Research Article

Eric Olson*

A Pilot Study in Archaeological Metal Detector Geophysical Survey

https://doi.org/10.1515/opar-2022-0243
received February 2, 2020; accepted May 12, 2022

Abstract: Metal detection (MD) has traditionally been viewed as a limited geophysical survey method for the identification of metal objects below the surface. However, this pilot study examines techniques utilizing the "ground balance" function, common to most modern metal detectors, to identify subsurface magnetic anomalies. The results of surveys have yielded inconclusive results on the use of metal detectors for feature identification. However, the results of this study suggest a high potential for more efficient and more productive archaeological reconnaissance surveys. The ground balance function, when combined with systematic sampling and geographic information systems interpolation methods, yields low-resolution subsoil magnetic susceptibility maps. Compared to other geophysical methods, such as gradiometry or electrical resistivity, the depth range of MD is limited. However, this technique, in upland contexts with shallow subsoils or sites with high potential for recent ground disturbing activities, can reveal subtle changes in the subsurface that traditional MD techniques would miss. Further studies are recommended to explore the many situations in which a metal detector can provide an informative alternative, though not a replacement, for other geophysical survey methods. This pilot study was funded by the National Geographic Society's Early Career Grant program.

Keywords: metal detection, geophysical techniques, reconnaissance survey, field methods, North American archaeology

1 Introduction

Most metal detection (MD) in North America conducted by professional archaeologists and hobbyists has focused on historical archaeological sites, particularly battlefields (Connor & Scott, 1998; Keller, Boyd, Groover, & Hill, 2011; Parsons, 2012; Powis, 2012; Skaggs & Severts, 2012). MD has seen limited application at historic American Indian sites (Keller et al., 2011; Stothers & Tucker, 2006) when there is an expectation of European trade metals. When prehistoric copper is expected, for example, at Old Copper Culture sites in the upper great lakes (Iwacha, 1979; Martin, 1999, p. 165), MD has been applied to prehistoric archaeological survey.

Modern metal detectors are highly sophisticated geophysical instruments. The goal of this pilot study was to understand the potential for MD not just as a form of metal identification, but as a low-resolution geophysical instrument for subsurface magnetic anomalies. Most metal detectors sold today have the capability to measure the conductivity of soils, making them potential, and extremely cheap, alternatives to other geophysical methods (i.e., gradiometry, electrical resistivity). As Espenshade et al. (2012, pp. 11–12) argue, MD should be required during evaluation of contact period/historic Indian remains, in addition to all phase II archaeological survey. MD has become an important complement to other geophysical methods in

*** Corresponding author: Eric Olson,** Department of Liberal Arts and Sciences, Cuyahoga Community College, 11000 West Pleasant Valley Rd., Parma, OH, 44130, United States of America, e-mail: eric.olson@tri-c.edu

determining the integrity of prehistoric archeological features (Espenshade, 2012, pp. 11–12; Hargrave, 2006, p. 276; Thomas & Stone, 2009). However, metal detectors applied to prehistoric (North American) sites are “assumed…will not detect prehistoric artifacts such as fire-cracked rock” (Hargrave, 2006, p. 276) or “not having a great deal of utility on pre-contact sites” (Pickard, 2014).

At the Fry Site in northwestern Ohio, 33LU 165, at least one metal detector “hit” yielded fire-cracked rock (FCR) and lithic debris, but no metallic objects (Stothers & Tucker, 2006, p. 202). At another site in Ohio, 33 PI 179, magnetic susceptibility readings were consistently higher and visually evident on heat maps in an area with a high density of FCRs (Schwarz, 2014, p. 87). The evidence of MD identifying nonmetallic objects and features is very limited in the literature. However, it is well established that archaeological thermal features have identifiable magnetic susceptibility (Jordanova, Jordanova, Petrovsky, & Kovacheva, 2001; Tite & Mullins, 1971). Many studies (Cross, 2008; Das, 2006; Igel, Preetz, & Altfelder, 2015; Preetz, Altfelder, Hennings, & Igel, 2009; Takahashi, Preetz, & Igel, 2013) have tried to understand and mitigate the effects of magnetic soils in MD. The very methods used to “tune” or “filter” out the magnetic signatures of soils, such as archaeological features, could be the very same methods to identify them.

Geophysical survey is already a well-established survey method within archaeology (Gaffney, 2008; Johnson, 2006). Methods such as gradiometry or electrical resistivity are not always available to archaeologists because of time and/or cost (Collins & Molyneaux, 2003, pp. 80–81). Not only is there an order of magnitude difference in cost of equipment, there is a significant difference in the amount of training between the equipment. Advanced Metal Detecting for the Archaeologist, an educational conference/class, offers training with metal detectors over the course of 2–4 days. Meanwhile, most minimum trainings in geophysical equipment such as a gradiometer can take an entire semester to learn. To really see the difference in training and equipment cost, one can simply look at the hobby community to see that MD is far more accessible than other geophysical methods (Thomas & Stone, 2009).

With this information in mind, the author designed a research proposal for the National Geographic Society’s Early Career Grant program, with the understanding that this study was highly experimental and may yield negative or inconclusive results. Metal detectors were designed to minimize the noise of magnetic soils; thus, the goal of this study was to use equipment in a way it was not originally intended. However, the potential information gained through experimentation was deemed worthy enough to pursue further by the National Geographic Society, given the limited cost of the equipment necessary. Aside from the cost of the metal detector, the only expenses of the project were time/labor. All other equipment and software were either freeware or already part of a typical archaeologist’s toolkit (i.e., shovels, screens, trowels, etc.).

2 Materials and Methods

The two most common types of metal detectors are pulse induction (PI) and continuous wave (CW) (Cross, 2008; Scott et al., 2012). CW measures the frequency difference, also known as phase shift, between the induction signal and the returning signal. Most metals and alloys have distinct frequencies that can be used to discriminate them. PI metal detectors measure the time delay between the outgoing electromagnetic signal and the returning electromagnetic signal. CW detection is more susceptible to the magnetic properties of soils than PI detectors (Das, 2006). Natural magnetism of soil is interference for most researchers (Cross, 2008; Igel et al., 2015; Takahashi et al., 2013), but increased sensitivity is needed to detect differences between soil anomalies. A CW detector was selected for this study.

Most detectors manufactured today feature a ground balance tuner. Ground balance provides the operator with the ability to account for magnetic soils (Scott et al., 2012, p. 41). Canceling or minimizing the interference of the ground magnetism would defeat the purpose of the study. Instead, the goal is to use these readings as a sample of the ground magnetism beneath the coil and to link them together using interpolations in geographic information systems (GIS) software.

Many detectors function on an audio-based detection method (the classic “beep” associated with finding metals) and use many different forms of discrimination to eliminate ground magnetism (Scott et al., 2012). An audio-based identification system is very crude and amounts to little more than a presence/absence indicated. For this study, a discrete method of quantifying readings was required. A digital display was necessary to quantify the signals coming from the detector coil, for both the ground balance readings and the target (metal) readings.

The metal detector selected for this study that met the above criteria was the Teknetics G2+ (First Texas Products, 2015). The G2+ provides a target (e.g., “metal”) phase shift reading and a ground phase shift reading between 0 and 99. The actual units are not provided, but for the purposes of this study, the only concern is the ability to quantify data collection. In addition to these features, the G2+ includes a pin-point feature, which is a standard feature expected in any metal detector used in archaeological survey (Espenshade et al., 2012, p. 10).

Unlike the standards of most metal detector surveys (Espenshade et al., 2012), which involve walking and sweeping the detector coil, this project required only the “pumping” of the coil at fixed intervals to capture ground balance readings. This stratified sampling strategy utilized in the field is common in electrical resistivity surveys (Marino, Olson, & Matney, 2017). Grid squares were staked out in 10 m intervals. The number of ground balance samples taken within each grid square ranged from 9 to 800. Because the detector coil is 30 cm long and 20 cm wide, the number of samples within a 10 m grid square cannot exceed 800 mathematically. The limitation of this technique is the size of the detector coil, which is measuring the magnetic susceptibility of the soil immediately beneath the coil.

Ground balance readings, per the Teknetics instruction manual (First Texas Products, 2015), were collected by pressing the “GG” button (short for “ground grab”) in the center of the detector head and pumping the coil up and down above the soil a minimum of three times. The coil head should be removed from the soil and brought back toward it several times, so that the detector can “see” the difference between air (which should have minimal to no magnetism) and the soil. These different readings are then averaged into the ground balance reading.

A nonmetallic tape was placed north-south and east-west along the grid squares, and the operator pumped the coil and recorded the ground balance reading every 50 cm north-south and every 25 cm east-west. The detector has a manufacturing mark on the coil indicating the center of the coil head. This mark is also used for pinpointing the exact location of readings.

At every site, ground balance readings were captured by the operator and recorded in a notebook either by a field assistant or by the operator with a mobile device on the application Google Sheets. In both the handwritten and typed notes cases, some formatting was required. Handwritten and digital spreadsheets were formatted for ease of recording, rather than the format necessary for import into GIS software. After notes were transcribed, or ready as is with Google Sheets, the spreadsheets were then uploaded into GIS software for interpolation.

Because the equipment used is originally intended to identify metals, all metal “hits” were also mapped and recorded. A “hit” is the common term used to describe when a metal detector detects a metallic object within range of the coil. A common mode in many detectors is a “discrimination” function, which can be preset to only detect specific frequencies indicative of specific metals and alloys, such as gold, silver, aluminum, and nickel. For this study, this function was not used. Instead, the “all-metal” or nondiscriminatory function was used. The settings, aside from the control site, were maintained at a gain of 60 and a threshold of –40 on the instrument. Threshold controls the intensity of receiver signal of the detector, which will most notably be heard if using audio-based detection. Gain adjusts the strength of signals; in other words, gain affects the sensitivity of the instrument.

Field sites were preplanned in some cases and opportunistic in others. The prearranged and permitted sites include those at the Bath Nature Preserve, Summit County, Ohio (including the Round Top A, Round Top B, Garden Pond, and Matney Sites), Grace Park in downtown Akron, Summit County, Ohio, and the Backyard Site #1 in Wadsworth, Medina County, Ohio. Sites surveyed under opportunistic conditions could not be excavated due in part because no prior excavation permissions had been acquired, and because they were not written into the original project proposal. However, in the case of opportunistic MD data, historical records were used to supplement archaeological information such as historical aerial photographs, maps, and other historical documents. Opportunistic survey sites include the Fir Hill former alumni association building at the University of Akron, Summit County, Ohio.

Ground truthing (Kern, 1999, p. 77) was planned for all prearranged sites, but not any opportunistic survey sites. Ground balance readings were recorded at the depth of the subsoil when it was reached in each test unit for a comparison of surface and subsurface readings. All surveyed areas were in the uplands, in locations where the B horizon is typically located between 20 and 30 cm below surface (Ritchie & Steiger, 1974).

Espenshade (2012, pp. 22–25) recommends removing grass, sod, and even the plow zone (PZ) entirely to ensure the metal detector is within the range of archaeological artifacts and features. The PZ, although unlikely to contain intact features, is likely to have significant archaeological context (Haldenby & Richards, 2010; Martens, 2016). It is also possible that metal detectors can detect FCR which may be in the PZ (Stothers & Tucker, 2006; Takahashi et al., 2013). All sites surveyed were cut and mowed to a height no greater than 2.5 cm above the surface.

The ground balance function on the G2+ is taking a reading of the ambient metals present in all soils and the subsoil, also known as the B horizon. The clay in the B Horizon, especially in the survey area of this project, Northeast Ohio, contains a higher amount of iron than the soil in the A or O horizon (Ritchie & Steiger, 1974). Ground balance readings, per the manufacturer recommendation (First Texas Products, 2015), are designed to minimize the "noise" of these iron-rich B horizons. These ground balance readings have estimated ranges for common soil conditions, published by the manufacturer (Table 1).

Most iron-rich B horizons should fall in the range of 40–75 according to the manufacturer. Depending on the metal detector, the specific number ranges may vary. The main goal of this project was to test whether the ground balance readings, when interpolated using systematic sampling, could be used to generate an accurate raster map of the areas of high and low magnetic susceptibility.

The GIS software used to interpolate ground balance readings was quantum geographic information system (QGIS), a freeware GIS program. Data were formatted and saved as comma-separated value files, which were then uploaded into QGIS and interpolated into grayscale raster layers. Interpolation maps were created from each dataset of MD ground balance readings. These interpolations had varying resolutions from nine readings per 10 m^2 to 800. All data points collected were interpolated using inverse distance weighted (IDW) algorithms. IDW algorithms should account for spikes and outlier data that would otherwise influence the resulting map (Mueller et al., 2003; Wheatley & Gillings, 2003, p. 103). The original plugin used for interpolation was the QGIS raster interpolation tool; however, the Archaeological Geophysics Toolbox was used to generate interpolation maps (Hulin, Simon, & Hatami, 2017) at the control site and after ground truthing had finished.

3 Results

The results can broadly be grouped into four categories: air testing, control site testing, excavated sites, and opportunistic sites. Air testing consisted of controlled testing of objects in the air to evaluate their effect on

Table 1: Estimated ranges of ground balance readings for soil conditions (First Texas Products, 2015)

Minimum	Maximum	Soil conditions
0	10	Wet salt and alkali
5	25	Metallic iron. Very few soils in this range. You are probably over metal
26	39	Very few soils in this range – occasionally some saltwater beaches
40	75	Red, yellow, and brown iron-bearing clay minerals
75	95	Magnetite and other black iron minerals
96	99	Values more than 95 are generally an indication of a search coil or electronics defect or out-of-calibration condition

the detector's signal. The control site was used to test variable settings and weather conditions of the detector. The excavated sites were used to test empirical cases. Opportunistic cases provided additional empirical data tested only through historical documentation.

The Bath Nature Preserve contained four of the excavated sites for the project: Garden Pond, Round Top sites A and B, and the Matney Site (Chlysta, Housel, & Manahan, 2017; Haney et al., 2004; Whitman & Tegland, 2002). None of these sites have any recorded metal that would interfere or drown out the magnetic signature of hearths, pits, or FCR. Grace Park, an active public park in downtown Akron, Summit County, Ohio, was the only other excavated site (aside from the control). This site had a very high potential for modern electromagnetic interference via modern trash and debris. Litter cleanup was conducted at all sites to minimize the interference of modern metals.

3.1 Air Testing

Before the start of fieldwork, the author conducted air tests of multiple different artifact classes and recorded their ground balance readings. The artifact classes included high fired ceramics (fired at temperatures above 1,000°C), low fired ceramics (fired at temperatures below 1,000°C), glass, and FCR. Air tests were conducted in the same location, outside of Olin Hall, University of Akron, on the same day. The metal detector was set to 60 gain, −40 threshold, and placed one meter off the ground. Periodically, the author's empty hand was placed in front of the metal detector as a control test, in addition to reading the empty air.

The result of air testing was inconclusive at distinguishing any artifact type from ambient electromagnetic noise (such as that from the sun, electrical cables, or other interference points). The apparent range for these four classes is the entire spectrum of ground balance readings. The means and standard deviations concentrate in the ground balance range of 30–60 s. From the G2+ manual, this is the common range for iron-rich B horizons. There was a weak correlation ($R^2 = 0.44$) between FCR weight and ground balance reading. Larger objects (e.g., complete bricks and larger pieces of FCR) had higher ground balance readings, whereas small objects were indistinguishable with the ambient ground balance readings of the air. Large clusters of FCR, bricks, or glass were not air tested. However, based on the higher readings for larger objects, it is possible that clusters of these artifact classes would be identifiable to the metal detector ground balance function.

3.2 Control Site

The Backyard Site #1 was used as a control site for both the soil conditions and the settings on the metal detector. A three-by-three-meter grid-square was laid out at the site, without consideration of archaeological potential. The potential at the Backyard Site #1 is low. The site is located at the backlot of a 0.2 hectare urban residential property. The northwest corner of the grid square contained a formerly excavated one-by-one-meter test unit excavated 6 months before the start of controlled sampling. This grid-square was surveyed multiple times under variable weather conditions and using different settings of gain and threshold on the detector.

The northwest one-by-one-meter survey area was excavated six months before metal detector testing (November 2019). This area yielded two pieces of possible FCR (later determined noncultural in the lab). The unit was backfilled, which mixed the clay-rich B Horizon near the surface. This likely explains the northwest corner of the survey grid in all but one case showing higher ground balance readings. The dark anomaly in the southeast corner of the survey area was an iron nail 10.5 cm long weighing 56.6 g. No other metallic artifacts were recovered during excavation; however, the eastern third of the survey area contained several large (>150 g) hematite concretions.

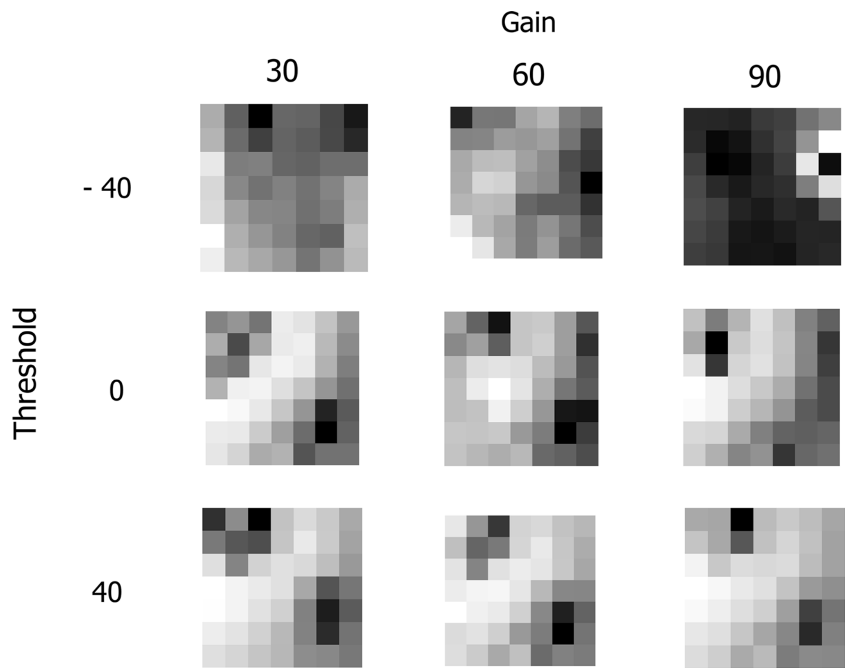

Figure 1: Nine different interpolation maps of the survey area, with data collected using variable settings on the detector. Specific ground balance readings were omitted from this figure, because the result of this control sample is to identify similarities in interpolation results and not identical ground balance readings. Each square represents an area approximately 25 by 50 cm.

The clear outlier of the control tests is the survey done with 90 gain and threshold of −40. The detector is extremely sensitive to electromagnetic fields at such a high gain (First Texas Products, 2015). The soil conditions were very dry on the day of survey; there had been no precipitation for the 4 days prior and a total of half a centimeter of rainfall in the week preceding the day of survey (Figure 1). Soils that poorly conduct electricity will yield lower ground balance readings (First Texas Products, 2015); dry, clay-rich soils are very poor conductors (Igel, Preetz, & Altfelder, 2015) (Figure 1).

The Backyard Site #1 site also served as a control location for soil moisture conditions and metal detector readings. Figure 2 shows the results of three different surveys under variable weather conditions. The conditions, from left to right, include the most to least precipitation preceding surveys. The survey conducted on May 15, 2020, was immediately after a rainy day and followed a very wet week. A total of 4.06 cm of precipitation accumulated in the week prior. The survey conducted on June 3, 2020, had 1.82 cm of rain accumulation in the week before the survey. The July 11, 2020, survey had 0.4 cm of rain accumulation in the week before survey, and two dry sunny days before survey. Overall, the same general pattern

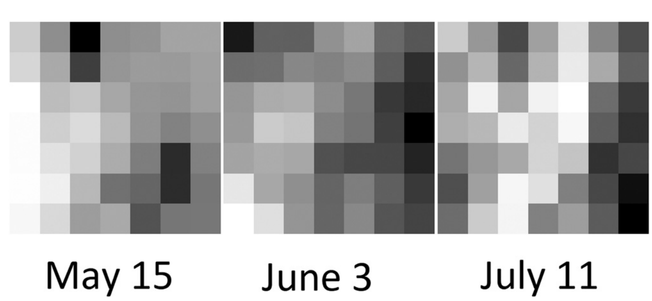

Figure 2: Interpolations using the same gain and threshold settings with different soil moisture conditions. Each survey was conducted with gain set to 60, threshold at −40.

occurs between all three cases, but the most gradual change between readings, and most consistent ground balance readings, occur in the most wet soil conditions. This is likely a reflection of deeper penetration of the metal detector electromagnetic field with the help of water in the soils.

3.3 Fir Hill

The Fir Hill survey area includes the former location of the University of Akron alumni association building. This site served as the primary opportunistic survey location. The alumni building was demolished in the summer of 2015; however, the sidewalks and associated landscape features (including the parking lot) remain at the site. Based on reports from eye-witness accounts of faculty who watched the demolition in 2015, the basement of the building was backfilled with debris from the home, in addition to fill dirt. The foundation walls were not removed.

The detector gave an error signal, indicating that the sensor was "overloaded" and maxed out on all indicators when placed above concrete sidewalks. The author could not determine if this was in part due to rebar reinforcement within the sidewalk, or if this was the result of the solid concrete creating a reflected signal bouncing back to the detector faster than the phase shift sensor could detect. The detector was tested on asphalt and other concrete surfaces in the area, including the paved brick walkway (formerly Buchtel Avenue) to the south. In all cases, except the paved brick walkway, the metal detector gave a "sensor overload" error signal.

The survey area was 10 m east-west by 20 m north-south. Figure 3 is an interpolation map of the ground balance readings. The former house location is immediately west of the sidewalks, which are clearly visible as the blackest areas of the map. There is a clear anomaly in the southeast corner of the survey area, which may be the result of buried concrete foundation for the old Alumni association sign. The area immediately south of the utility, and east of the front of the building, was the former front yard. The ground was still slightly compacted from the ephemeral footpath going from the front door to the west to the road on the east. A small cluster of darker anomalies east of the concrete sidewalk are several "hits" on the detector, in the range typical of small coins.

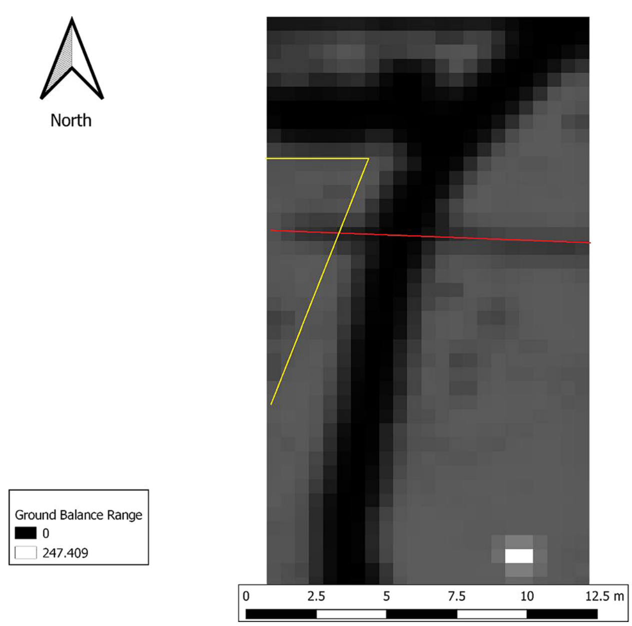

Figure 3: Interpolation map of Fir Hill Survey. Former house location outlined in yellow. Old water line and electrical lines running to house drawn in red. The front door was immediately south of the utility line.

3.4 Grace Park

Grace Park is in a public park in downtown Akron that is approximately 2.8 hectares. Grace Park is one of the oldest parks in the City of Akron, dating to the 1840s (Price, 2012). Minimal improvements have been made to the park, partly due to the stipulation by Simon Perkins that "no buildings or structures of any kind shall be erected on the same" (Price, 2012). Since the park's founding, it has accumulated the dropped coins, other pocket contents, and trash of passers-by. Before MD could start, a preliminary surface survey was conducted to clear the area of metal trash, such as soda cans, bottle caps, coins, pull tabs, and snack bags lined with aluminum.

The archaeological record at Grace Park is currently unknown. No previous investigations have ever taken place within the park. Recent historical research in the greater Akron area has revealed numerous archaeological sites discovered during the late nineteenth and early twentieth centuries (Olson, 2017). Grace Park has a higher than usual potential for intact prehistoric archaeological sites because of its use as a cattle grazing ground (Price, 2012) and subsequently as a public park. Both activities are minimally ground disturbing and unlikely to destroy subsurface features. Aside from the ground disturbances related to the construction of pavilions, light fixtures, and sidewalks, there are likely still undisturbed soils within the park.

The ground balance readings at Grace Park were substantially higher than the readings from all other sites, as evidenced by the lighter shade of the raster interpolation (Figure 4). The typical readings ranged in the 70 and 80s, which was higher than any other test site. This was likely due to the high density of metal trash found at the site; however, after excavation began, this hypothesis changed. Test units hit sandy, iron-rich subsoil at very shallow depths, typically around 15–20 cm (Figure 5).

The combination of the ground balance interpolation and location of metal detector hits was used to select test units. Test units with higher ground balance readings with no metal detector "hits" and areas with higher readings and iron-bearing "hits" were selected for ground truthing.

Test unit 2 yielded the most artifacts. Within test unit 2 was what appeared to be a very large excavated fire pit, backfilled with the contents of a possible camp, picnic, or even a homeless person's shanty. The disturbed soils began at 10 cm below surface and continued well into 60 cm below surface, well beyond the B Horizon identified in other shovel test units. The feature was an oval-shaped basin filled with bottle glass, small ceramic fragments, large chunks of wood charcoal, and other glass fragments. Of note are a large cast

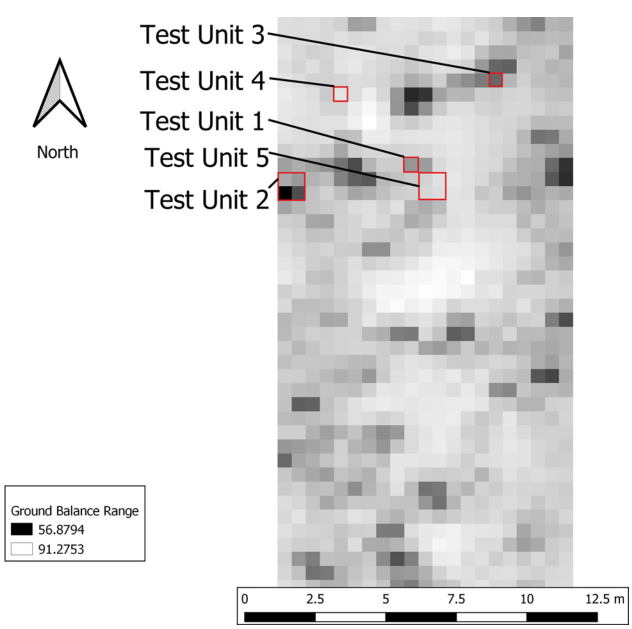

Figure 4: Interpolation map of the Grace Park survey area with test unit locations and assigned numbers in red.

Figure 5: Planview of test unit 5, facing east. Example of sandy, iron-rich subsoil in the top half of the unit floor.

iron cooking pot, upended at the bottom of the pit, and two license plates. The contents of the pit included several alcohol bottles, a half-refitted milk bottle, and a few small plate fragments. Only half of one of the license plates could be removed from the test unit. The other fragments were lodged in the unit wall.

3.5 Bath Nature Preserve Sites

Most of the excavated sites were within the Bath Nature Preserve in Northeastern Ohio: Round Top A and B, Garden Pond, and the Matney Site (Figure 6). Round Top A and B and the Garden Pond site were surveyed with the same 25 cm × 50 cm interval as Fir Hill, Grace Park, and the control site. The Matney Site was sampled every 5 m and ground truthed with a 30 cm diameter bucket auger. All sites at Bath Nature Preserve, except the Matney Site, were geophysically surveyed in 2004 by the University of Akron (Haney et al., 2004). However, the exact coordinates and details of these geophysical surveys could not be recovered or relocated precisely.

Starting from the north moving south is Round Top A site. Round Top A (33 SU 358) has been previously surveyed, and projectile points, flakes, and FCR have been recorded (Chlysta et al., 2017; Whitman & Tegland, 2002). A few pieces of FCR, flakes, and one tip of a ground stone axe were recovered during excavation of 10.5 m^2 of soil at the site. None of the excavation units placed within the MD survey grid yielded any evidence of subsurface features (Figure 7).

Round Top B (33 SU 358) was first identified in a 2002 reconnaissance survey (Whitman & Tegland, 2002). The site is in a small swale north of a kettle lake. The site is bound to the west and east by submerged natural gas utility pipes. Immediately south of the site is a gravel access road, approximately 2 m wide, which runs to the gas well connected to the pipes to the north. South of this access road is a paved asphalt walking path put into the nature preserve after the 2002 archaeological survey. A corrugated steel culvert runs underneath the asphalt walking path. The ground is clearly disturbed in the deepest part of the swale,

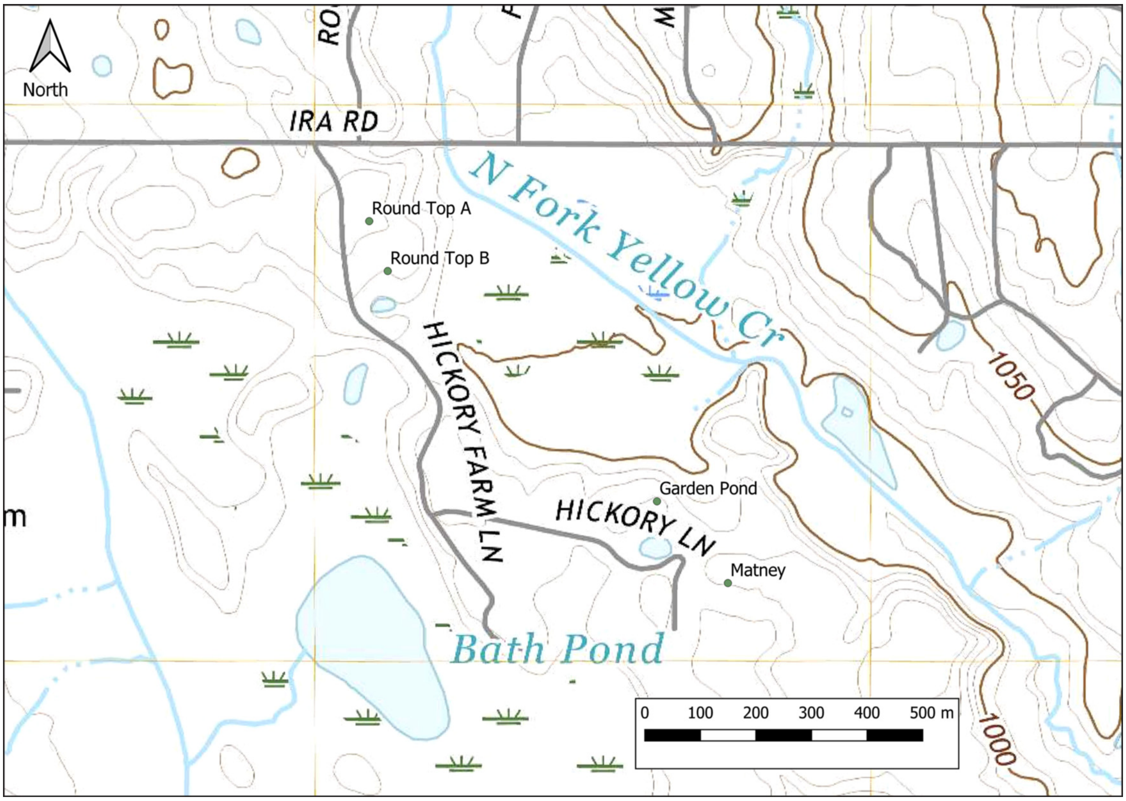

Figure 6: Locations of sites surveyed within Bath Nature Preserve.

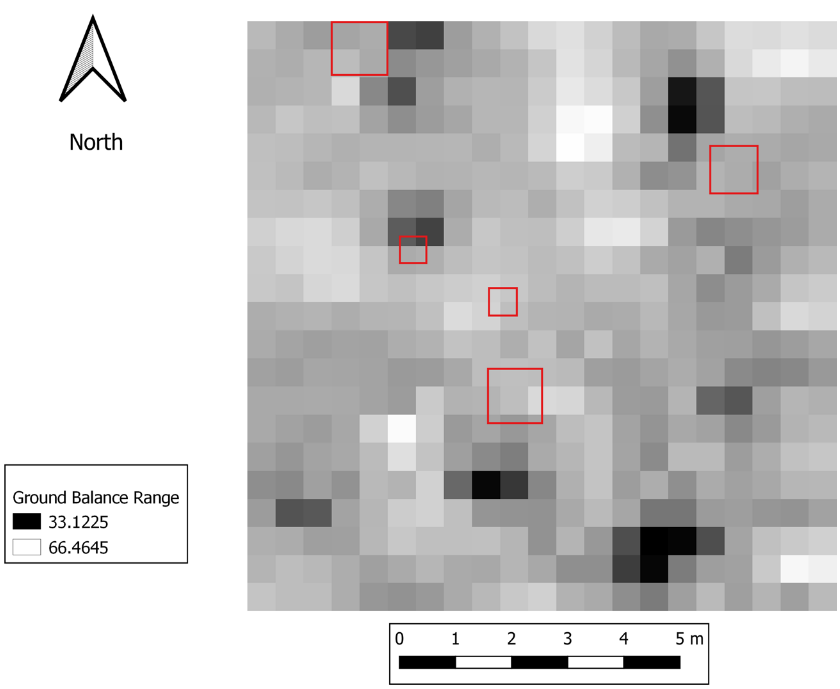

Figure 7: Interpolation map of Round Top A ground balance readings. Test units in red.

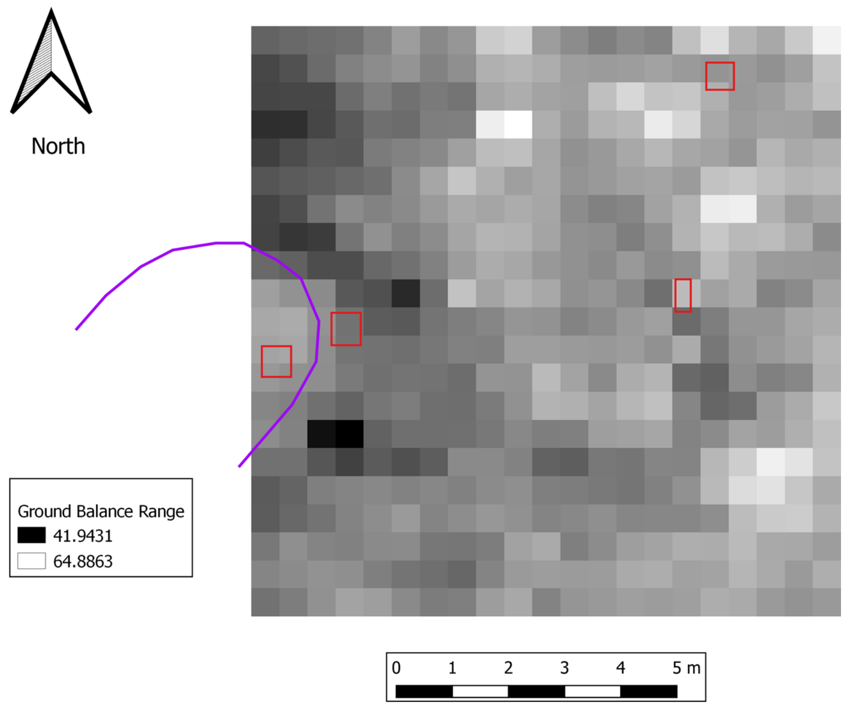

Figure 8: Interpolation map of Round Top B. Culvert location drawn in purple. Shovel test locations in red.

possibly indicating recent ditch digging activities to manage the direction of water into the culvert (Figure 8). The 2002 survey identified FCR, flakes, and a possible postmold feature at this site. However, no photographs of the feature were taken at the time of fieldwork because of weather conditions (heavy rain). In the summer of 2004, a geophysical field school, led by Dr. Timothy Matney and the University of Akron, was conducted at the site. Both electrical resistivity and magnetic gradiometry surveys were conducted in this swale. No ground truthing excavations were conducted at the time (Haney et al., 2004).

No artifacts were identified during excavations, except a single unidentified piece of farm equipment (possibly a harness buckle). However, test unit 2 yielded a substantial number of size-sorted limestone gravel. The gravel was likely used in the grading and fill of the culvert immediately west of the survey area, and the access road to the south was also made of the same size-graded gravel. A quick inspection with the metal detector revealed a large linear ferrous object running the length of the swale to the culvert. Based on this evidence, it is highly likely that a second metal culvert was buried in the swale to direct the flow of water, and gravel was placed around the culvert. It was clear from test unit 2 that the western edge of the survey area had been disturbed in the recent past. The gravel was the same size grade (in the United States it is known as commercial #57 limestone gravel) as the gravel access road immediately to the south of the survey area.

Round Top B was the only site were a rough approximation of the 2004 geophysical survey could be determined (Figure 9). The primary reason the old geophysical survey could be relocated was due in large part to the culvert and access road, which were included in the survey area in 2004.

The Garden Pond site (33 SU 359) is bisected by the same asphalt walking path that goes north to Round Top B (33 SU 358). This site was also identified in the same archaeological survey as the Round Top sites (Whitman & Tegland, 2002). Field schools, led by the University of Akron, were conducted at the site in 2004 (Tim Matney, personal communication, 2019). Artifacts recovered from the site include flakes, FCR, and charcoal fragments. No features were recorded in 2002 or 2004. In 2007, a geophysical field school was conducted at the site, led by Dr. Tim Matney. Gradiometric and Electrical Resistivity surveys were conducted at the site. The exact locations of these surveys unfortunately could not be determined relative to the survey location of this project.

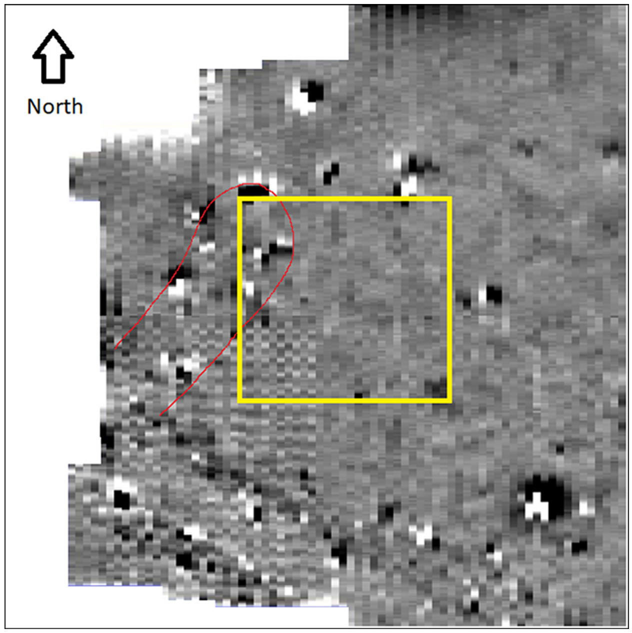

Figure 9: Round Top B Area Geophysical Survey from 2007, University of Akron. The culvert area is drawn in red, and the approximate location of the metal detector survey is outlined in yellow. Note the parallel lines to the southwest, which is the location of an extant gravel access road. Image courtesy Tim Matney. Nanotesla per meter values could not be located from original survey.

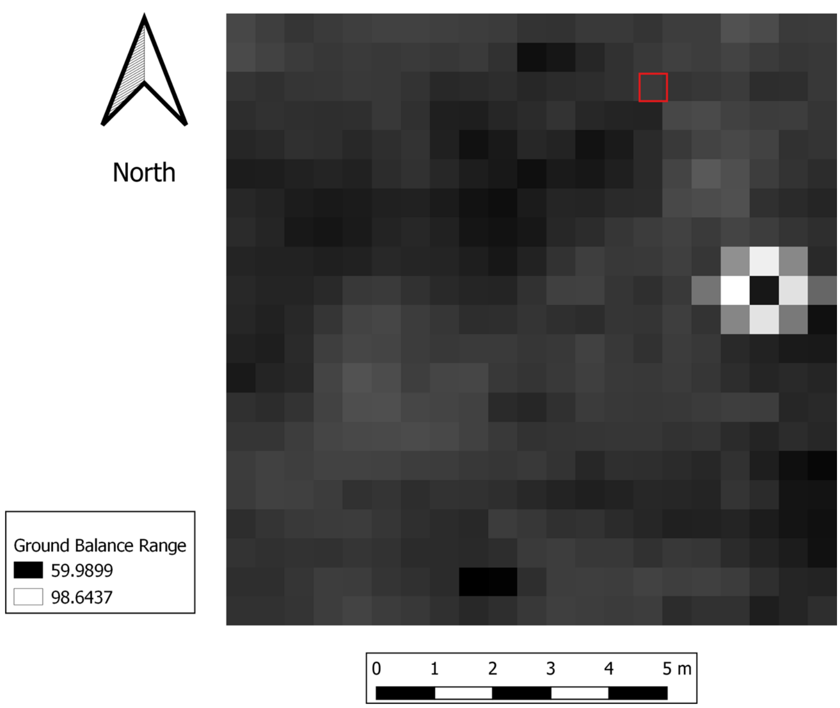

Figure 10: Location of shovel test and interpolation map at Garden Pond. Shovel test locations in red. Note the anomaly in the eastern center of survey area. This was an unidentified ferrous object.

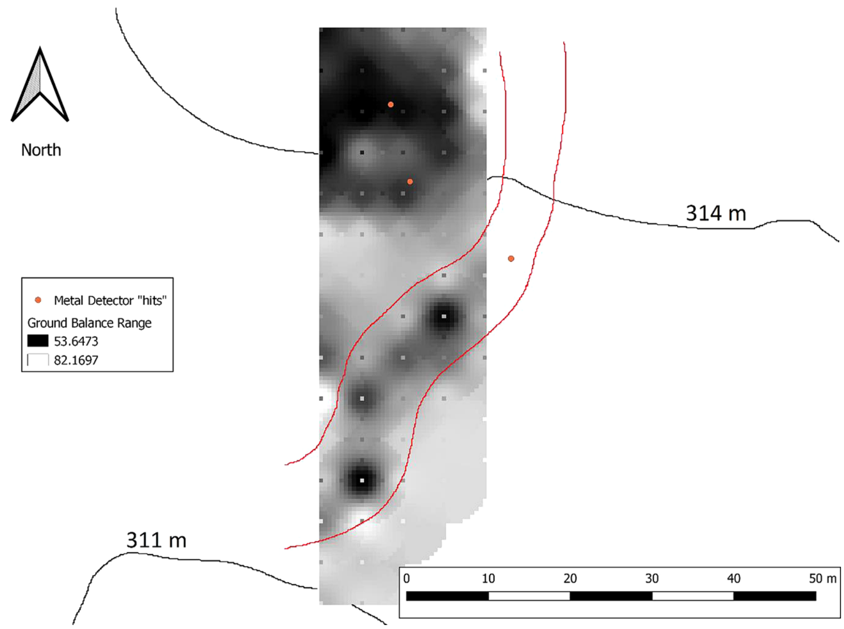

Figure 11: Interpolation map of the Matney Site, with locations of positive auger tests. Note the change in readings as the elevation decreases, and the clear spike of readings following the compacted dirt road running through the survey area drawn in red.

A total of six shovel test pits, 25 cm × 25 cm square, were excavated at the Garden Pond site. However, only two pieces of FCR and a few fragments of charcoal were collected. The single shovel test within the MD survey area failed to yield any cultural information. An unidentified ferrous object was located using a bucket auger, which is a clear anomaly in the interpolation map in the eastern center of the map (Figure 10).

The southernmost site excavated as part of the project was the Matney Site. The site was "seeded" with modern materials designed to emulate an archaeological feature in the early 2000s, such as an intentionally buried brick wall and fire pit. Because of time constraints of the Cuyahoga Community College field school, a "rough and ready" field method was used to sample the site. Rather than survey with the metal detector in 25 cm × 50 cm increments, students collected ground balance readings every 5 m. In addition to these ground balance readings, sweeping MD transects were walked every 5 m north to south. Only one metal object was identified in the central eastern portion of the project area. The hit was ground truthed with a 30 cm diameter bucket auger. The objects recovered were two pieces of square cut nails. The hit was located along a 2 meter-wide access road that ran along the eastern edge of the survey area and turned southwest toward a gas well over a kilometer to the southwest. In addition to ground truthing metal detector hits, bucket augers were used to excavate ground balance reading locations every 5 m east-west and every 10 m north-south. Figure 11 is the interpolation map of the Matney Site. From the interpolation map, the compacted dirt access road running through the survey area is distinguishable.

4 Discussion and Conclusions

The results of this pilot study have yielded new information about several archaeological sites, as well as information on a new technique in MD. The lessons learned in this project evolved over the course of completion. For example, using spreadsheet applications like Google Sheets on a mobile device rather than handwritten notes vastly improved recording time and the time needed to generate an interpolation map. The Archaeological Geophysics Toolbox on QGIS, as well as year-to-year improvements in the software, lead to faster computer processing times in data interpolations and reducing overall time on the project.

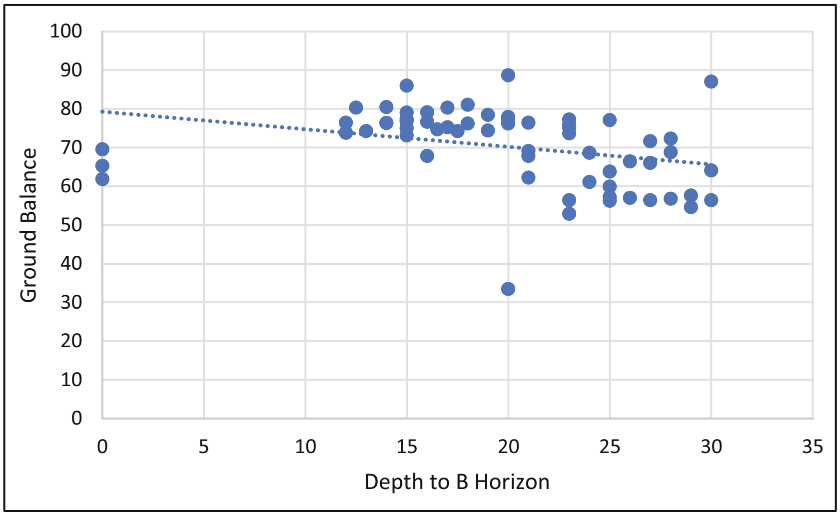

Figure 12: Linear regression of ground balance readings over subsoil depth. $N = 62$.

Espenshade (2012) recommends the removal of topsoil to bring the coil closer to the subsurface and therefore closer to features. All the sites sampled for this study were conducted in uplands with B horizon depths between 20 and 30 cm. The coil head was within range to detect the magnetism of the B horizon in these contexts. Data were also collected for the depth of subsoil of each test excavation, and in at least three cases, ground balance readings were collected at sterile subsoil. These readings were graphed on a scatter plot and run through a linear regression (Figure 12).

The scatter plot in Figure 12 shows the depth of subsoil over the reading for the ground balance. If the distance from the coil head to subsoil is a significant factor of these ground balance readings, we should expect a clear linear relationship between depth to subsoil and ground balance readings. The B horizons in all survey conditions were iron rich and relatively shallow to the surface (Ritchie & Steiger, 1974). Readings should fall in the 40–75 ground balance range (First Texas Products, 2015). The iron content of the clay subsoil has a weaker signal, just as buried metal objects have a weaker signal, the further from the coil head the object is. The closer the subsoil is, the higher the ground balance reading. However, from the linear regression, there is almost no linear relationship between these variables. The R value of this linear relationship ($R = 0.03$) is almost none, and the strength of this correlation explains only 9% of the total sample ($R^2 = 0.09$). This regression is based on 62 cases.

These results have a couple of caveats. The first is the data, which are constricted by the device. B Horizons should range between 40 and 75 on the machine, which is not a true ratio scale measurement. The other caveat is the contents of the A Horizon. Some soils contained very few pieces of glacial gravel, but in numerous cases, the A Horizon contained iron-bearing rocks that may have hyperinflated the ground balance readings of the detector. These are known as “hot rocks” in the hobbyist community (First Texas Products, 2015). Most of the survey areas, being in glacial till deposits, contained numerous rocks ranging in size from pebbles to small cobbles roughly 400 g in size. As stated in the results, weight of FCR has a weak correlation with ground balance readings, which may have factored into the ground balance readings relative to the depth of the B Horizon.

The general rule of thumb is that the diameter or maximum width of the detector head (in the case of oval-shaped heads like the one in this study) is also the maximum detectable depth of the detector. Thus, this technique is not very useful at detecting fluctuations in the B horizon in deeper deposits such as alluvial areas or in survey conditions where the coil head cannot be brought close to the surface (i.e., tall grass or underbrush). The methodology in this study was applied to one survey area in a floodplain, which failed to identify anomalies (Gintert, Matney, & Olson, 2018). The results of this survey yielded a map like a topographic map of the project area, suggesting the ground balance readings correlate closely with the depth of the B Horizon. The same pattern of depth of the B Horizon is visible at the Matney Site. As the detector coil becomes farther removed from the iron-rich B horizon, the weaker the signal becomes.

The results of this pilot study suggest that this application of MD at archaeological sites can identify and delineate historical ground disturbing activities, such as grade and fill for road construction, that alter the depth of iron-rich B Horizons; however, the results are inconclusive for identifying subsurface archaeological features. At historical sites, or locations where there is a high potential for metallic "noise" (such as Grace Park or Fir Hill), this method can reduce the uncertainty or need to ground truth every positive metal detector hit at a site. At Grace Park, the ground balance readings, paired with ferrous MD hits, revealed the locations of subsurface historical features. This method could prove useful at historical sites with the potential for low artifact density features or structureless historical sites.

The most promising technique may prove to be the "rough and ready" sampling strategy used at the Matney Site. Sampling larger areas may be a more efficient use of the metal detector, which is restricted to sample sizes no smaller than the coil head dimensions. Other geophysical survey methods, such as gradiometry, can collect data below the sample sizes gathered here (less than 25 cm). Thus, finely detailed, small survey areas may be less informative than applying this technique to hundreds of square meters, such as reconnaissance surveys. Although it should not be considered a replacement or equal alternative to other geophysical methods like gradiometry or electrical resistivity, for the cost of a metal detector, this method has the potential to yield information that otherwise would be missed in most reconnaissance surveys that do not use any geophysical methods.

Acknowledgments: This project would not be possible without the funding of the National Geographic Society Early Career Grants Program. The author could not have completed this work without the diligent work, support, and assistance of Damon Mullen both in the field and at the computer. Excavation of the test sites would not have been possible without the support and coordination of Lara Roketenetz. The physical excavations were made possible by the hard work of Summer Campers, Girl Scouts, and students at the Cuyahoga Community College Field School.

Funding information: The work was financed in part by the National Geographic Society Early Career Grants Program.

Author contributions: The author has accepted responsibility for the entire content of this manuscript.

Conflict of interest: The author states no conflict of interest.

Data availability statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

References

Chlysta, J., Housel, K., & Manahan, T. K. (2017). *2015 KSU investigation of the round top site* (*33Su358*). Kent: Department of Anthropology, Kent State University.

Collins, J., & Molyneaux, B. (2003). *Archaeological survey. Archaeologist's Toolkit* (Vol. 2). New York: Rowman Altamira.

Connor, M., & Scott, D. (1998). Metal detector use in archaeology: An introduction. *Historical Archaeology*, *32*(4), 76–85.

Cross, G. (2008). *Soil electromagnetic properties and metal detector performance: Theory and measurement. Defence R&D Canada, Contract report 2009-062*. Suffield: Defence Research and Development Canada.

Das, Y. (2006). Effects of soil eletromagnetic properties on metal detectors. *IEEE Transactions on Geoscience and Remote Sensing*, *44*(6), 1444–1453.

Espenshade, C. (2012). Yes, but how?: Increasing the efficiency of metal detector survey. In T. G. Powis (Ed.), *Proceedings of the Advanced Metal Detecting for the Archaeologist: Helen, Georgia* (pp. 14–32).

Espenshade, C., Scott, D., Severts, P., Skaggs, S., Powis, T., & Silliman, G. (2012). A discussion of standards for metal detecting. In T. G. Powis (Ed.), *Proceedings of the Advanced Metal Detecting for the Archaeologist Conference: Helen, Georgia* (pp. 5–13).
First Texas Products. (2015). *Teknetics G2 + Owner's Manual*. El Paso: First Texas Products.
Gaffney, C. (2008). Detecting trends in the prediction of the buried past: A review of geophysical techniques in archaeology. *Archaeometry*, *50*(2), 313–336.
Gintert, C., Matney, T., & Olson, E. (2018). *Archaeological geophysical reconnaissance of the alleged 1813 Boatyard site in the valley view area, city of Akron, Summit County, Ohio*. Stewards of Historical Preservation, Technical Report No. 6.
Haldenby, D., & Richards, J. (2010). Charting the effects of plough damage using metal-detecting assemblages. *Antiquity*, *84*, 1151–1162.
Haney, S., Heeney, A., Hochstetler, B., McNeill, R., Sutter, J., & Warino, C. (2004). *Archaeological geophysical surveys in bath nature preserve. Paper presented for archaeo-geophysics class*. Akron, Ohio: Department of Classical Studies, Anthropology, and Archaeology, University of Akron.
Hargrave, M. (2006). Ground truthing the results of geophysical surveys. In J. Johnson (Ed.), *Remote sensing in archaeology: An explicitly north american perspective* (pp. 269–304). Tuscaloosa: University of Alabama Press.
Hulin, G., Simon, F., & Hatami, N. (2017). AGT – Archaeological geophysics toolbox for QGIS. *ISAP News*, *51*, 7–8.
Igel, J., Preetz, H., & Altfelder, S. (2015). Predicting Soil influence on the performance of metal detectors: Magnetic properties of tropical soils. *Journal of ERW and Mine Action*, *13*(1), 103–107.
Iwacha, H. (1979). The use of metal detectors in archaeology. *Manitoba Archaeological Quarterly*, *3*(2), 13–16.
Johnson, J. (2006). *Remote sensing in archaeology: An explicitly North American perspective*. Tuscaloosa: University of Alabama Press.
Jordanova, N., Jordanova, D., Petrovsky, E., & Kovacheva, M. (2001). Changes in magnetic properties of baked archaeological samples. Implications for palaeointensity determination. *Studia Geophysica et Geodaetica*, *45*(3), 297–318.
Keller, C., Boyd, C., Groover, M., & Hill, M. (2011). *Archaeology of the battles of fort recovery, mercer county, Ohio: Education: Education and protection*. Applied Anthropology Laboratories, Ball State University, Reports of Investigations 78.
Kern, A. (1999). Geophysical survey as a conservation tool. *Nebraska Anthropologist*, *118*, 74–79.
Marino, M., Olson, E., & Matney, T. (2017). *Archaeological geophysical survey of the old summit county infirmary at Schneider Park, Akron, Summit County, Ohio. Report prepared for the Akron Engineering Bureau*. Stewards of Historical Preservation, Technical Report No. 3.
Martens, J. (2016). The plow zone as context: Metal detecting, research and heritage management. In J. Martens & M. Ravn (Eds.), *Plow zone as context: New challenges for research, management, and dissemination. Article collection* (pp. 13–22). Kristianland: Portal Publisher.
Martin, S. (1999). *Wonderful power: The story of ancient copper working in the lake superior basin*. Detroit: Wayne State University Press.
Mueller, T. G., Dhanikonda, S. R. K., Pusuluri, N. B., Karathanasis, A. D., Mathias, K. K., Mijatovic, B., & Sears, B. G. (2003). Optimizing inverse distance weighted interpolation with cross-validation. *Soil Science*, *170*(7), 504–515.
Olson, E. (2017). No shovel required: An archaeological inventory of Greater Akron, Ohio. *Current Research in Ohio Archaeology*. https://www.ohioarchaeology.org/component/content/article/140-resources/research/articles-and-abstracts-2017/514-no-shovel-required-an-archaeological-inventory-of-greater-akron-ohio. Ohio Archaeological Council: Columbus.
Parsons, T. (2012). Rivers and rifles: The role of Fort Heiman in the Western theater of the civil war. *Journal of Kentucky Archaeology*, *1*(2), 16–38.
Pickard, B. (2014). Archaeology and metal detecting: Are they actually old friends or did they just get along. *Ohio History Connection, Archaeology Blog.* (web accessed November 21, 2017). https://www.ohiohistory.org/learn/collections/archaeology/archaeology-blog/2014/may-2014/archaeology-and-metal-detecting-are-they-actually.
Powis, T. G. (2012). Archaeology in the kill zone: Using Metal detectors on the civil war battlefield site of pickett's mill. In T. G. Powis (Ed.), *Proceedings of the Advanced Metal Detecting for the Archaeologist Conference: Helen, Georgia* (pp. 143–158).
Preetz, H., Altfelder, S., Hennings, V., & Igel, J. (2009). Classification of soil magnetic susceptibility and prediction of metal detector performance – Case study of Angola. *Proceedings of SPIE*, *7303*(730313), 1–11.
Price, M. (2012). Local history: Akron park must remain so forever – Or else. *Akron Beacon Journal*. (March 26. Web accessed 12/7/2017). https://www.ohio.com/akron/lifestyle/local-history-akron-park-must-remain-so-forever-or-else.
Ritchie, A., & Steiger, J. R. (1974). *Soil survey of summit county, Ohio*. Columbus: United States Department of Agriculture, Soil Conservation Service.
Schwarz, K. (2014). A Jack's Reef horizon settlement cluster in the Central Scioto Valley. *Midcontinental Journal of Archaeology*, *39*(3), 280–302.
Scott, D., Espenshade, C., Severts, P., Skaggs, S., Powis, T., Adams, C., & Haecker, C. (2012). Advances in metal detector technology and applications in archaeology. In T. G. Powis (Ed.), *Proceedings of the Advanced Metal Detecting for the Archaeologist Conference: Helen, Georgia* (pp. 33–54).
Skaggs, S., & Severts, P. (2012). discrimination detecting at the allatoona pass battlefield pilot project. In T. G. Powis (Ed.), *Proceedings of the Advanced Metal Detecting for the Archaeologist Conference: Helen, Georgia* (pp. 87–102).

Stothers, D. M., & Tucker, P. M. (2006). *The fry site: Archaeological and ethnohistorical perspectives on the Maumee River Ottawa of Northwest Ohio*. Morrisville: LuLu Press.

Takahashi, K., Preetz, H., & Igel, J. (2013). Influence of soil properties on the performance of metal detectors and GPR. *Journal of ERW and Mine Action*, *17*(1), 52–57.

Thomas, S., & Stone, P. (2009). *Metal detecting and archaeology*. Woodbridge, UK: Boydell Press.

Tite, M. S., & Mullins, C. (1971). Enhancement of the magnetic susceptibility of soils on archaeological sites. *Archaeometry*, *13*(2), 209–219.

Wheatley, D., & Gillings, M. (2003). *Spatial technology and archaeology: The archaeological applications of GIS*. Boca Raton: CRC Press.

Whitman, L., & Tegland, J. (2002). *Final report of the Phase I archaeological survey for the multi-purpose trail at the bath nature preserve, bath township, Summit County, Ohio*. The University of Akron Community Archaeology Program. Report submitted to the Bath Township Trustees.