetic signature of the interment itself that in certain contexts might be useful in grave identification.

Susceptibility maps completed at the burial level of several graves at the Terrill Cemetery did indicate a number of spatially discontinuous, high susceptibility zones within the coffin that appear to correlate with the location of decomposed skeletal remains. Perhaps coincidentally, or perhaps representative of some common cause, these susceptibility maps indicated a series of susceptibility highs oriented diagonally across the middle part of the body, a pattern that Linford also documented over an Anglo-Saxon burial. Unfortunately, we were not able to collect soil samples from the defined susceptibility zones within these two graves at the Terrill Cemetery to add to Linford's discussion of potential causes for susceptibility enhancement of graves. Though we were able to analyze samples from two other burials at this cemetery, we are limited in the conclusions that we can draw from them due to the small number of samples and the considerable variation they exhibit as well as a lack of comparable samples from well outside the burial at similar depths.

Linford (2004) suggested measurement of susceptibility as a method for mapping inhumations when the contrast is not sufficient for detection with magnetometry and also for grave identification during excavation in cases when human skeletal remains are not preserved and grave goods are lacking. Where burials are deep (i.e. > 1 m), it is unlikely that near-surface surveys of susceptibility would be of assistance in their identification. And though our studies suggested, in accordance with Linford, that the burial itself is magnetically enhanced, they also indicated that these high susceptibility zones would be spatially discontinuous. Down-hole studies extending into the burial (in cases where an intact vault or coffin was lacking), therefore, would probably not be conclusive as a single test might or might not sample one of these high susceptibility zones. Confidence might be improved with multiple tests within a grave, yet this approach does not seem to us to be an improvement on studies focused on grave shafts. In cases where excavation is involved, however, and where there are no skeletal remains and grave goods, our results also indicate that susceptibility studies might be used for grave identification.

In sum, the unmarked graves project has indicated that integrating down-hole geophysical and soil magnetic studies with near-surface geophysical techniques has the potential to improve the results gained with near-surface surveys alone. Grave shafts may be identified by anomalously low magnetic values and magnetic patterns that relate to disturbance and infilling. These patterns, though relatively consistent, are subtle and not invariable. Variability is probably related to the different ways in which graves are prepared and underscores the difficulties of working in these challenging cemetery environments. Down-hole susceptibility measurements provide a relatively non-destructive and efficient means of evaluating anomalies detected through near-surface surveys and identifying others that might not be detected by near-surface means. They serve as an additional tool, but not a replacement, for existing technologies.

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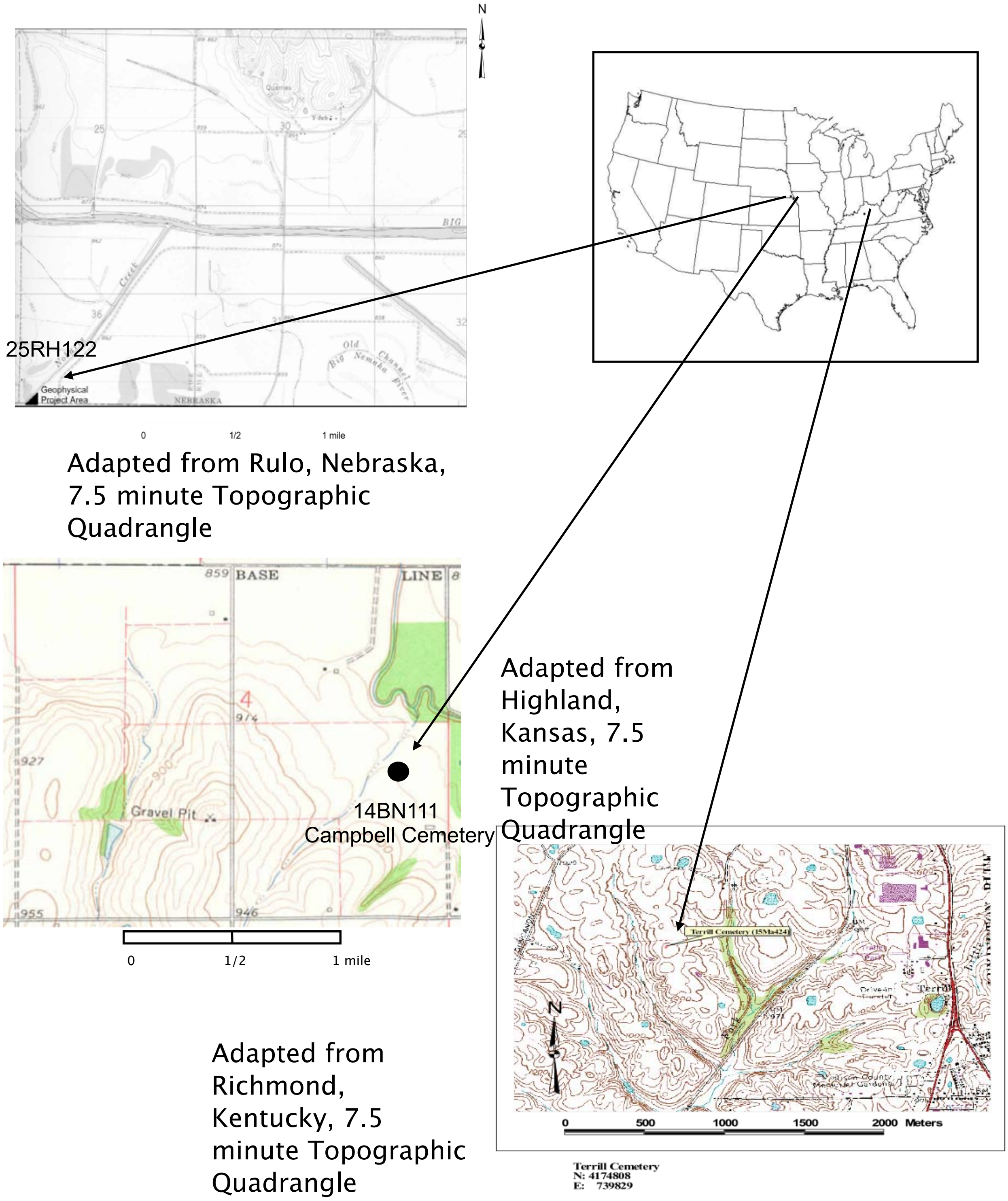
Identification of Unmarked Graves

Report Figures and Tables



Adapted from Rulo, Nebraska, 7.5 minute Topographic Quadrangle

Adapted from Highland, Kansas, 7.5 minute Topographic Quadrangle

Adapted from Richmond, Kentucky, 7.5 minute Topographic Quadrangle

Terrill Cemetery
N: 4174808
E: 739829

Figure 1. Location of the three cemeteries investigated as part of this project.

Figure 2. The location of the Sac and Fox family cemetery (above) and a 1907 photo of the spirit house burials (below).

Figure 3. The Campbell Cemetery.

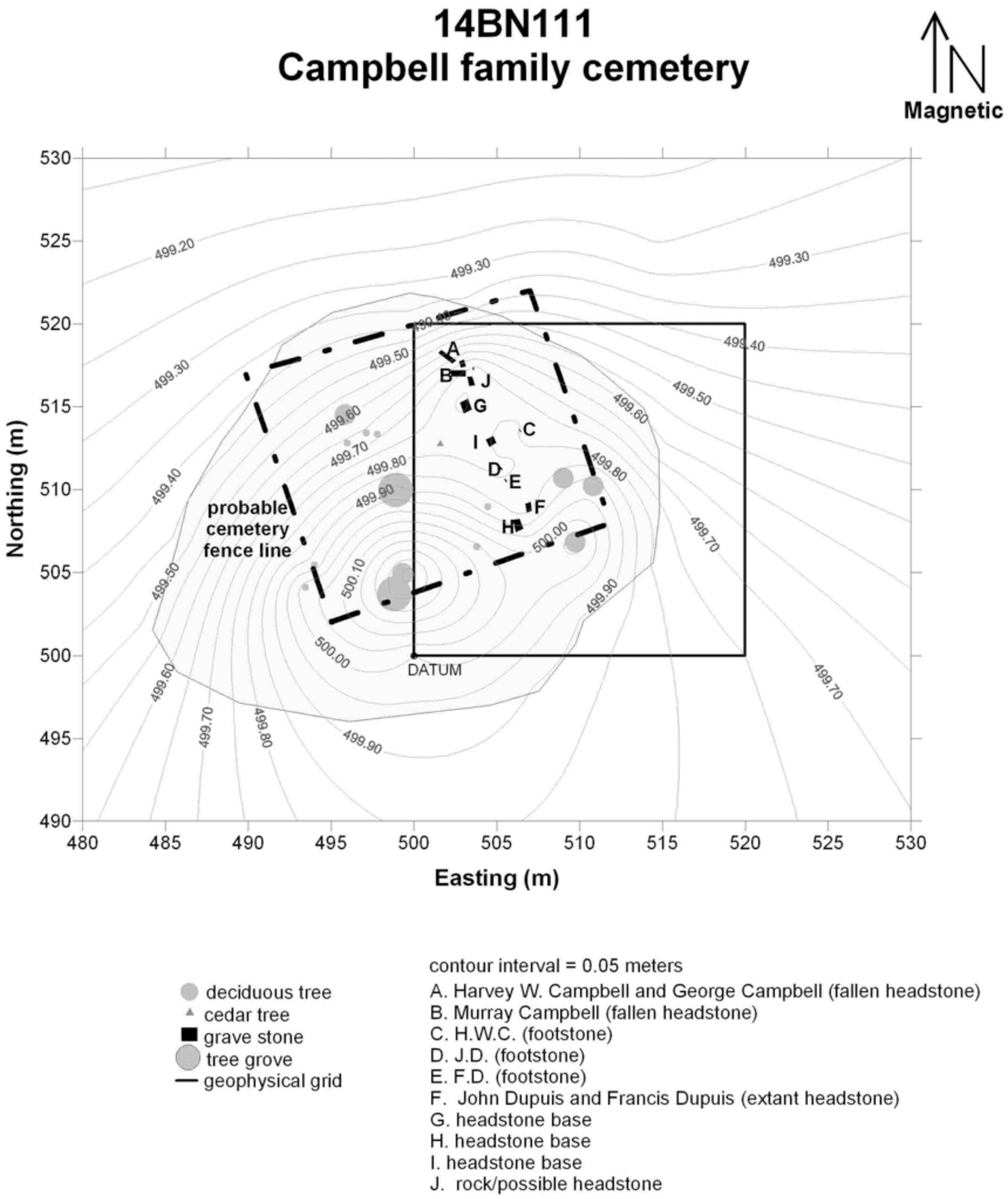


Figure 4. Plan map of the Campbell Cemetery.

Figure 5. Terrill Cemetery before and after the removal of trees.
(Courtesy of the Kentucky Archaeological Survey)

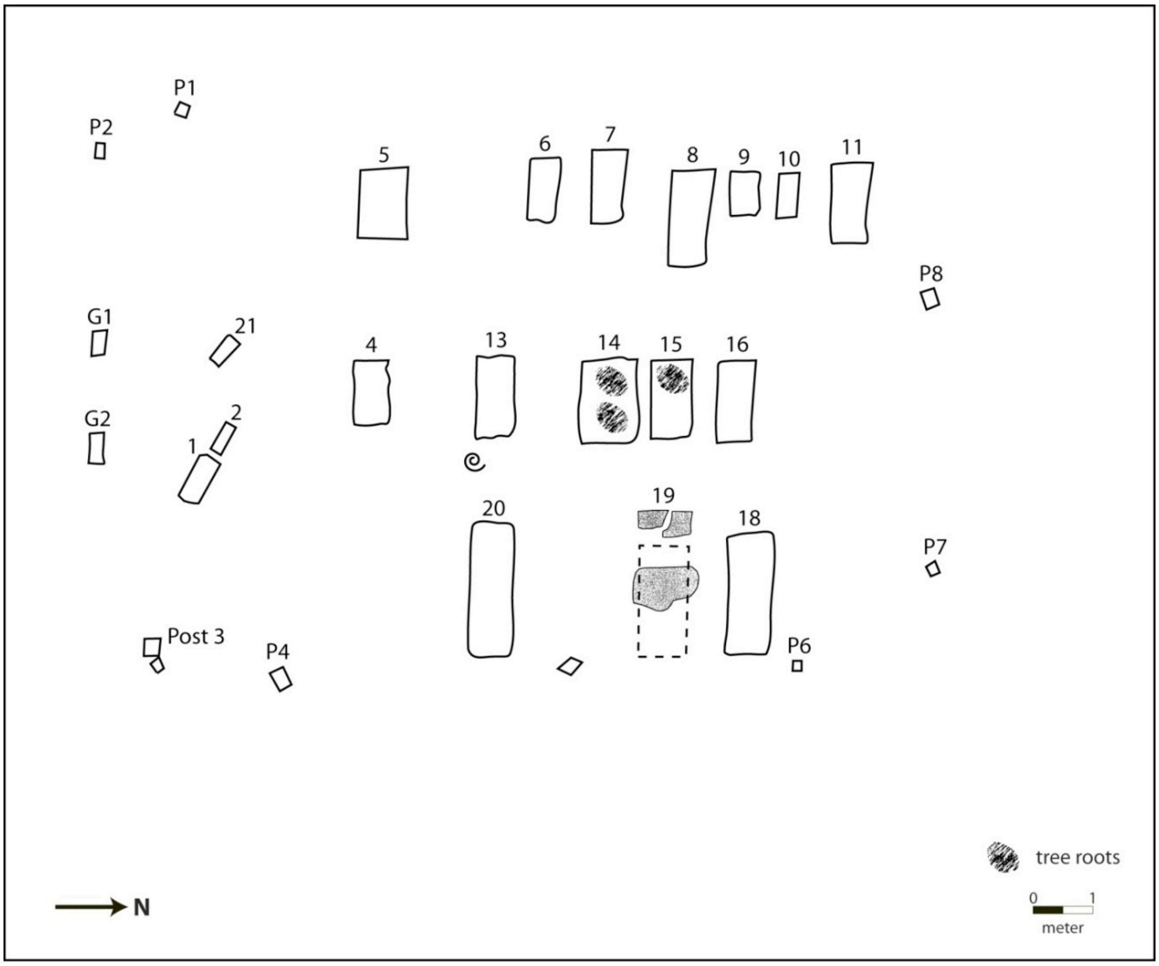


Figure 6. Plan map of the Terrill Cemetery. Burials 14 and 15 are shown although they were later discovered to be the result of tree root disturbance. (Courtesy of the Kentucky Archaeological Survey)

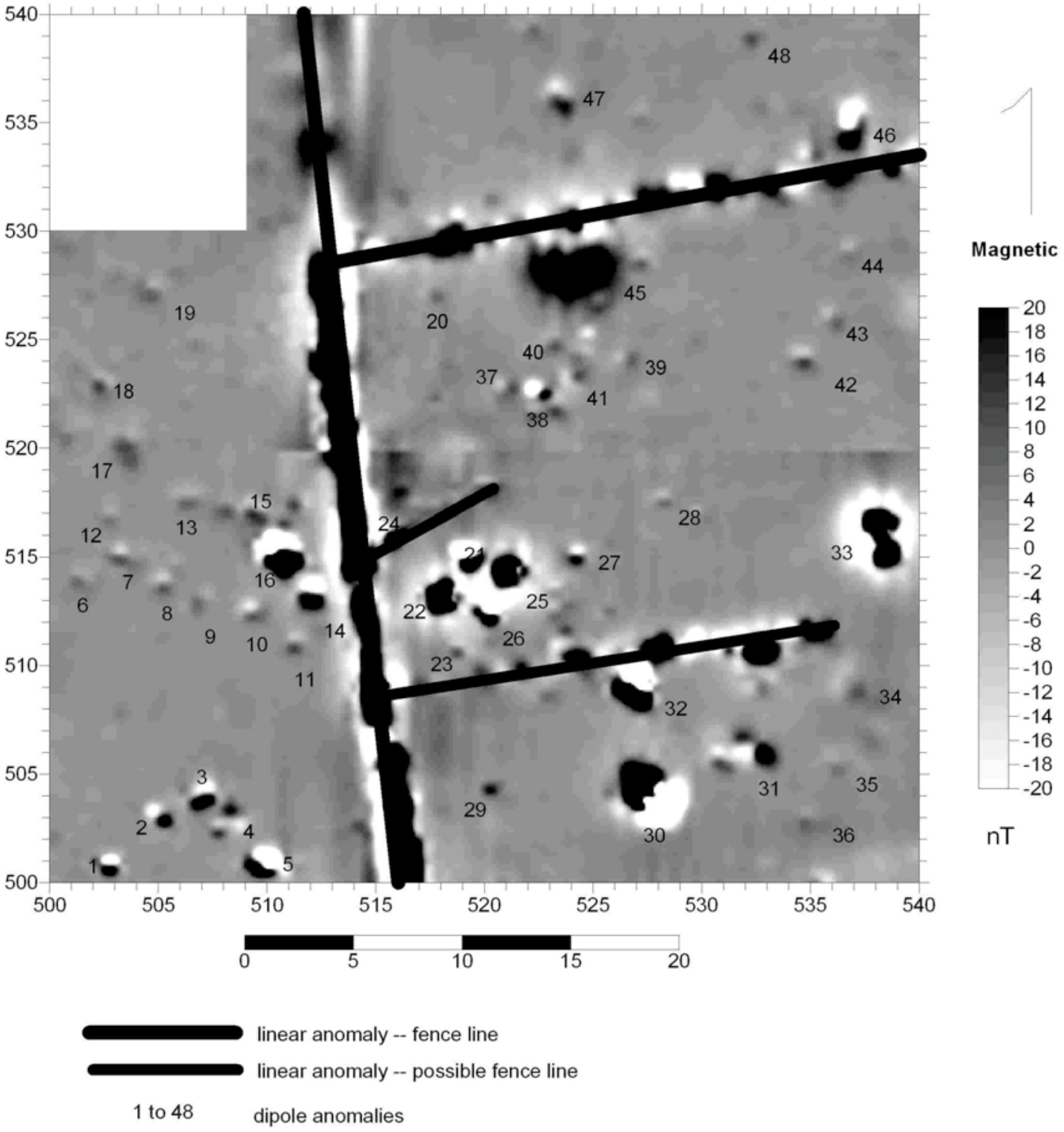


Figure 7. Gradiometer results at the Sac and Fox family cemetery.

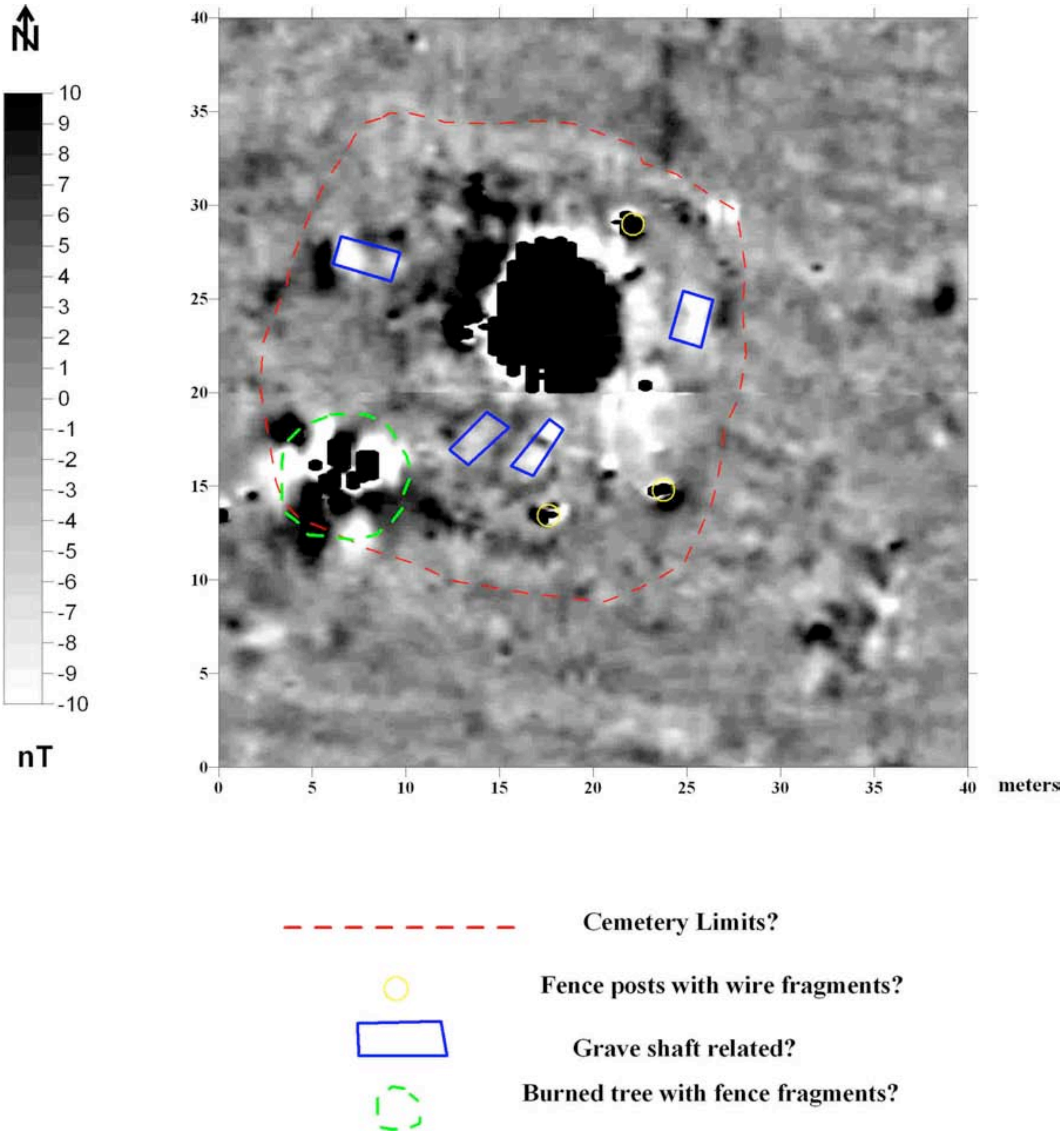


Figure 8. Gradiometer results at the Terrill Cemetery with preliminary interpretation.

Figure 9. Coring with the JMC backsaver (above) and Oakfield push tube probe (below).

Figure 10. Down-hole tests at the Campbell (above) and Terrill (below) cemeteries.

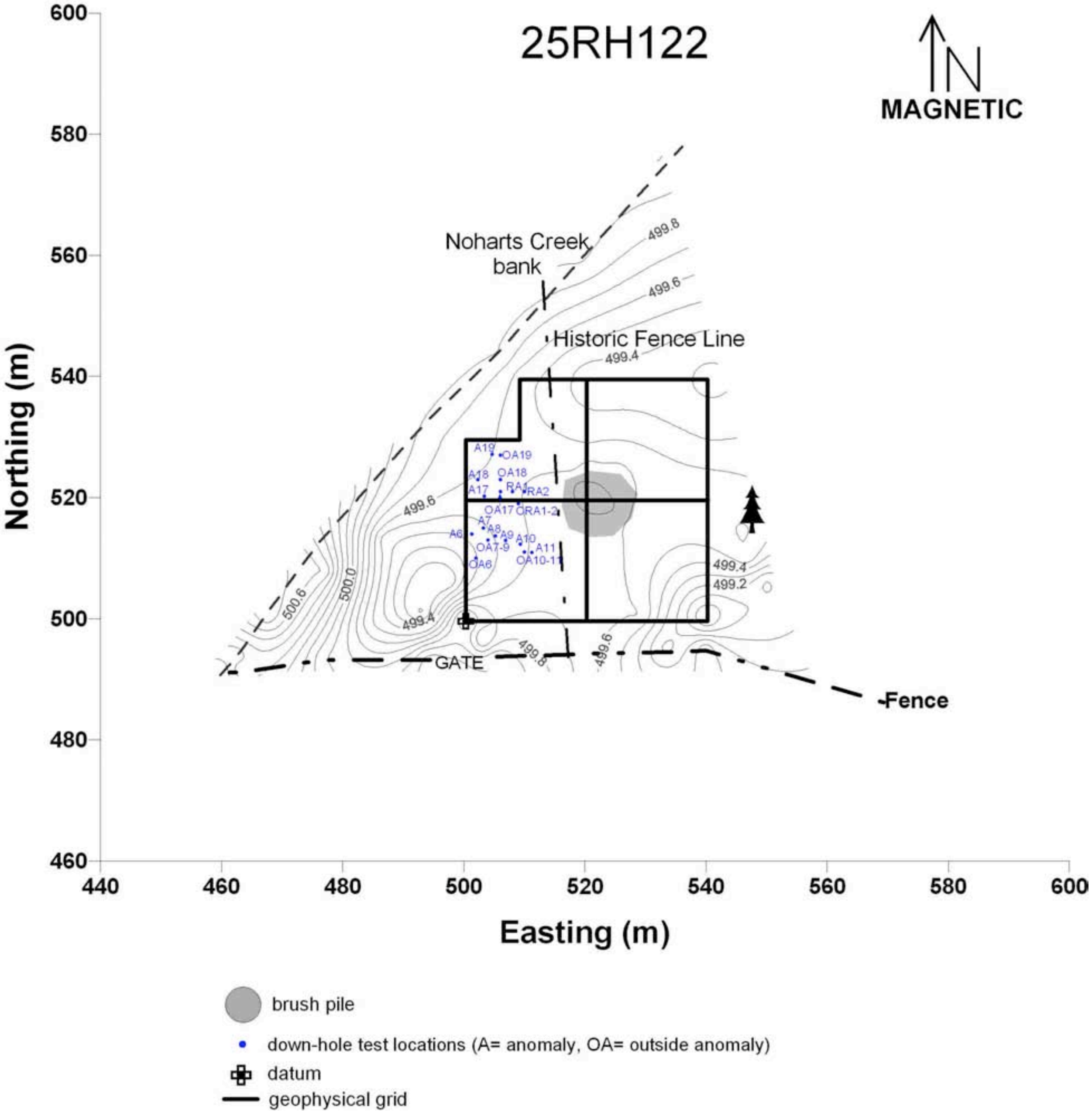


Figure 11. Location of down-hole tests at the Sac and Fox family cemetery.

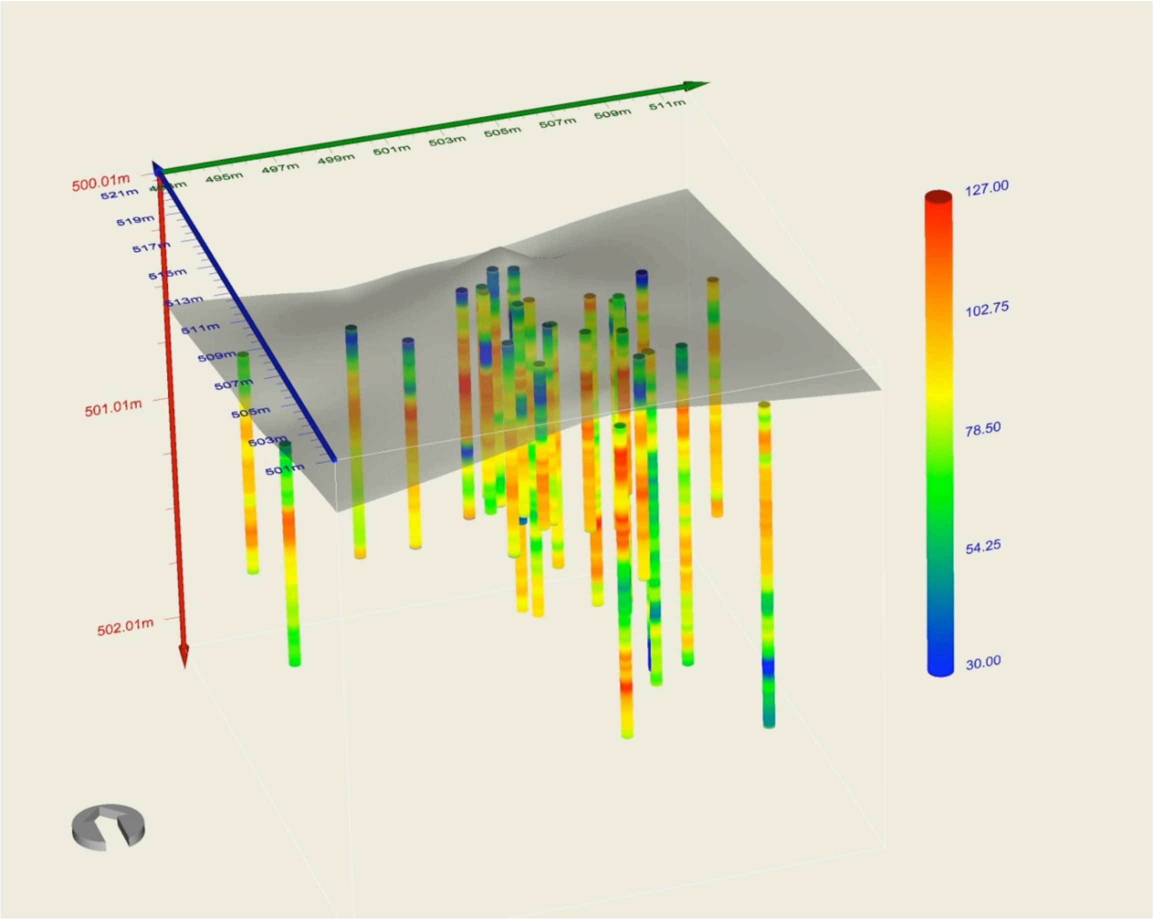


Figure 12. A three-dimensional presentation of down-hole tests at the Campbell Cemetery. Multiply values by 1.7E-5 to approximate SI susceptibility.

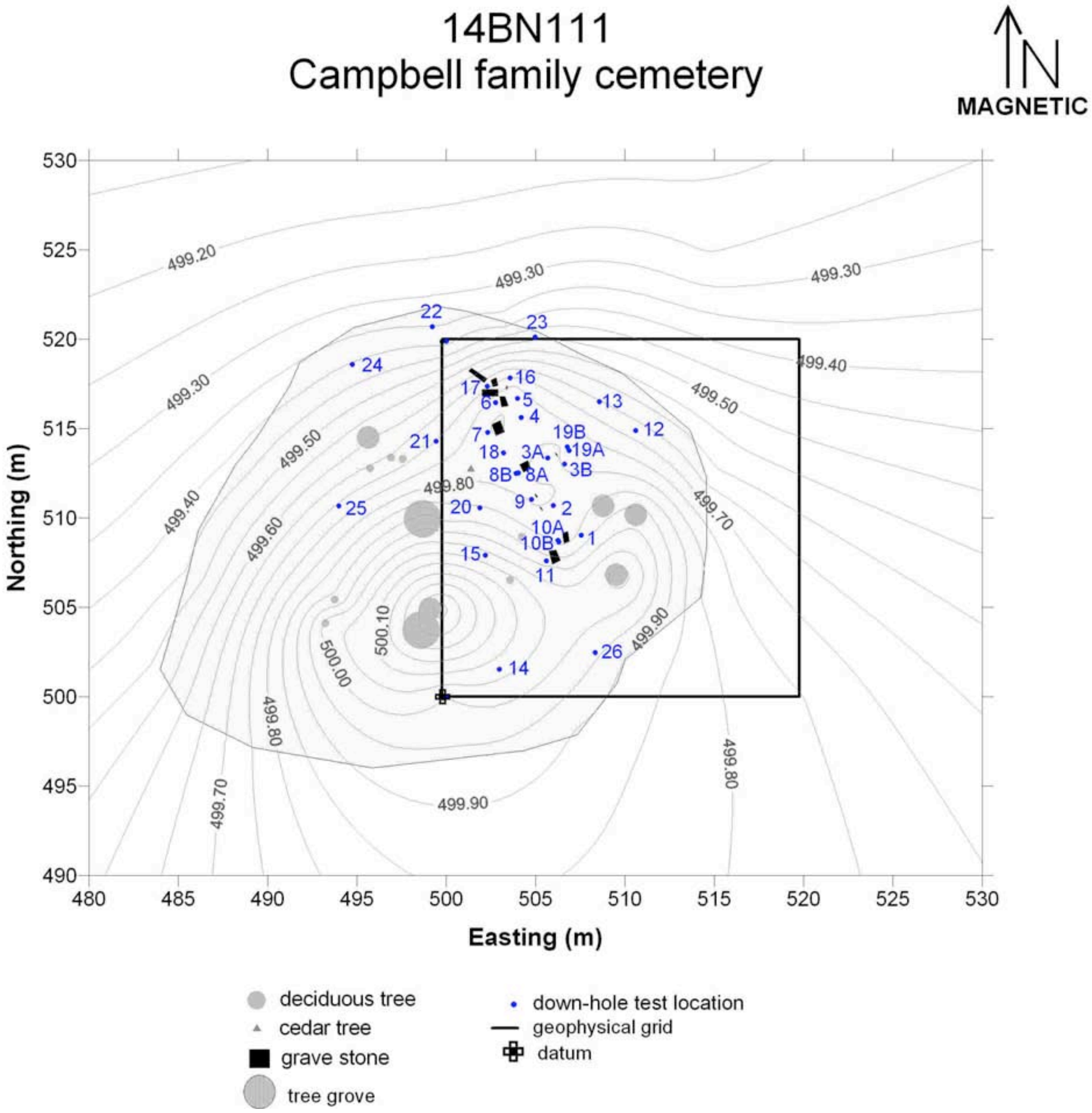


Figure 13. Location of down-hole tests at the Campbell Cemetery.

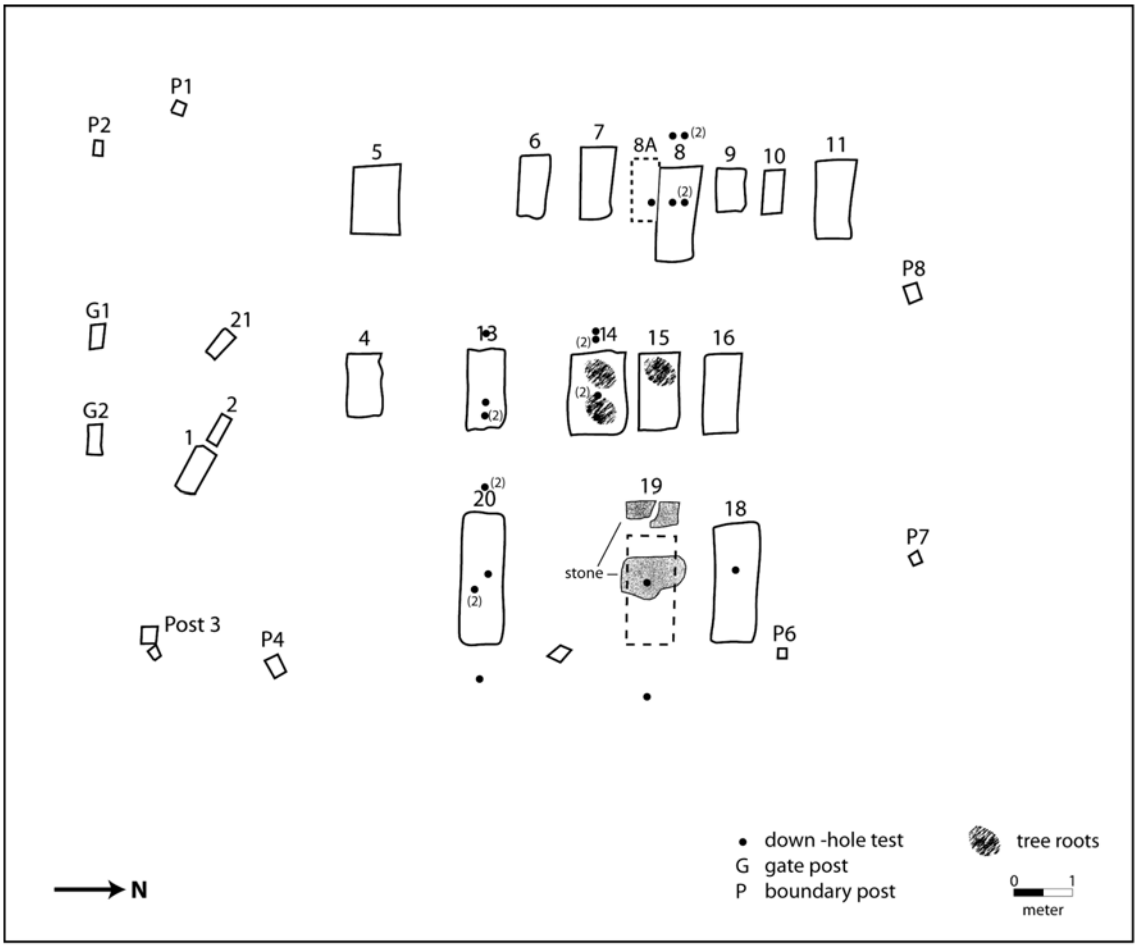


Figure 14. Location of down-hole tests at the Terrill Cemetery. The location of the second test conducted within or outside of a grave shaft is designated by the number 2 (in parentheses).

Figure 15. Penetrometer testing at the Campbell Cemetery.

Figure 16. Collecting soils for magnetic analyses.

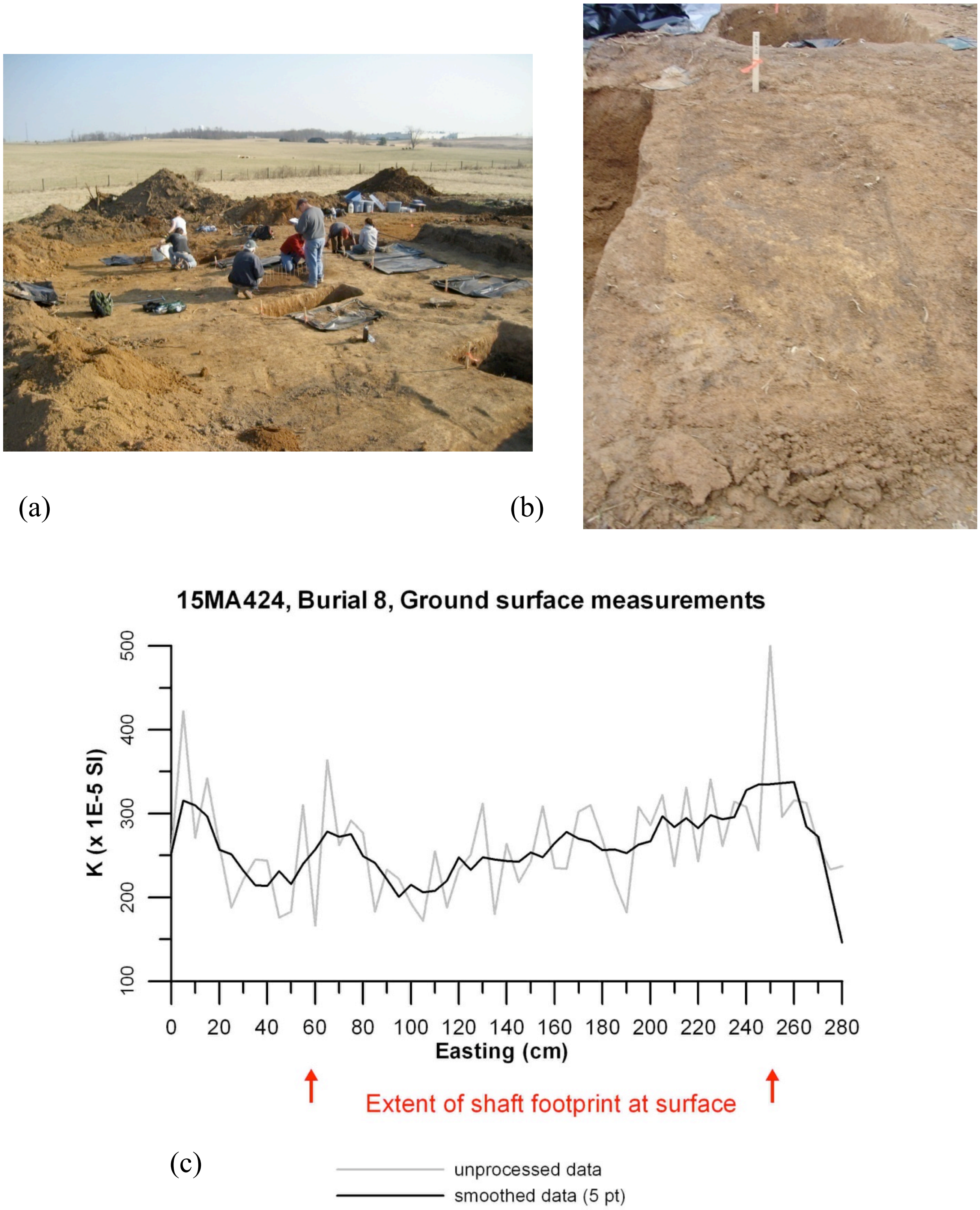


Figure 17. Definition of grave shafts at the exposed surface: (a) general view of the cemetery and grid layout for measurements in c below (Photo courtesy of the Kentucky Archaeological Survey); (b) Burial 19 shaft soil contrasts; (c) susceptibility transect across the Burial 8 shaft.

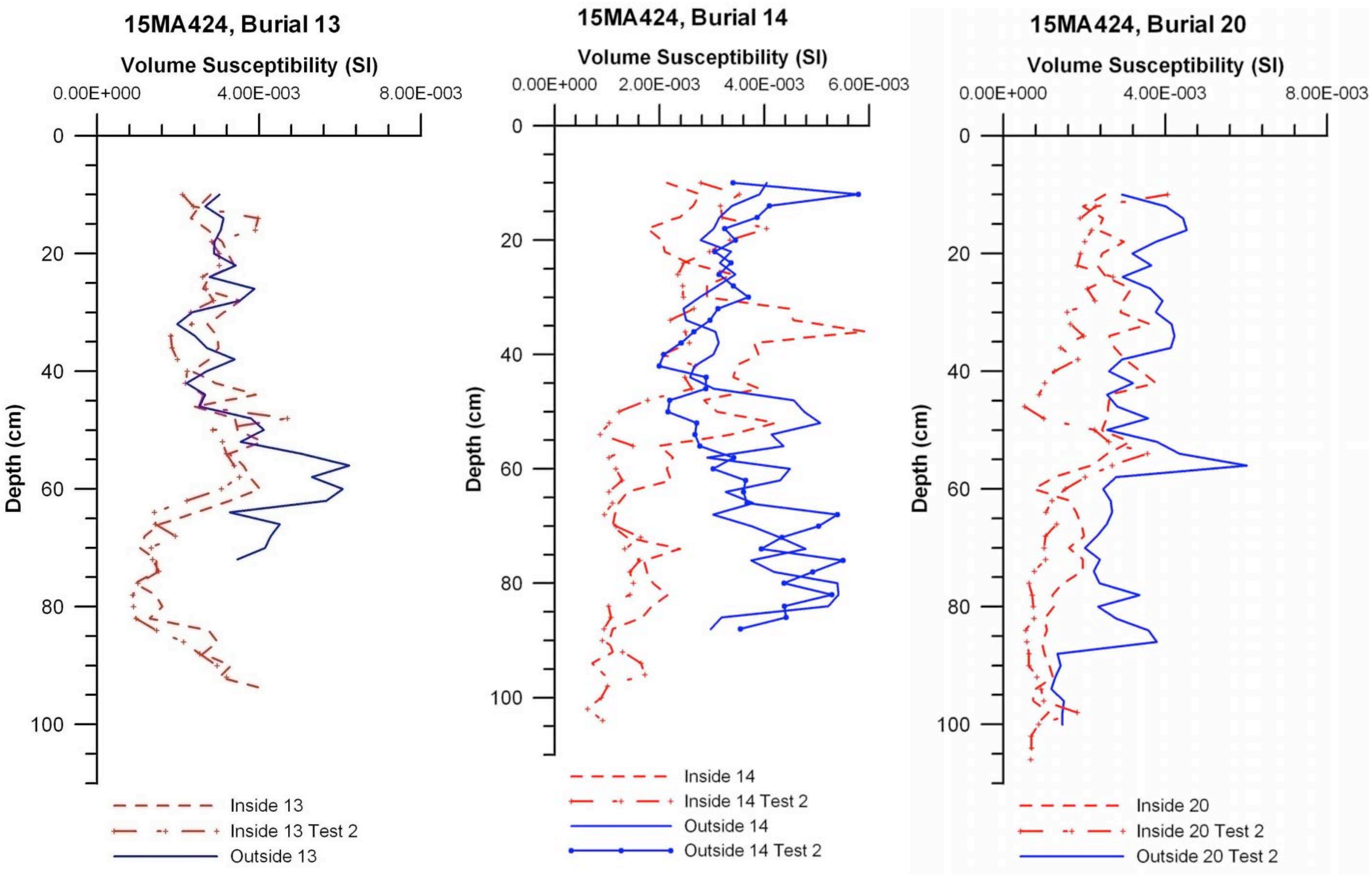


Figure 18. Down-hole tests associated with three grave shafts defined at the Terrill Cemetery. Excavation of the Burial 14 shaft indicated that this was not a grave but disturbance associated with tree roots.

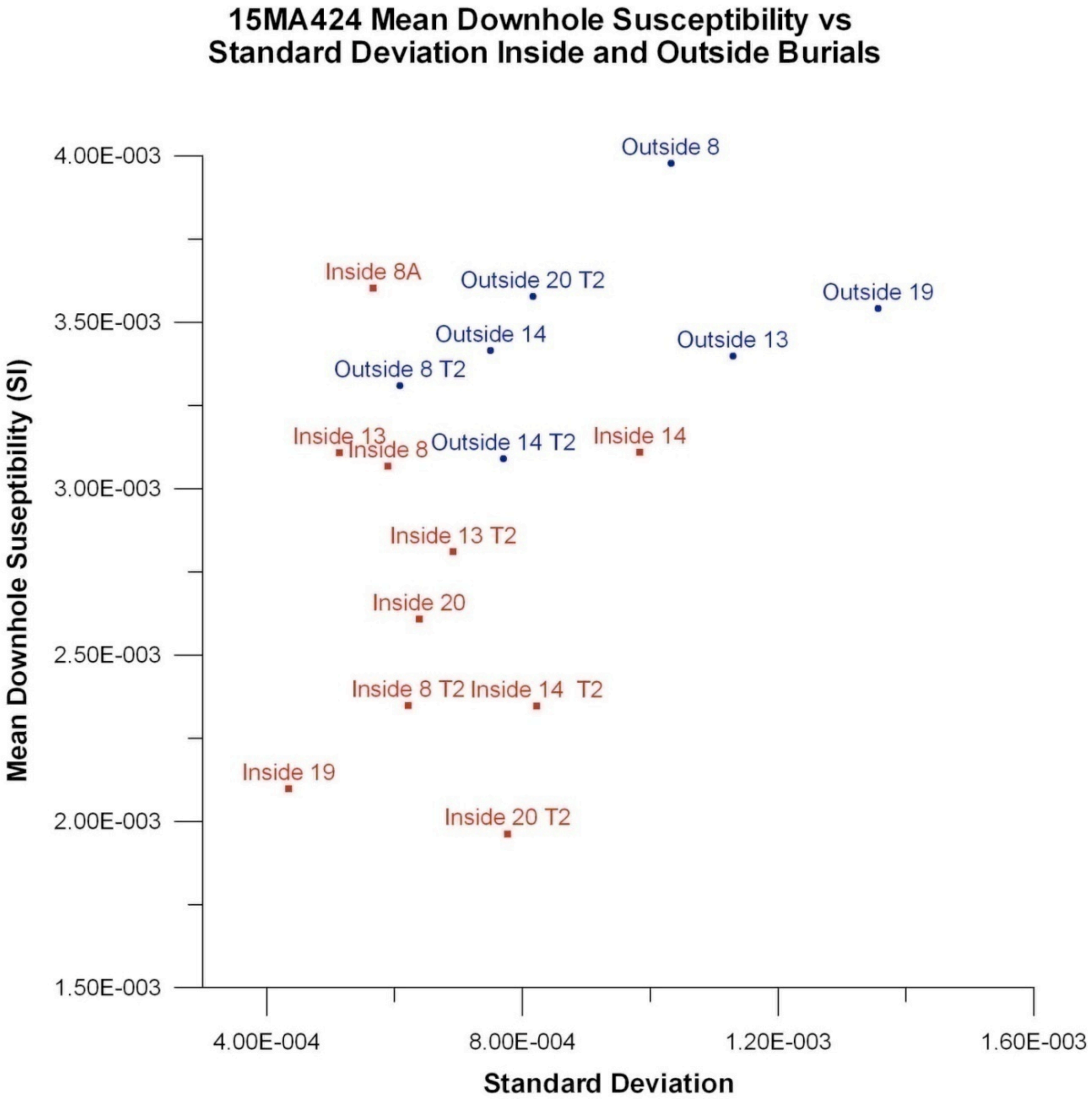


Figure 19. Mean susceptibility values versus standard deviation for all down-hole tests at the Terrill Cemetery. Tests inside grave shafts are shown in red and tests outside the shafts are labeled in blue.

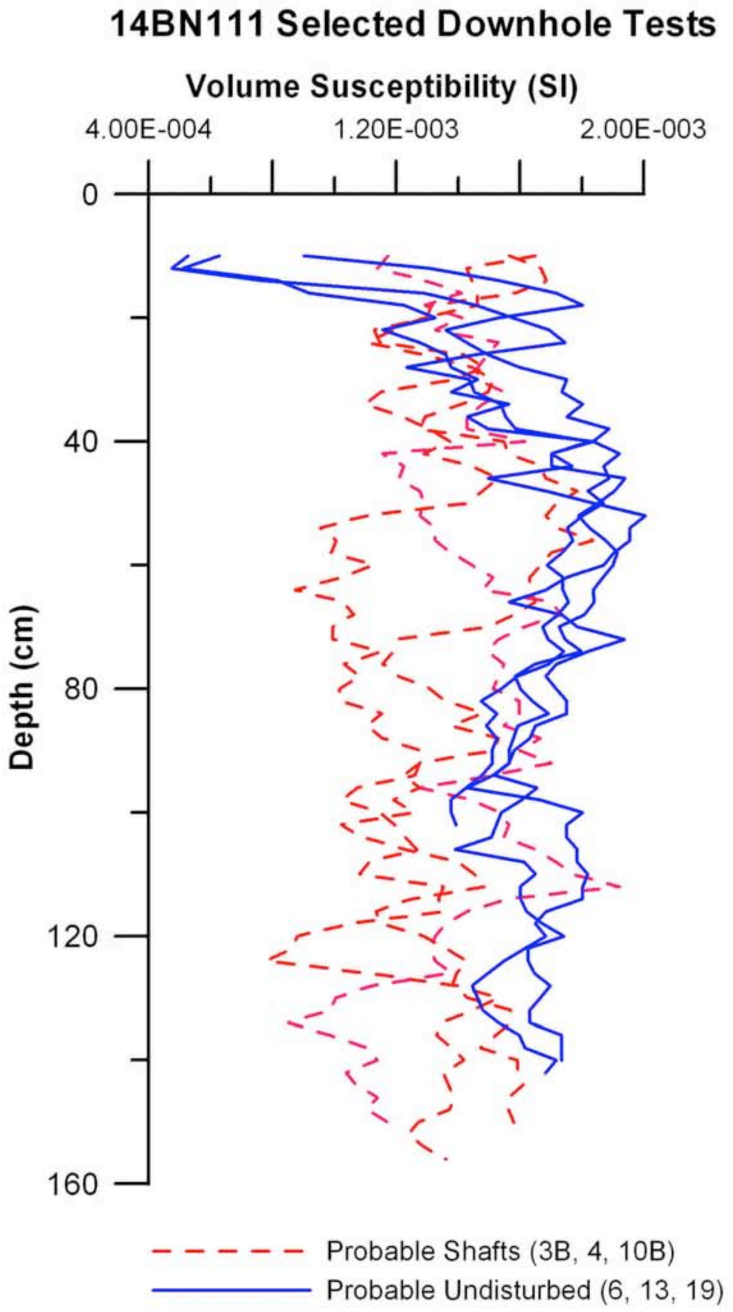


Figure 20. Selected tests at the Campbell Cemetery illustrating down-hole susceptibility contrasts between grave shafts and undisturbed areas.

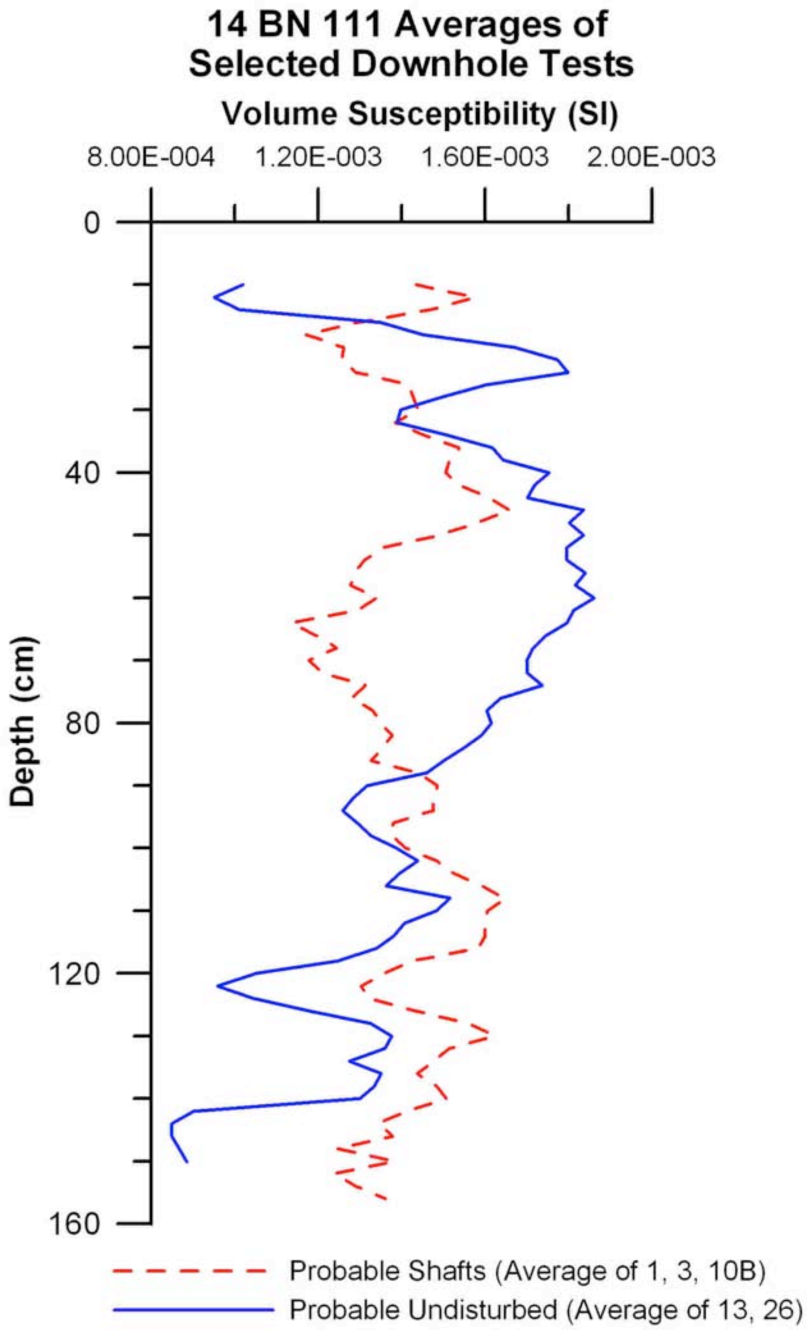


Figure 21. Average magnetic profiles of grave shafts and undisturbed ground at the Campbell Cemetery produced using a number of probable shaft and undisturbed ground locations.

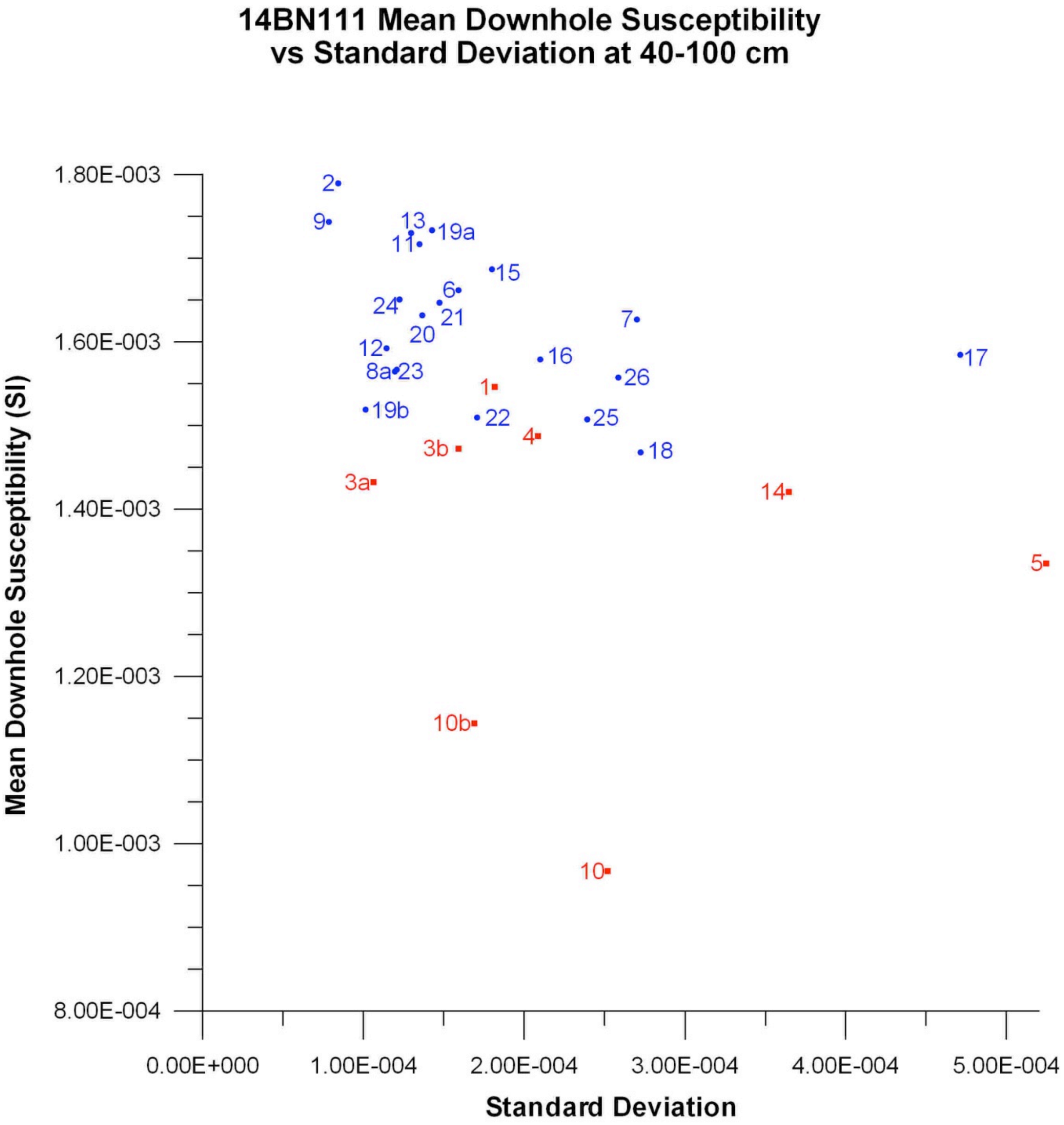


Figure 22. Mean susceptibility values versus standard deviation for all down-hole tests at the Campbell Cemetery. Probable grave shafts are indicated in red. Other tests labeled in blue are either undisturbed or of uncertain classification.

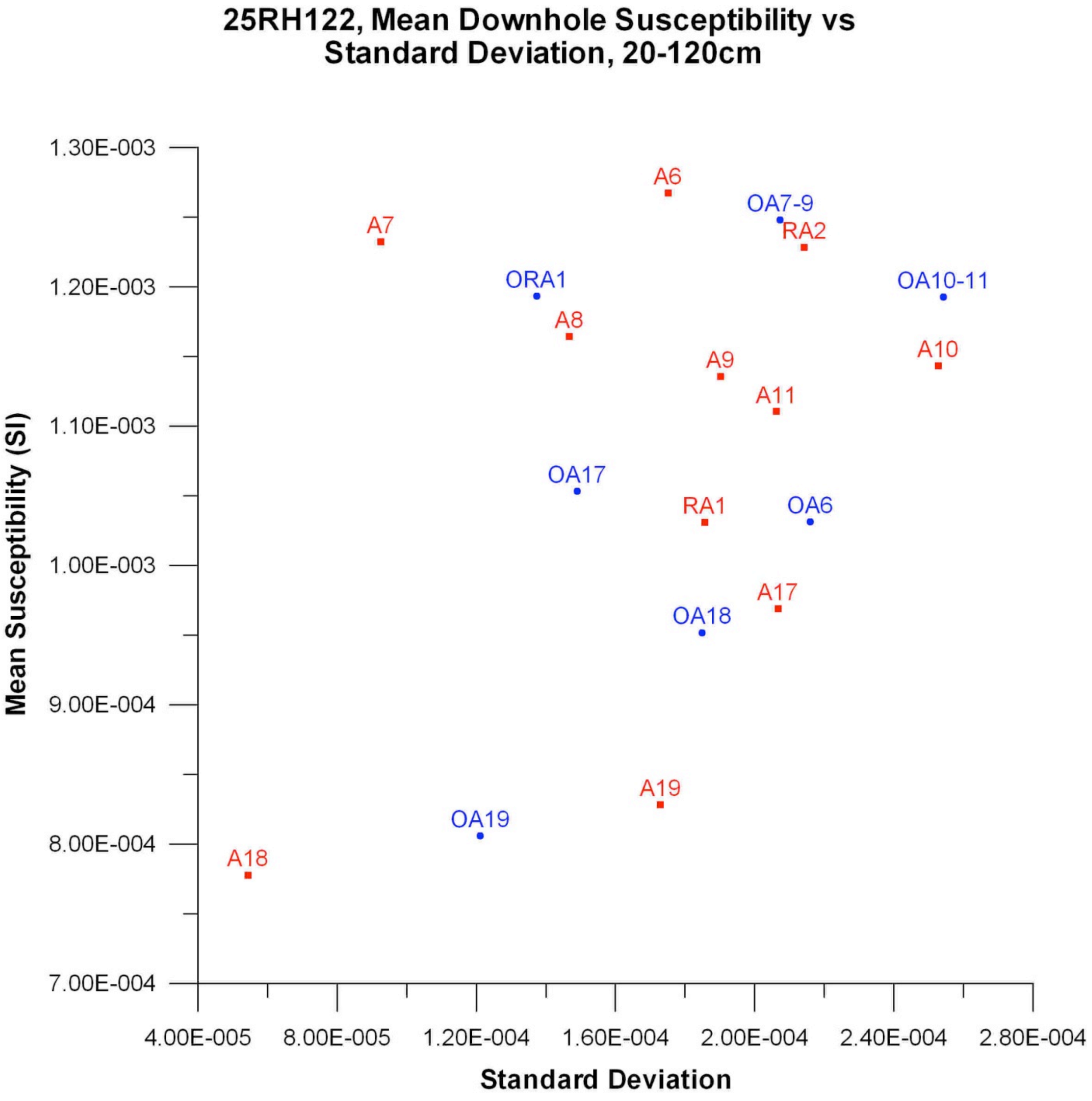


Figure 23. Mean susceptibility values versus standard deviation for all down-hole tests at the Sac and Fox family cemetery. Tests within anomalies (A#s) are labeled in red while tests outside anomalies (OA#s) are labeled in blue.

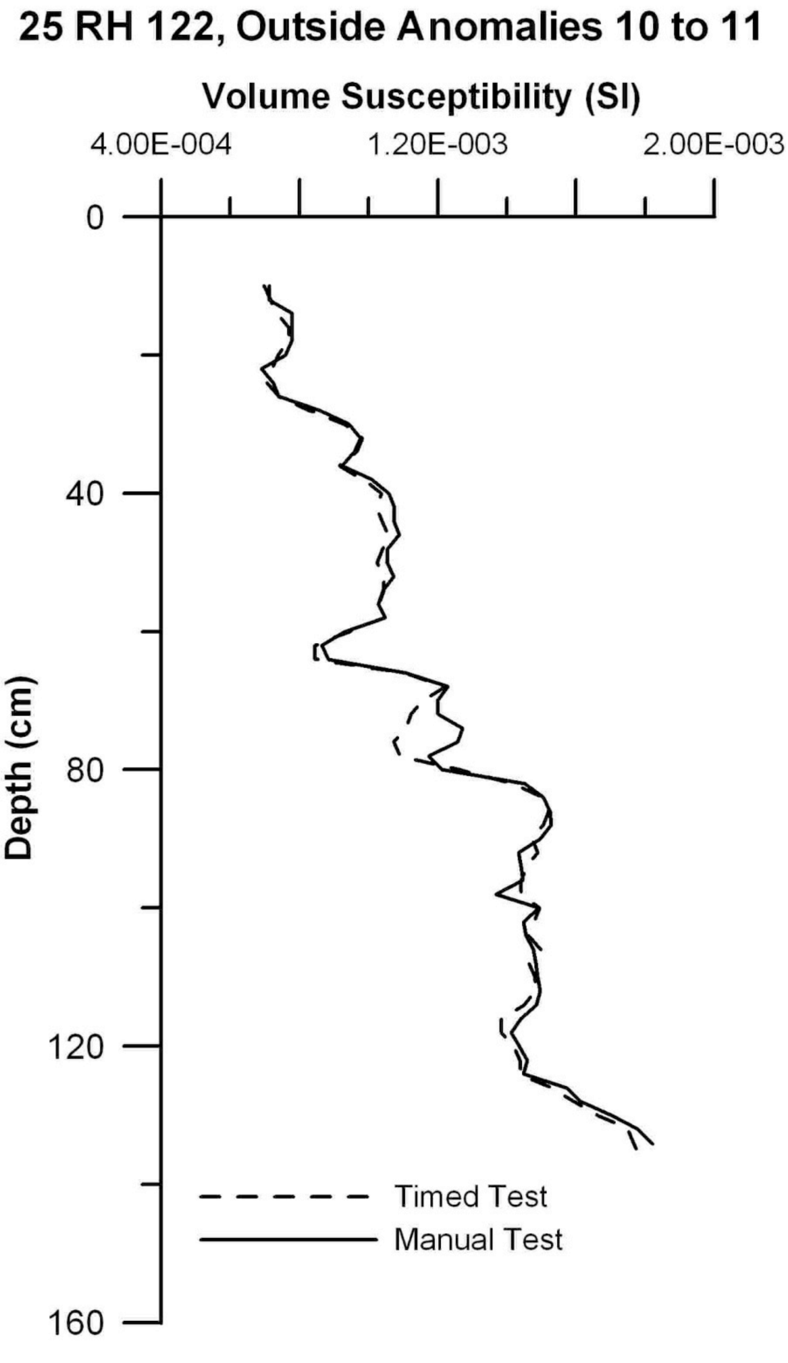


Figure 24. Agreement of timed and manual down-hole tests. An example from the Sac and Fox family cemetery.

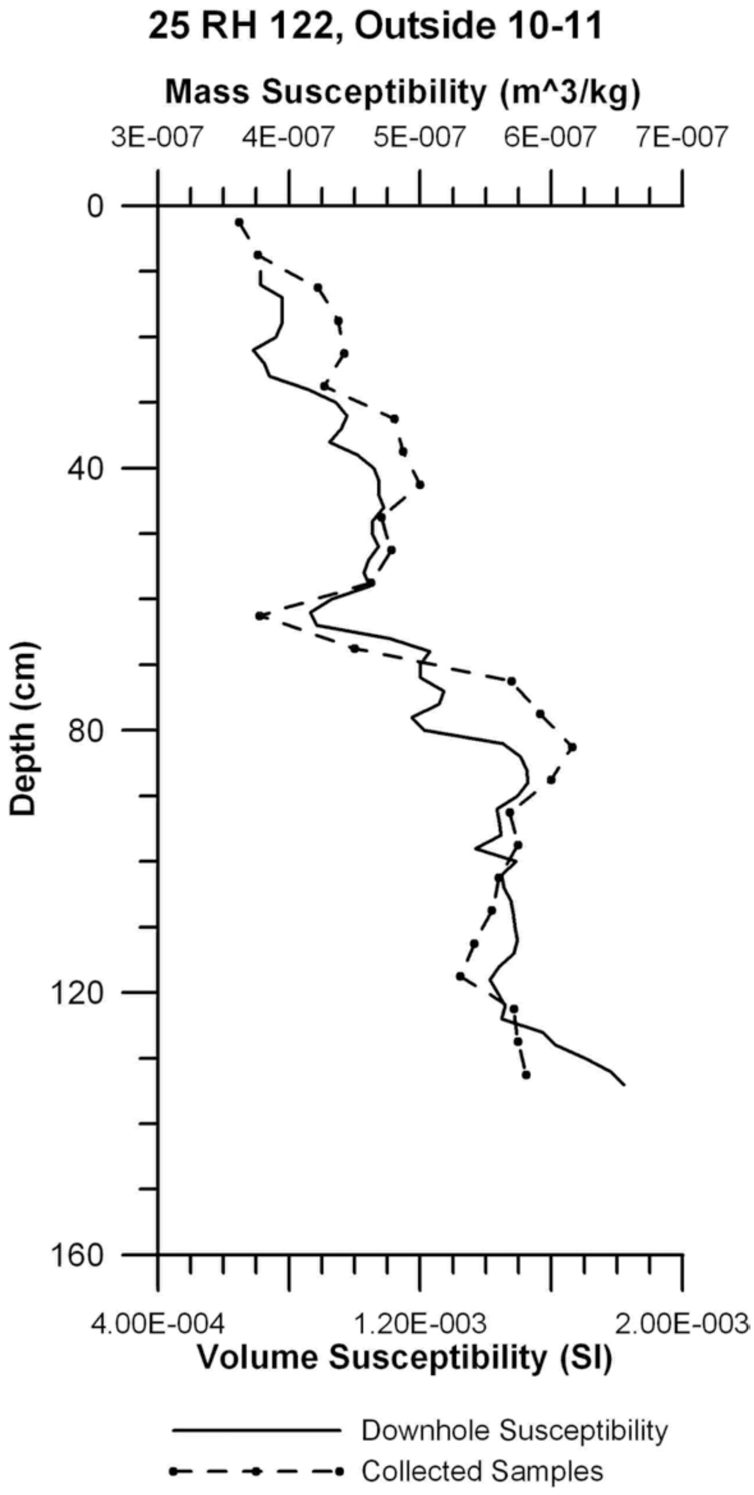


Figure 25. Agreement of down-hole tests and mass magnetic susceptibilities measured on collected samples . An example from the Sac and Fox family cemetery.

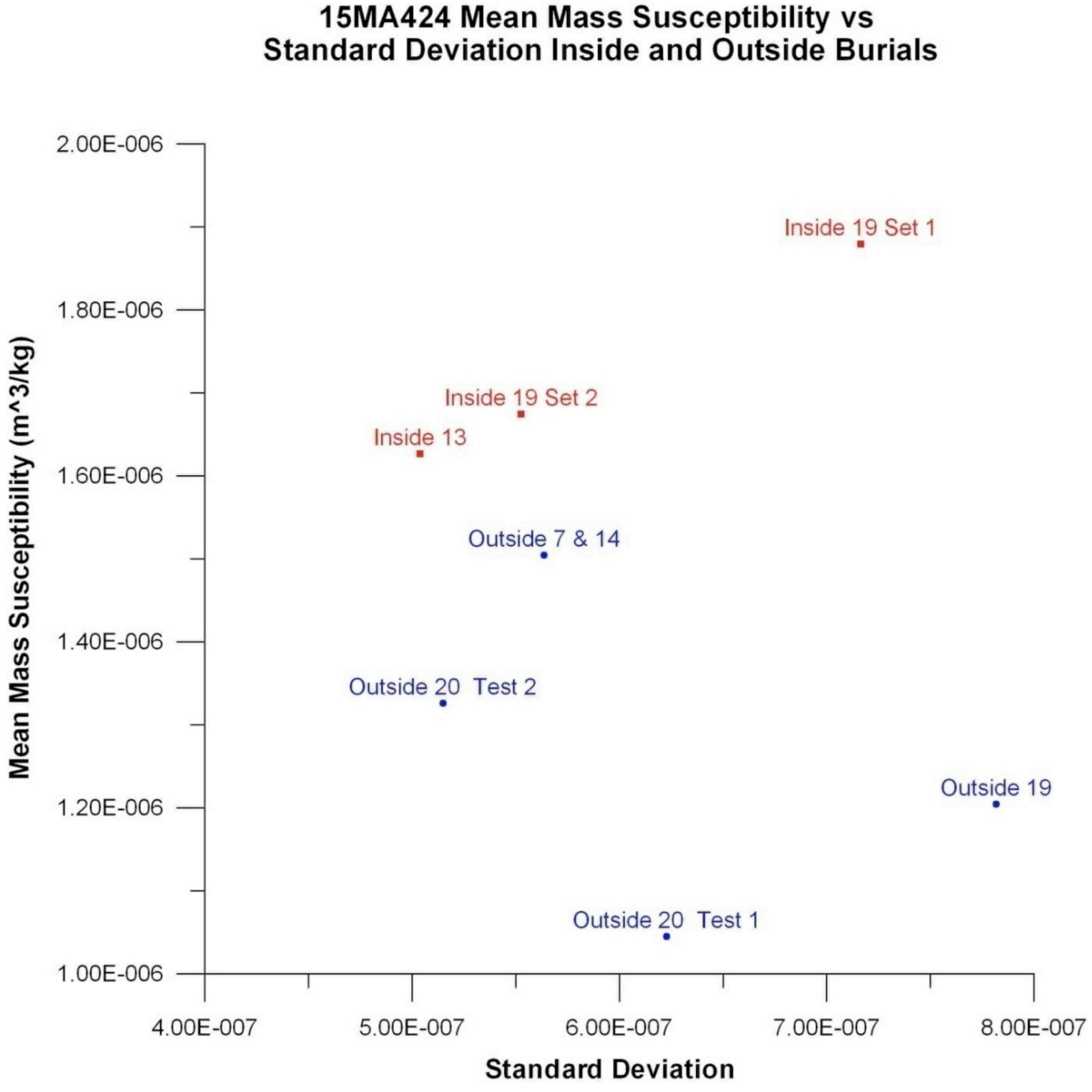


Figure 26. Mean mass magnetic susceptibility values versus standard deviation for all sampled locations at the Terrill Cemetery. Locations of samples collected inside grave shafts are shown in red and those from outside the shafts are labeled in blue.

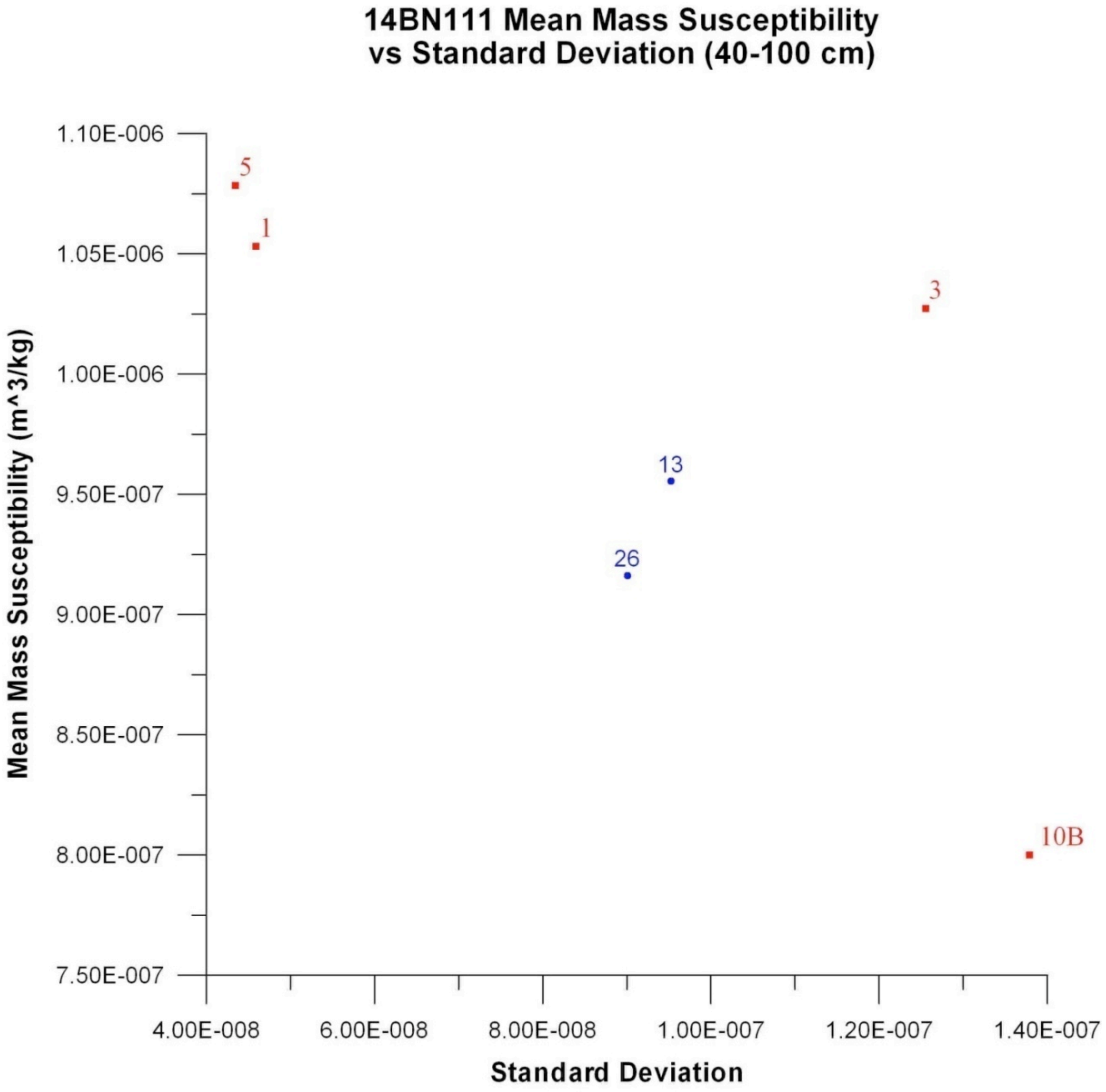


Figure 27. Mean mass magnetic susceptibility values versus standard deviation for all sampled locations at the Campbell Cemetery. Locations of samples from probable grave shafts are shown in red and those from undisturbed areas are labeled in blue.

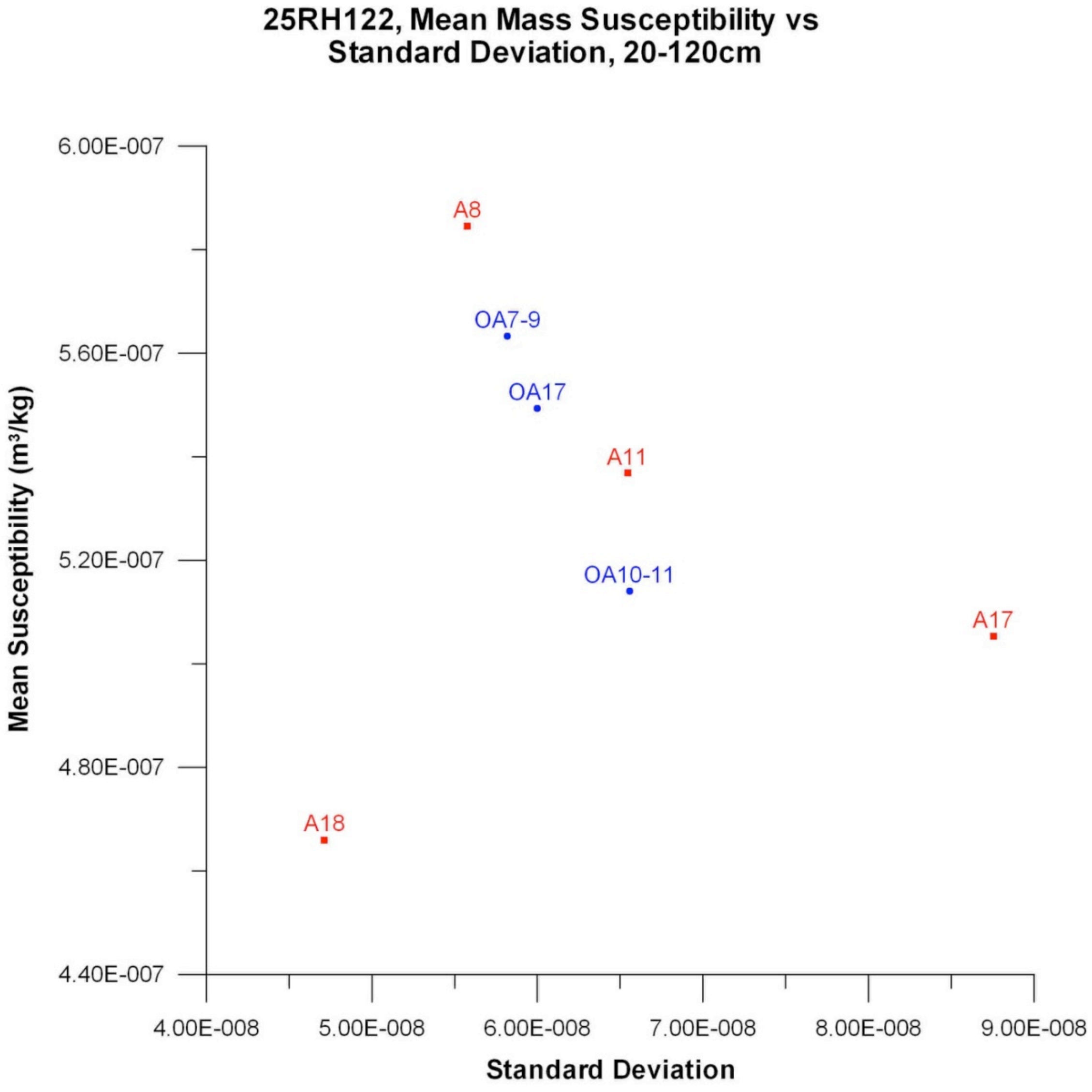


Figure 28. Mean mass magnetic susceptibility values versus standard deviation for all sampled locations at the Sac and Fox family cemetery. Locations of samples collected inside anomalies are labeled in red and those from outside anomalies are labeled in blue.

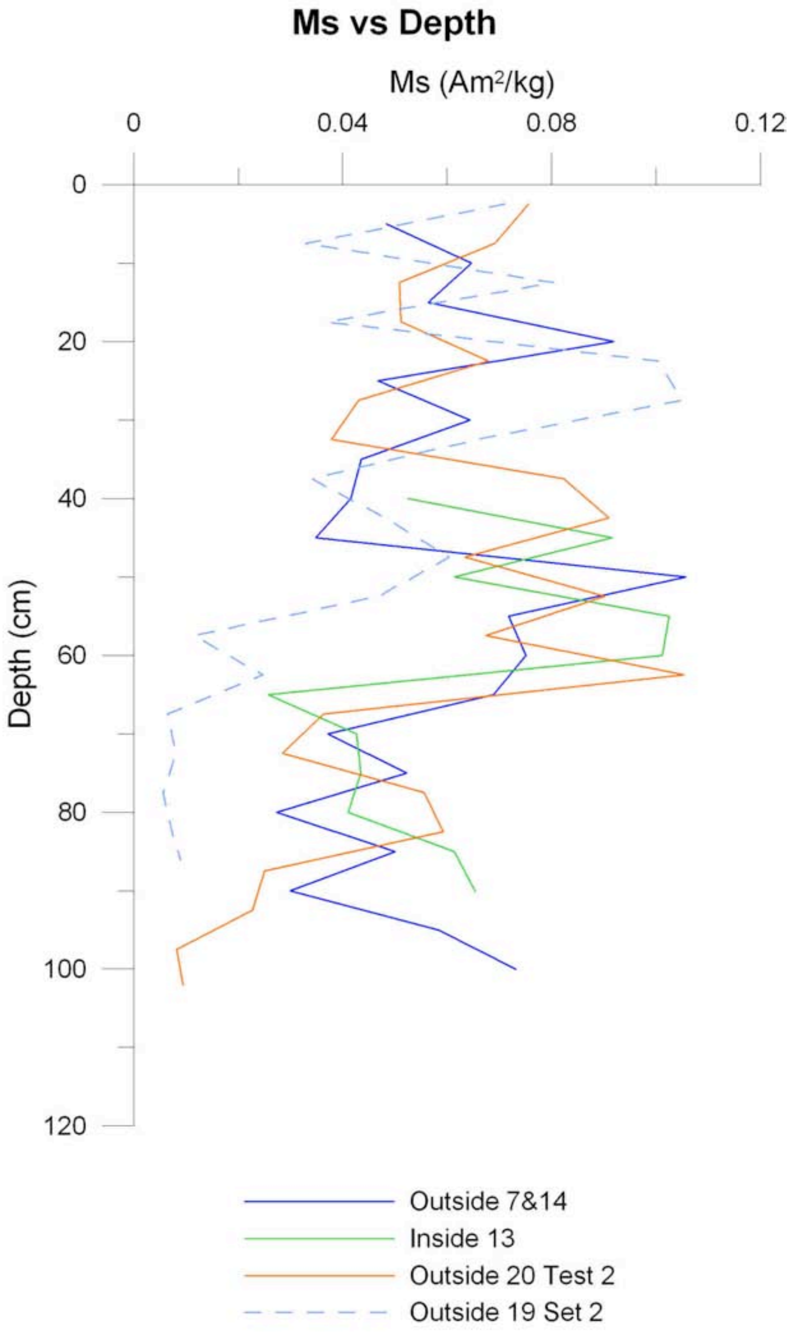


Figure 29. Variation of saturation magnetization with depth for samples collected within and outside grave shafts at the Terrill Cemetery.

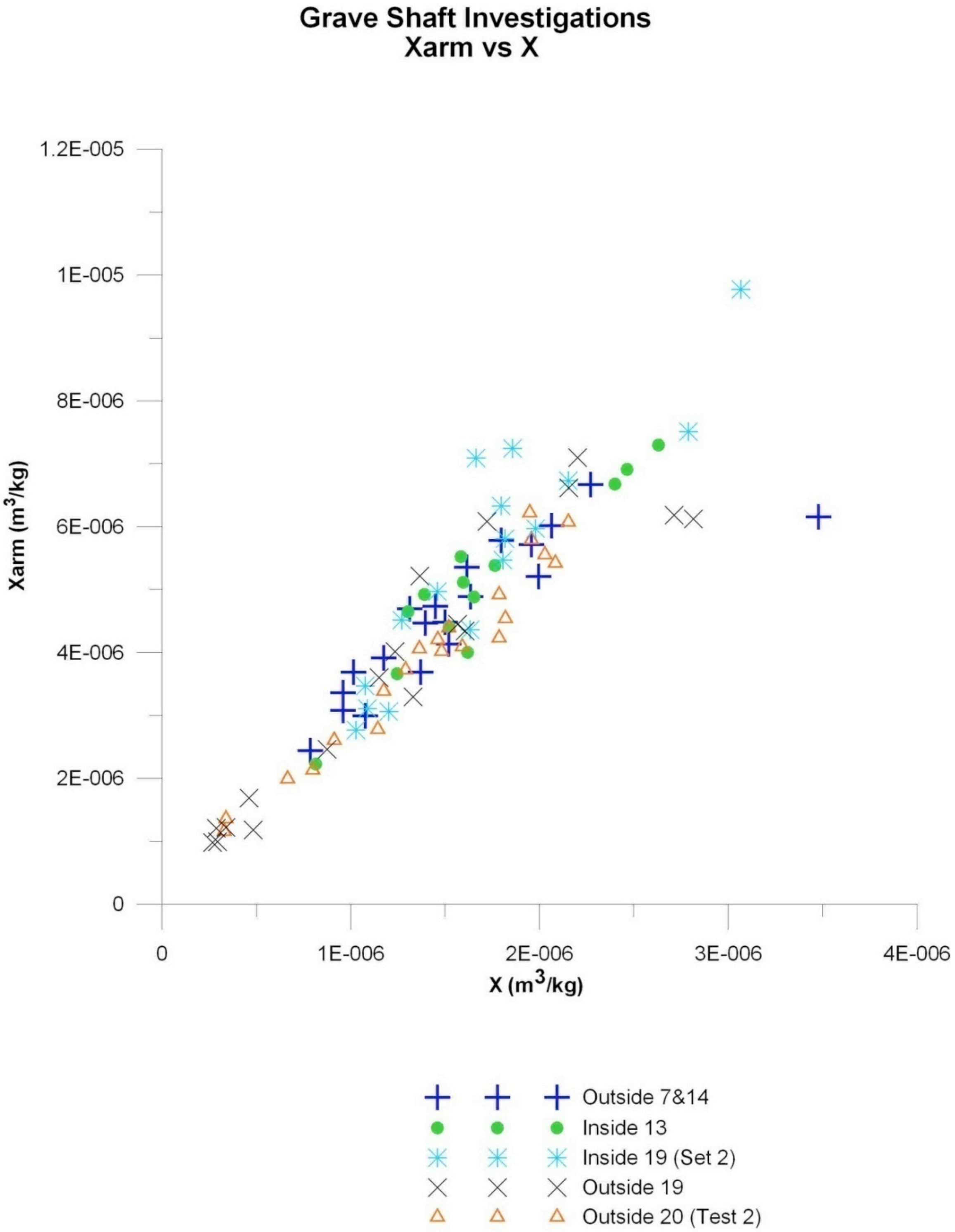


Figure 30. Plot of ARM susceptibility versus mass magnetic susceptibility for samples collected within and outside of grave shafts at the Terrill Cemetery.

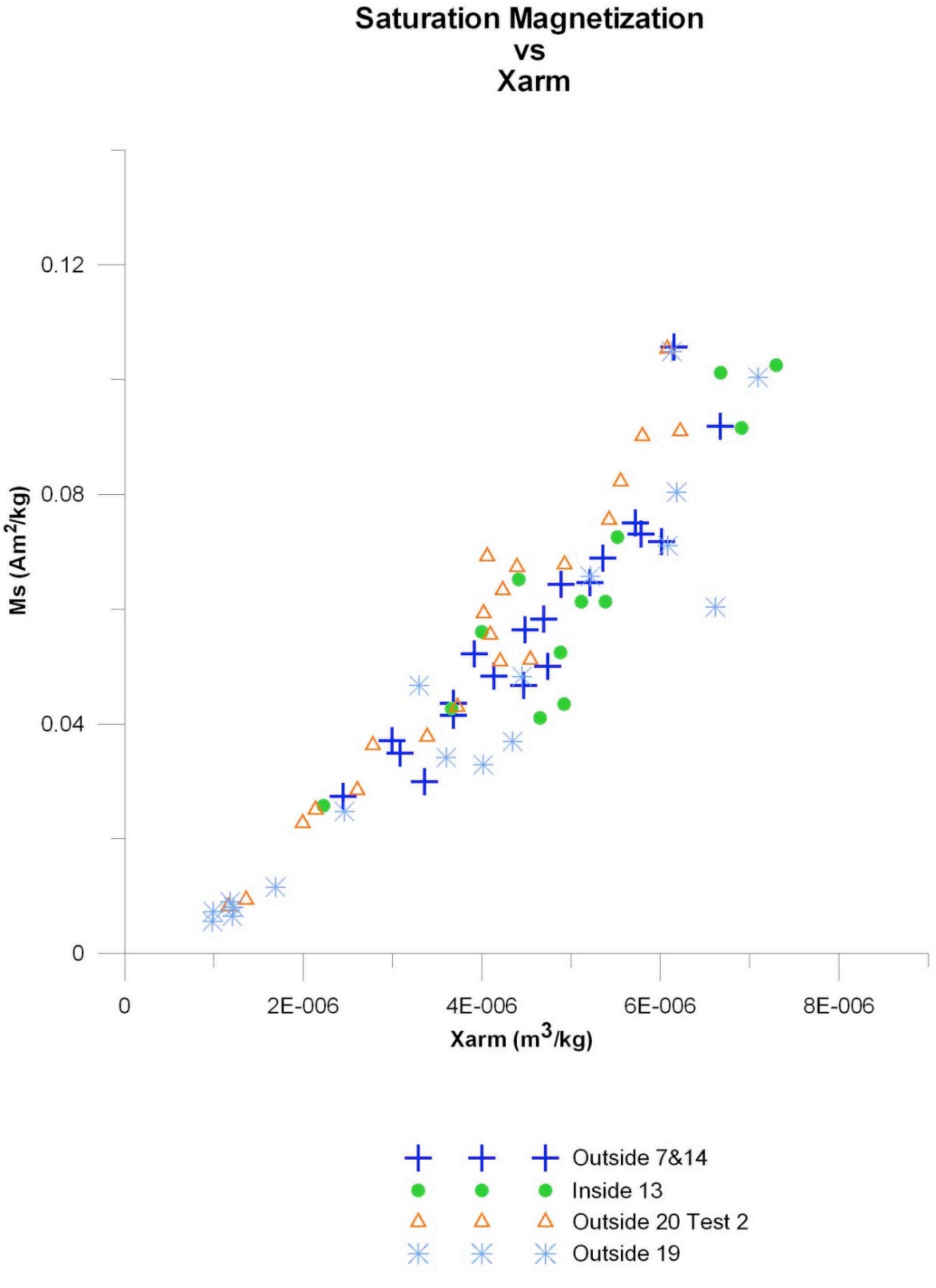


Figure 31. Plot of saturation magnetization versus ARM susceptibility for samples collected within and outside of grave shafts at the Terrill Cemetery.

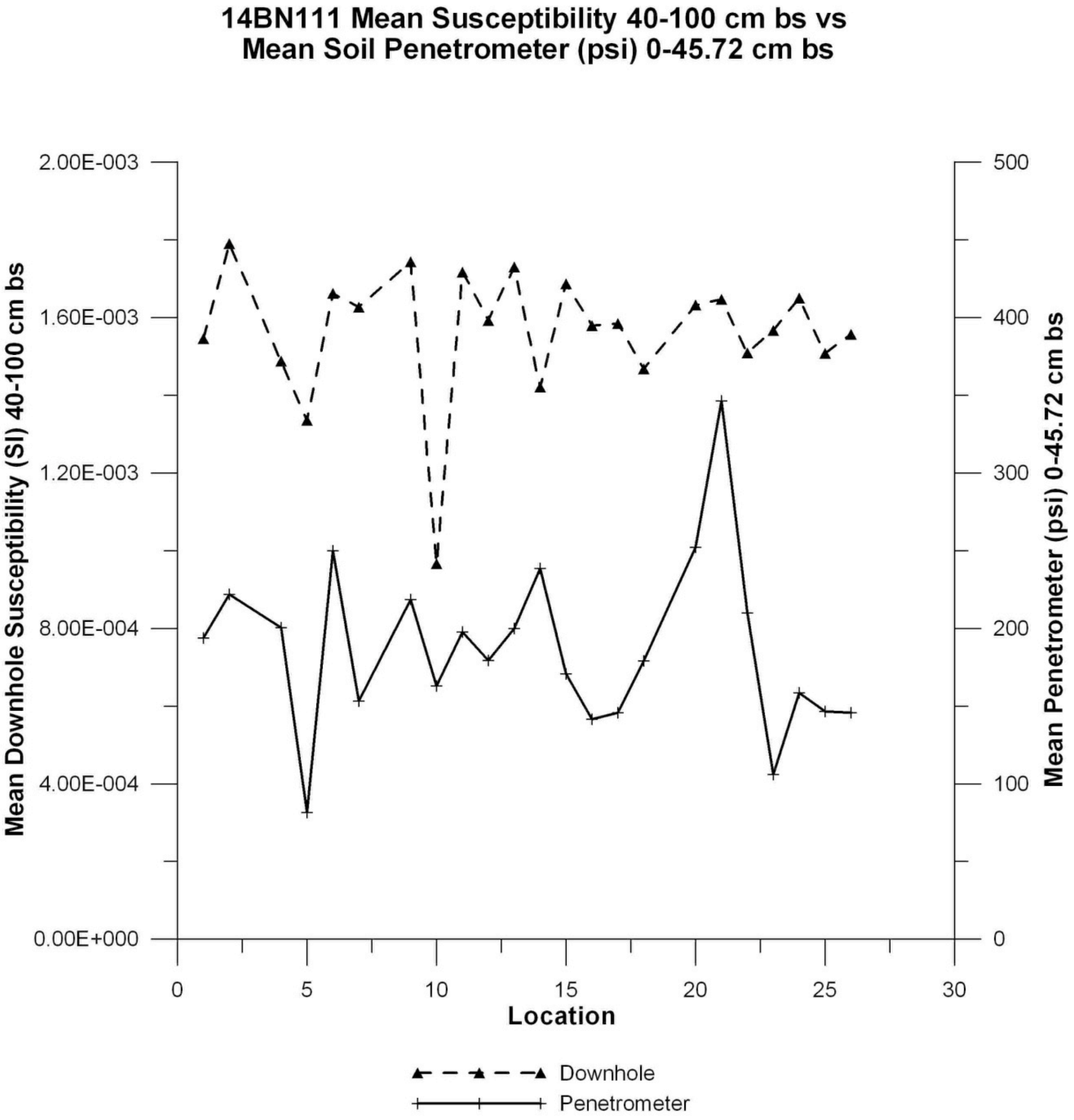


Figure 32. Average down-hole susceptibility and penetrometer readings at each of the 30 locations at the Campbell Cemetery.

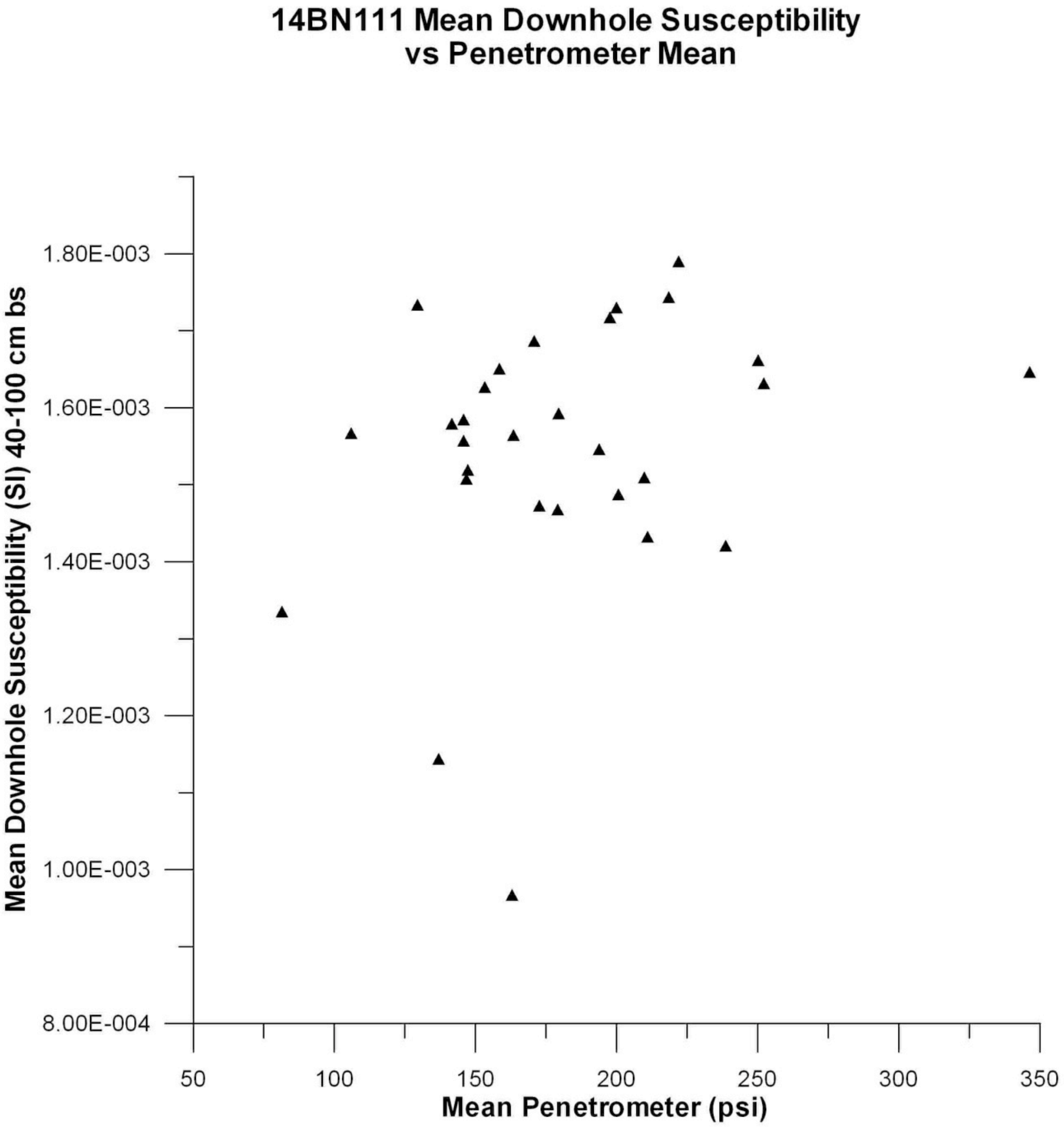


Figure 33. Average down-hole susceptibility versus penetrometer readings for the 30 locations tested at the Campbell Cemetery.

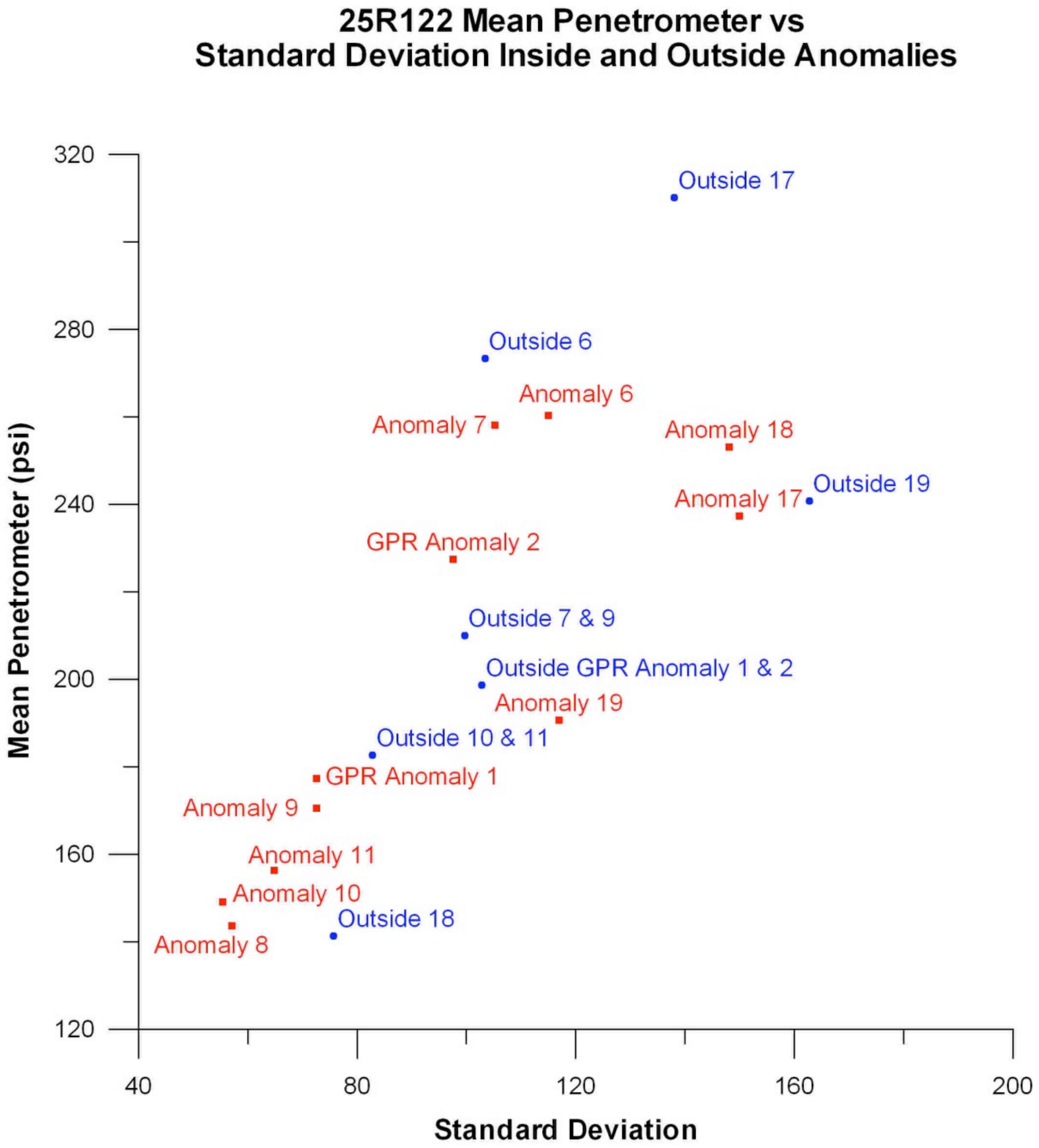


Figure 34. Mean penetrometer readings versus standard deviation for locations tested inside and outside anomalies at the Sac and Fox family cemetery.

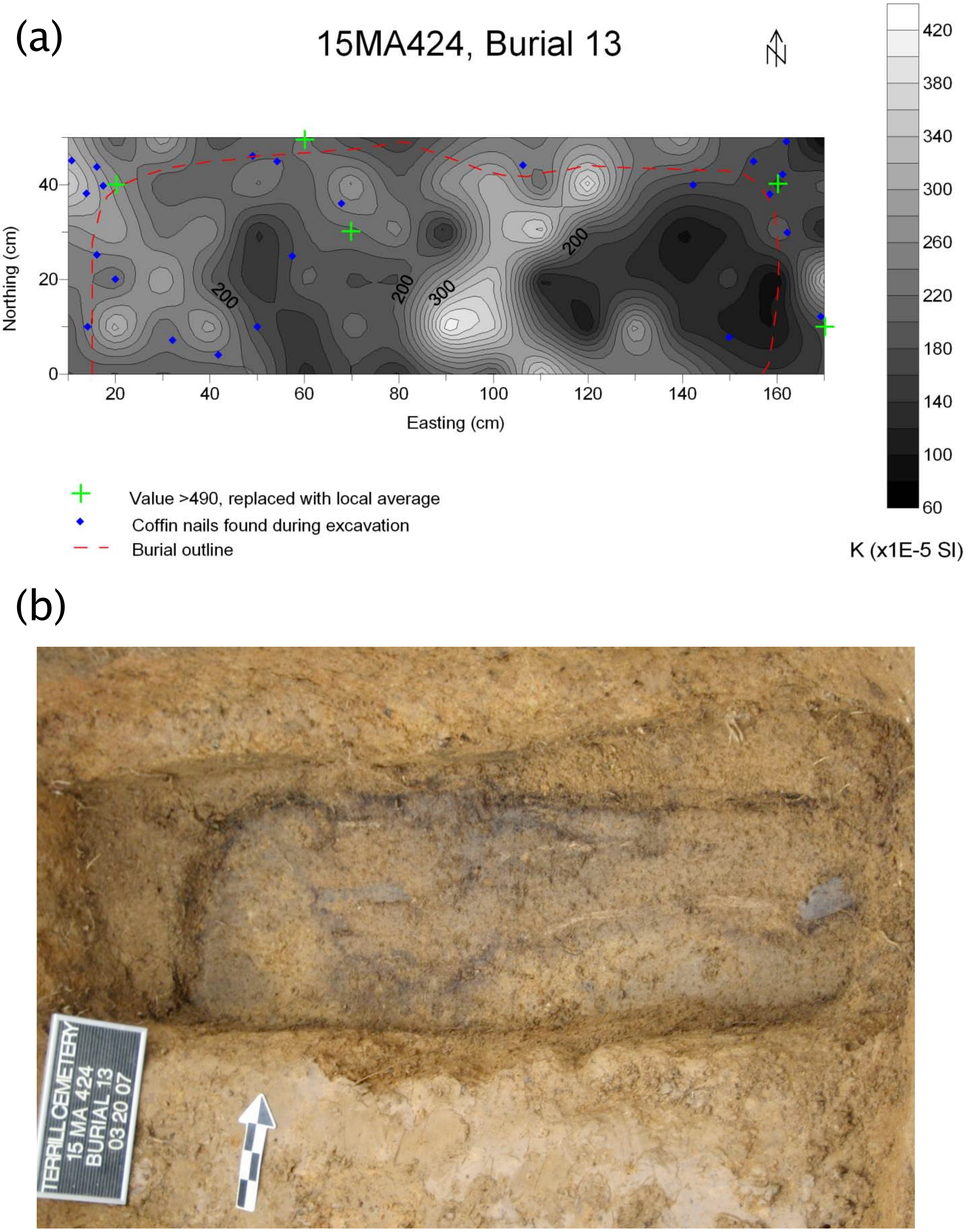


Figure 35. Susceptibility survey of Burial 13: (a) Contour map of susceptibilities at burial level collected at 10 cm intervals. (b) Photo of Burial 13 showing the poor condition of remains and the location of soil stains and decomposed bones. The head is to the west. (Photo courtesy of the Kentucky Archaeological Survey)

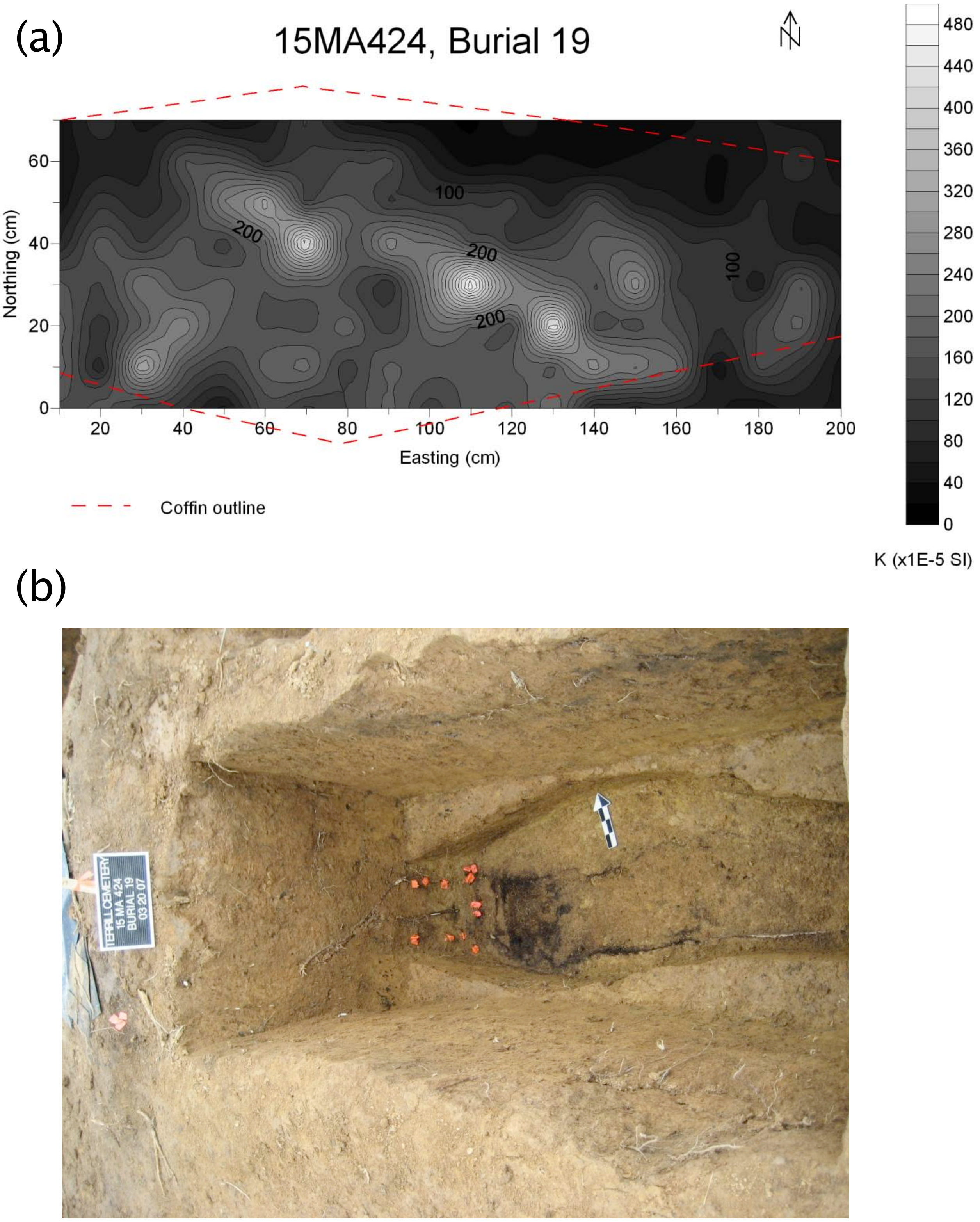


Figure 36. Susceptibility survey of Burial 19: (a) Contour map of surface susceptibilities at burial level collected at 10 cm intervals. (b) Photo of Burial 13 showing coffin remains and nails . These were removed prior to the susceptibility survey. The head is to the west. (Photo courtesy of the Kentucky Archaeological Survey)

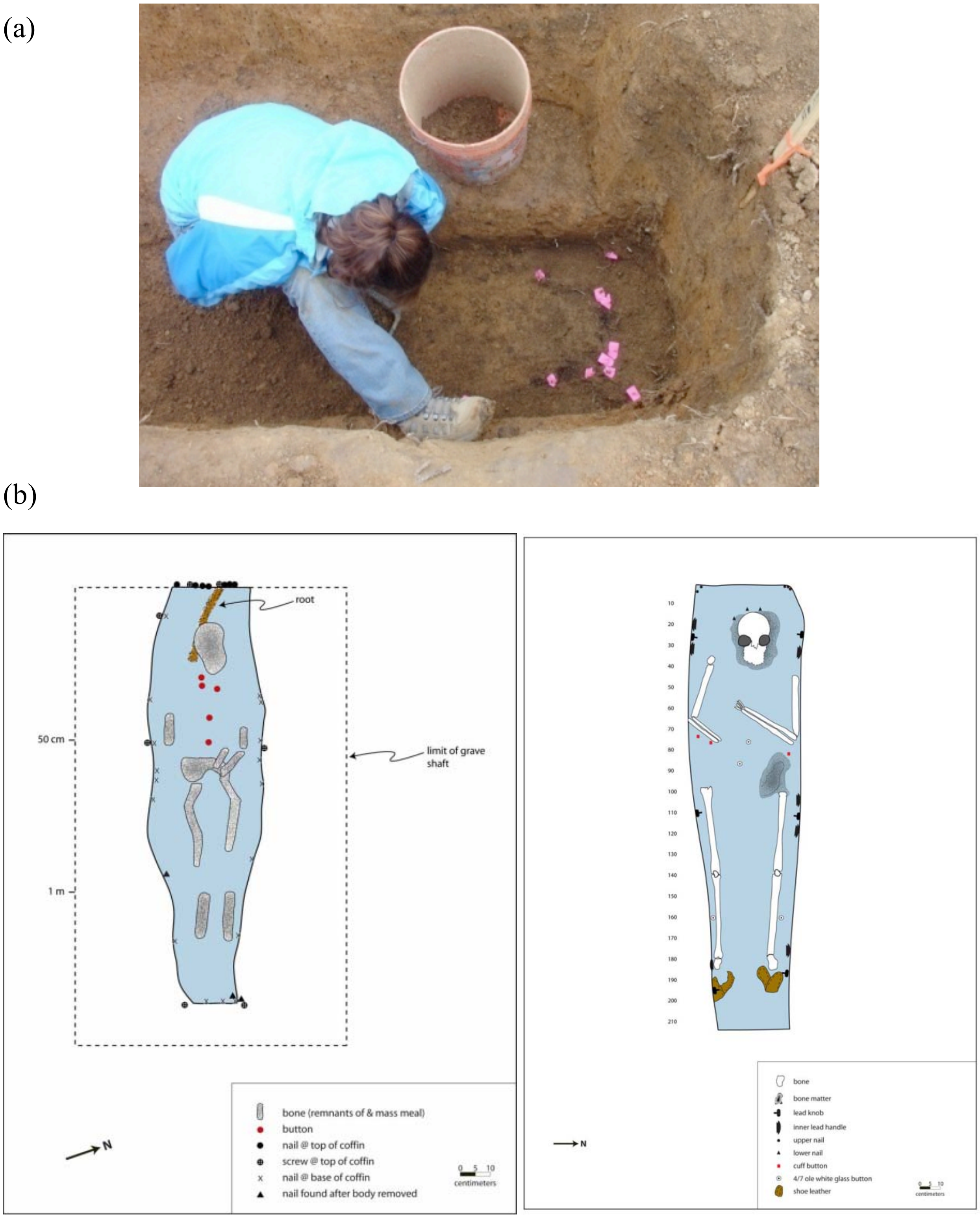


Figure 37. Excavation of burials at the Terrill Cemetery: (a) Excavating Burial 13. Flags mark nail locations. (b) Plan views of Burials 1 (right) and 20 (left). (Planview maps courtesy of the Kentucky Archaeological Survey)

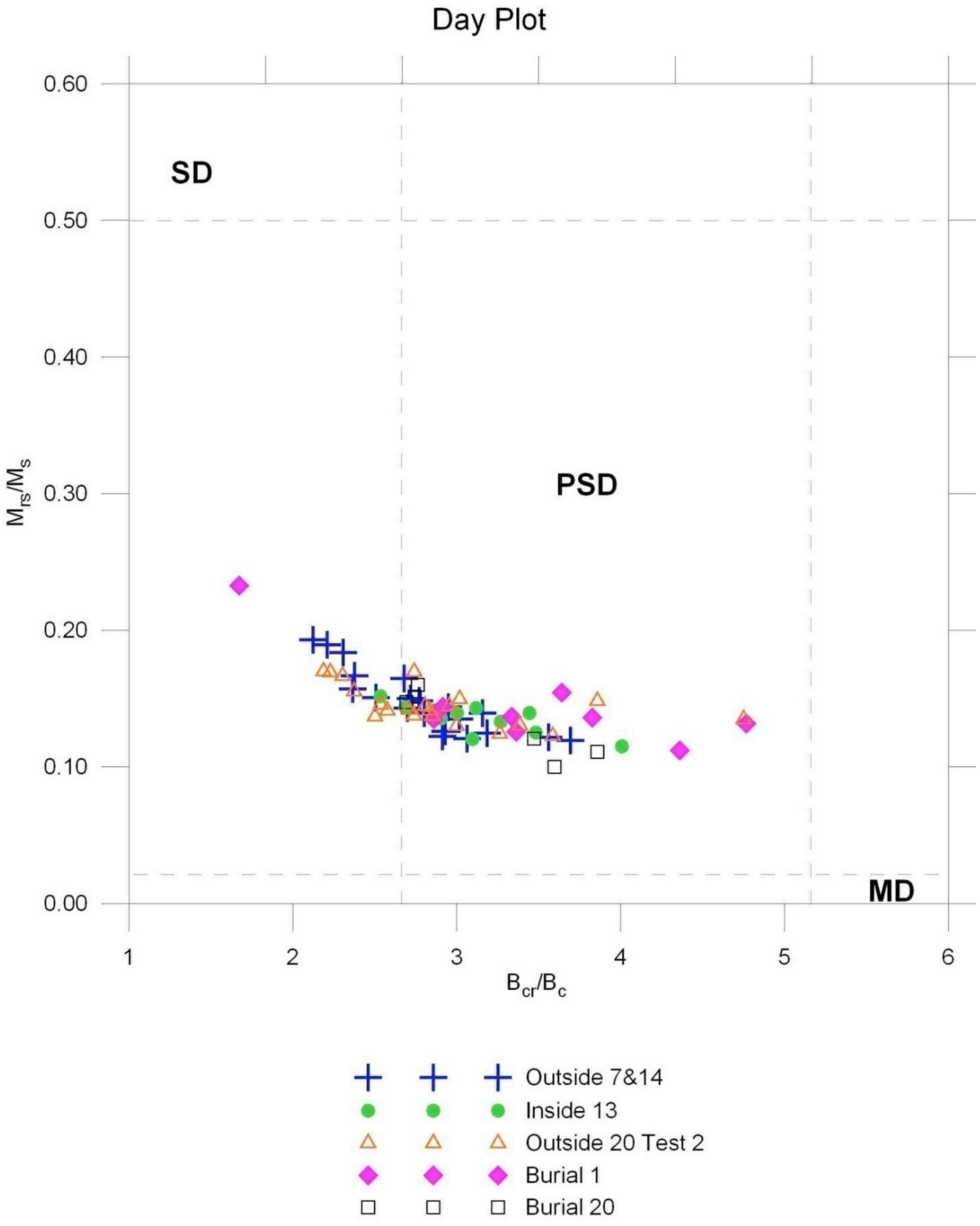


Figure 38. Day plot of samples from the Terrill Cemetery.

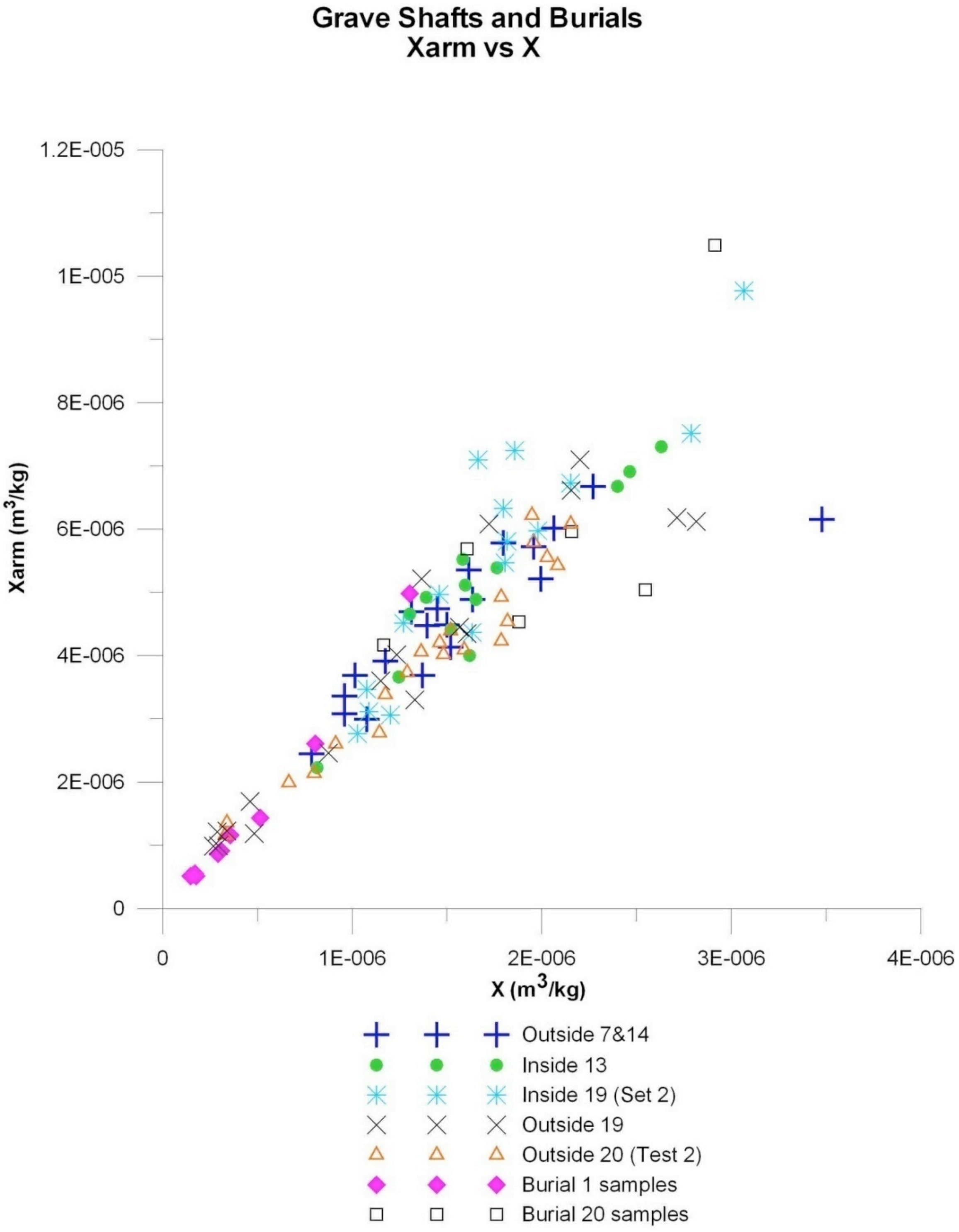


Figure 39. Plot of ARM susceptibility versus mass susceptibility for all samples collected from the Terrill Cemetery.

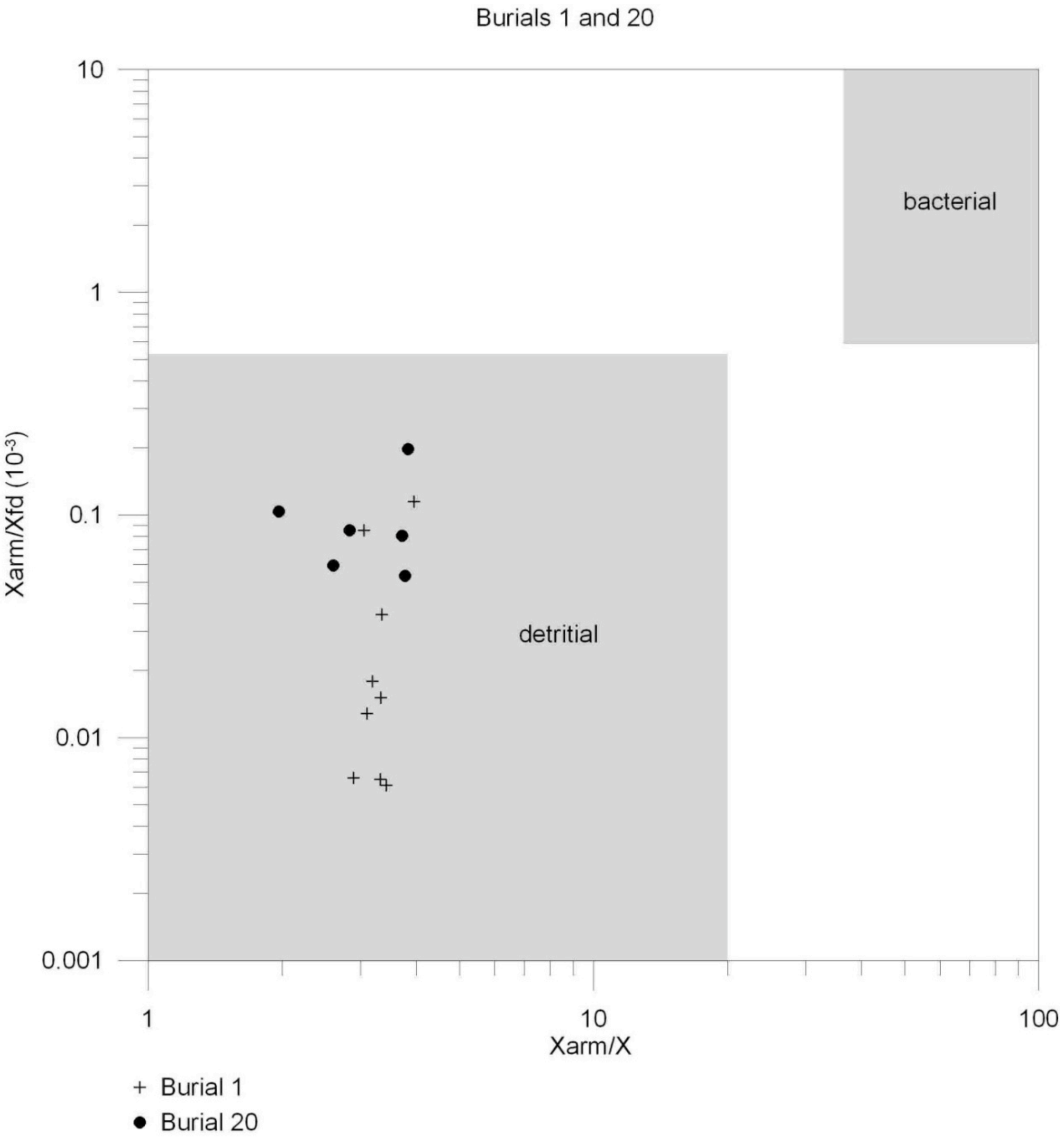


Figure 40. Logarithmic biplot of χ_{arm}/χ_{fd} versus χ_{arm}/χ to investigate the origin of fine-grained magnetic particles in Burial 1 and 20 samples.

Table 1. Relationship of down-hole test and geophysical anomaly locations. Anomaly locations are derived from interpretation maps presenting magnetic gradient, resistance, conductivity, and ground-penetrating radar anomalies (De Vore 2004b).

Campbell Cemetery				
14BN111				
Anomaly Location in Relation to Down-hole Tests				
Down-hole Test	Magnetic	Conductivity	Resistance	GPR
1			x	
2				
3A	x			
3B				
4			x	
5				x
6				x
7				
8A			x	
8B			x	
9				
10A				
10B				
11				
12				
13				
14				
15				
16				
17				
18	x			
19A				
19B				
20				
26				
*21-25 Not within geophysical grid				

Table 2. Average saturation magnetization values for down-hole locations and burials sampled at the Terrill Cemetery

15MA424 Collected Samples
Average Saturation Magnetization and Mass Susceptibility

	Average Ms	Average X
Grave Shaft Investigations	Am^2/kg	m^3/kg
Outside 7&14	5.71E-02	1.57E-06
Inside 13	6.29E-02	1.69E-06
Inside 19		1.73E-06
Outside 19	4.19E-02	1.27E-06
Outside 20 Test 2	5.43E-02	1.41E-06
Burial Samples		
Burial 1	8.53E-03	3.46E-07
Burial 20	9.51E-02	2.04E-06