Archaeology Guidelines Supplement

Geophysical Survey

State Historic Preservation Office

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Geophysical Survey

Table of Contents

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Geophysical Survey

Remote Sensing Tools for Locating and Documenting Cultural Resources

Remote sensing tools provide a quick, nondestructive way to map and locate cultural resources. From satellite photographs to profiles of features within the ground imaged by radio waves, remote sensing techniques share a common distinction: they all provide information about what is on or below the surface without the need for excavation.

Geophysical Survey: Introduction

Geophysical survey is a type of remote sensing used in archaeology to identify archaeological features of potential interest within the ground. It involves the use of various instruments to collect sample readings at a set interval or rate as the instruments are moved across the survey area. Typically, the sample readings are then transferred to a computer and used to make a map. When detected, archaeological features stand out as unusual, or anomalous, areas in the data maps, as compared to the background geophysical signature of the site. Locating subsurface archaeological features, such as graves, storage or cooking pits, and foundations, can be an important part of a research design on any Phase I, II, or III archaeology project. Geophysical survey can detect many kinds of archaeological features without the need for digging or other major ground disturbances, in most cases. Therefore, it can be a relative ly quick way to identify important archaeological features and other features of note.

A range of different survey instrument types is available for use on archaeological projects. Three of the most commonly used instruments are: magnetometer, ground penetrating radar, and earth resistance meter. Other instrument types sometimes deployed on archaeology projects include electromagnetic conductivity meter, magnetic susceptibility meter, and metal detector.

Deciding which instrument or group of instruments, to use on a project depends on the types of features one is looking for and the ground conditions within the survey area. In most cases, the instruments can detect features as much as about one to two meters below surface. Certain materials or objects can be detected even deeper if the correct instrument is used.

Instruments and What Can Be Detected

Geophysical survey instruments can detect many kinds of archaeological features, but detectability depends on several important variables, including contrast, depth, and size/data density. A feature or object must be geophysically different, or contrast, from its surroundings if it is to appear in geophysical survey results. Furthermore, these differences must occur relative ly close to the surface and cover a wide enough area to be detected. Each survey technique measures a different geophysical property or measures similar properties but in a different way.

Magnetometer: A passive instrument that does not transmit any signals, magnetometers detect the earth's existing magnetic field or the magnetism of objects (Figure 1). There are several different sensor types, with the most commonly used in archaeology being fluxgate and alkali vapor (cesium) optically pumped systems. Most instruments are configured as gradiometers, meaning there are two sensors present in each magnetometer probe and the instrument records the difference between the two. Magnetometers detect two magnetic properties: magnetic susceptibility (things that react to a magnetic field) and remnant magnetism (things that have their own magnetic field). In practice, magnetometers are good at detecting pit-type features, including storage pits, cooking pits/earth ovens, refuse pits, and areas of burning, as well as iron objects and igneous or other magnetic rocks. They can be used in rural or urban sites, though excessive iron objects within the survey area can overly-complicate the resulting images. Magnetometer survey results are typically shown as black and white maps, with black as positive and white as negative (in the United States). Survey instruments are fast, relative ly high resolution, and can work in all weather and all settings. However, the instruments can be easily overwhelmed by too much magnetic signal and many different kinds of things in or on the ground can look similar. Instruments can be used for quick site scanning to identify large targets, or more commonly magnetic data are collected by moving the instrument back and forth along transects, sometimes in survey blocks, to collect data on a timed interval. Newer instruments are GPS/GNSSS guided and do not require survey blocks. For general information on magnetometers in archaeology, see Bevan and Smekalova (2013); Gaffney and Gator (2003); Kvamme (2006).

Magnetometers

Type: Fluxgate Gradiometer, single probe, carried

Data Collection Modes: Pre-established grid blocks for area surveys; scanning

Use Areas & Conditions: All

Detects: Changes in earth's magnetic field, iron objects, pit features, filled ditches, burned earth (e.g., hearths, bricks)

Typical Application: American Indian sites, Historic period farmsteads, cemeteries

Pros: Can be used in areas with obstacles (e.g., cemeteries, woods)

Cons: Slower than multi-probe systems, requires grid and experienced operator

Minimum Recommended Data Density: 8 samples/meter in-line, transect spacing 50 cm

Type: Fluxgate Gradiometer, multi-probe, cart-based

Data Collection Modes: GPS/GNSS based area survey; scanning

Use Areas & Conditions: Open, relative flat ground

Detects: Changes in earth's magnetic field, iron objects, pit features, filled ditches, burned earth (e.g., hearths, bricks)

Typical Application: American Indian sites, Historic period farmsteads

Pros: Data collection and processing very fast, thus could be used to search for sites (with subsurface features), as well as locate features on known sites; no survey grid needed

Cons: Cannot be used under tree cover (needs satellite signal) or in area with numerous obstacles (e.g., most cemeteries

Minimum Recommended Data Density: 8-10 samples/meter in-line, transect spacing 50 cm

Figure 1. Examples of magnetometer systems.

Ground Penetrating Radar: Also known as GPR or georadar (Figure 2). Ground penetrating radar systems transmit radiowaves of a set frequency range into the ground and then wait a designated amount of time for reflections to return to the surface. Reflections are created by objects (e.g., rocks, metals) and layers (e.g., soil/sediment or archaeological midden) that slow down or speed up the radio wave's velocity. The instrument records the intensity of the reflections and their two-way travel time. This information is then plotted as a profile, or radargram, of the ground beneath the radar, tracking its location as the radar is moved across the site. Radargrams are then merged into three-dimensional volumes that can be sliced horizontally at a designated depth (i.e., two-way travel time) beneath the surface. Radio frequencies between about 200 MHz and 800 MHz are most used in archaeology. Lower frequency systems (e.g., 100 MHz) can penetrate deeper into the ground but can only detect larger targets, while higher frequency systems (e.g., 900-1000 MHz) can detect smaller features but are limited to very shallow surveys. Most archaeological surveys in Ohio are conducted with 400-500 MHz systems. These typically penetrate about one meter into the ground, or deeper on sandy soil. Depth penetration can be limited (attenuated) by conductive, typically clayey, soils. Radar is excellent for mapping hard targets such as stone foundations. It can also detect some pit- and shaft-type features, such as graves, wells, and storage/refuse pits. Surveys are relatively fast and high resolution. Radar data can be collected in grid or GPS/GNSS modes. For more on ground penetrating radar in archaeology, see Conyers 2012, 2013, 2016; Gaffney and Gator 2003; Novo 2013.

Ground Penetrating Radar

Type: Single channel, push cart

Data Collection Modes: Pre-established grid blocks for area surveys; scanning; GPS/GNSS guided surveys

Use Areas & Conditions: All areas but avoid wet surface/standing water or freezing-thawing surface, works through pavement

Detects: Building foundations, shaft-type features (e.g., cisterns, wells, privies), roads/paths, graves

Typical Application: Historic period sites (farmsteads, urban settings), cemeteries

Pros: high-density 3D data, can locate features at variety of depths, can work in areas with obstacles

Cons: single channel systems are time intensive, depth penetration can be limited (60-80 cm) in Ohio (but this varies), data processing and interpretation can be challenging

Minimum Recommended Data Density: 40-50 traces per meter, 25-50 cm transect spacing

Recommended Frequency Range: ca. 200-700 MHz

Type: Multiple channel, push cart or vehicle mounted array

Data Collection Modes: Typically GPS/GNSS Guided

Use Areas & Conditions: Flat surfaces, few obstacles, avoid wet surface/standing water, freezing-thawing surface

Detects: Building foundations, shaft-type features (e.g., cisterns, wells, privies), roads/paths, graves, pits, large posts

Typical Application: Historic period sites (farmsteads, urban settings), paved settings, Precontact period?, towed behind/in front of vehicle

Pros: Very high-density 3D data (some systems have 6.5 cm transect interval), can locate features at variety of depths, covers large area quickly

Cons: Large, hard to maneuver by hand, costly

Minimum Recommended Data Density: exceeds data density needs

Frequency Ranges: ca. 500-600 MHz

Figure 2. Examples of ground penetrating radar systems.

Earth Resistance Meter: Sometimes referred to as an electrical resistance or resistivity meter (Figure 3). Resistance is one of the slower types of geophysical survey. It measures the ground's ability to conduct electricity, which is affected by soil moisture and the presence of ions (charged atoms or molecules). Things that make the ground drier (e.g., stone or sand) will create higher resistance readings. Lower readings often result from features that collect moisture, such as organic layers and filled pits, or sediments with more numerous ions. Archaeological applications involve four metal electrodes: two that apply an electrical current to the ground and two used for measuring changes in voltage. Resistance meters measure a volume of soil around the electrodes. Archaeological features must sufficiently change the resistance of this volume to be detected. Electrode spacing and arrangement impacts the depth and resolution of resistance surveys. Smaller, low and high contrast features can be detected with close (25-50 cm) electrode spacing while larger, deeper features can sometimes be detected in wider-spaced (100-150 cm) arrays. Most archaeological surveys are performed with the twin probe array, in which a pair of mobile current and voltage probes separated by a fixed distance is used to collect readings at a regular interval along transects of set spacing. The other two electrodes, another pair of current and voltage probes, is set at great distance from the survey area (usually 15-20 meters away). This approach can identify features down to about 1-1.5 meters below surface. Resistance meters are good at detecting large earthen features such as mounds and enclosures, buried roads and paths, and some pit-type features such as graves. For more on earth resistance, see Gaffney and Gater (2003) and Somers (2006).

Earth Resistance Meter

Type: Twin Probe Array

Data Collection Modes: Pre-established grid blocks for area surveys

Use Areas & Conditions: Unpaved areas, must be somewhat moist

Detects: Building foundations, shaft-type features (e.g., cisterns, wells, privies), roads/paths, graves, earthworks

Typical Application: Precontact period earthworks, Historic period sites (farmsteads, urban settings), cemeteries

Pros: Easy to use, not affected by metal (like the conductivity meter), can change detection depth, can be configured to log multiple depths per location

Cons: Quite slow, has trouble in very dry weather and around high-voltage transmission lines, wooded areas often problematic, cannot be used in frozen or intermittently frozen ground

Minimum Recommended Data Density: Two samples per meter, 1 meter transect spacing; in cemeteries, must be at least 50 transect intervals

Type: Towed or pulled system, typically a "square" array

Data Collection Modes: Pre-established grid blocks for area surveys, or GPS/GNSS linked

Use Areas & Conditions: Unpaved areas, must be somewhat moist; instrument rarely used in Ohio

Detects: Building foundations, shaft-type features (e.g., cisterns, wells, privies), roads/paths, graves, earthworks

Typical Application: Precontact period features, Historic period sites (farmsteads, urban settings), cemeteries

Pros: High density (8 samples per meter), not affected by metal (like the conductivity meter), can record three probe configurations

Cons: Has trouble in very dry weather, cannot be used in frozen or intermittently frozen ground, technically challenging; muddy or wooded areas problematic

Minimum Recommended Data Density: Eight samples per meter, 1 meter transect spacing; in cemeteries, must be at least 50 transect intervals

Figure 3. Examples of earth resistance meters.

Electromagnetic Conductivity Meter: Sometimes referred to as EM or Conductivity Meter (Figure 4). Conductivity meters are not often used in American archaeology, but perhaps they should be. Most instruments in this class can detect two major properties of the soil: (1) the soil's ability to conduct electricity and (2) the soil's reaction to an applied magnetic field—a property known as magnetic susceptibility. This is an "active" instrument; it transmits a signal in order to take measurements. Unlike a resistance meter, a conductivity meter does not have to physically touch the ground to record the soil's ability to conduct electricity. Instead, it creates or transmits small magnetic fields, which in turn cause electricity to flow in the ground.

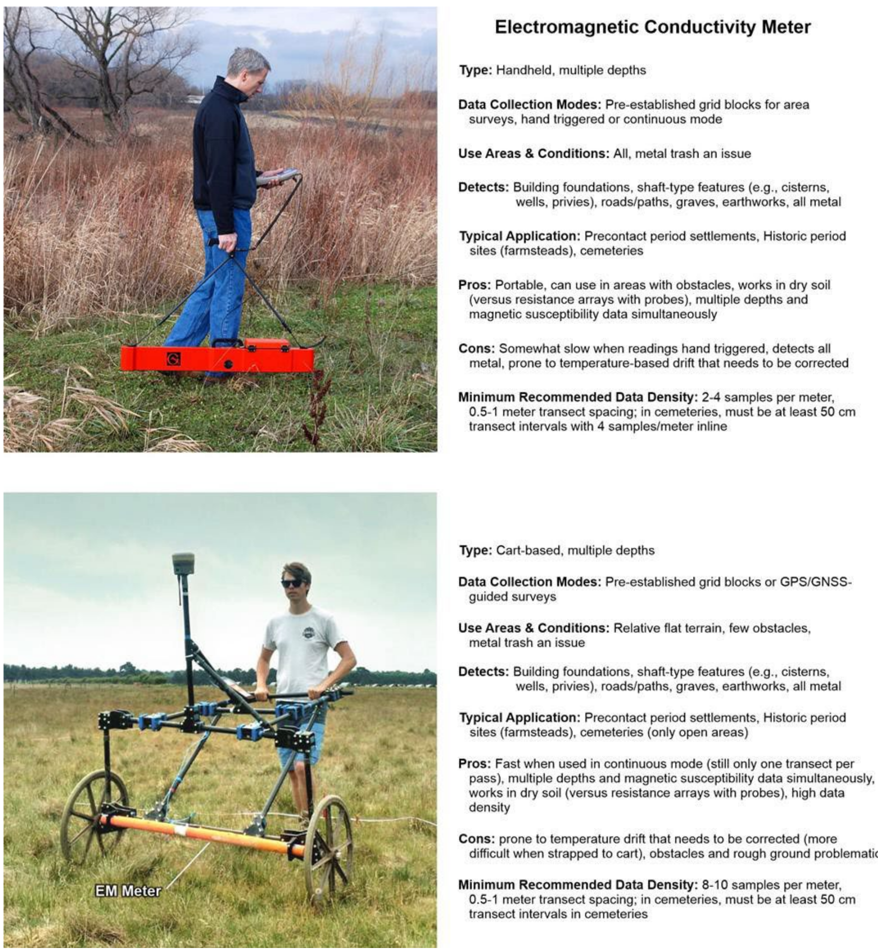

Figure 4. Examples of electromagnetic conductivity meters.

The flowing electricity creates a secondary magnetic field, which is then detected by the instrument's receiver and used to measure conductivity and magnetic susceptibility simultaneously, with most instruments. EM instruments can detect many of the same things that resistance meters can detect, such as the distinct changes in soil type that often accompany earthwork embankments or mound fill, buried building foundations and roads, and variable moisture levels in pit-type features, such as storage pits, cooking pits, and graves. They also can detect soils that react to magnetic fields, such as are common in archaeological midden and burned areas. Thus, they can detect hearths, cooking pits, building floors (that have experienced burning), and sheet midden. While magnetometers also detect magnetic susceptibility, the sensor configuration typically used in archaeology (i.e., gradiometer) filters out flat layers of material such as midden and focuses in on smaller features like pits and hearths. There are two major challenges to using EM instruments. Conductivity meters are somewhat slower to operate than most magnetometers, though today's instruments have a continuous mode that helps speed up data collection. They also are sensitive to all metals, not just iron. Therefore, sites with numerous metal objects can produce cluttered results maps. This can be useful on Post-Contact sites if knowing where metal objects are located is important, but on other sites the numerous anomalies created by metal can block out the signals from features of interest. For more on electromagnetic conductivity, see Bosnall et al. (2013) and Clay (2006).

Magnetic Susceptibility Meter: Some objects and soils become magnetized when in the presence of a magnetic field; this is a property known as magnetic susceptibility. Magnetometers measure a combination of susceptibility and permanent magnetism, while magnetic susceptibility meters only detect susceptibility. They do this by creating a small magnetic field and then measuring the response to it. Mapping susceptibility can be useful on archaeology sites at several scales, including (a) locating sites as part of large-area, low-data-density surveys, (b) mapping features and midden within high-data-density surveys within sites, and (c) using susceptibility within excavation units, on excavation floors or profiles, to identify features or midden layers that are not easily defined by soil color or texture. Magnetic susceptibility can be measured with two types of devices: dedicated magnetic susceptibility meters (Figure 5) or electromagnetic conductivity meters (the "in-phase" component of their signal) (Figure 4). Magnetic susceptibility meters can have one or more dedicated sensors built into the machine or they can have the capacity for attaching a range of sensor types for (a) taking sample readings in the laboratory on loose soil samples or solid soil cores or (b) taking readings in the field on a surface (e.g., the ground surface to map midden in the plow zone or a profile for identifying layers of interest) or in a small borehole (e.g., a "downhole" susceptibility meter sensor). Magnetic susceptibility surveys can be good at identifying midden concentrations or locating features, but the data must be collected at the appropriate density for the desired target (e.g., low density for locating broad trends in midden or high-density for finding discrete features). Since topsoil generally has a higher susceptibility than clay subsoil, and surface fires can enhance topsoil susceptibility, there are environmental and site formation processes that can appear in susceptibility data and be similar to archaeological features of interest. Floodplain settings can be especially challenging survey areas because unknown amounts of sediment can be brought in or taken away from the survey area by flooding. Good results have been recorded in Ohio on small and large Pre-contact period and Historic period sites. While susceptibility meters can detect pit-type features, magnetometers are much faster and higher in resolution for this application. Depending on the sensor or instrument type being used, susceptibility meters have a depth range from 1 cm to several meters, and resolution decreases with depth unless measurements are taken in a borehole. Surveys to map midden in the A horizon (i.e., plow zone) and to locate features just below the A horizon are most common. For more on magnetic susceptibility, see Dalan (2006, 2008), Dalan and Banerjee (1998), and Evans and Heller (2003).

Magnetic Susceptibility Meter

Type: Field sensor for surface measurements

Data Collection Modes: Scanning, data logging in grid, connect to GPS/GNSS for large ungridded surveys, continuous mode for timed interval data collection

Use Areas & Conditions: Flat ground, with or without vegetation

Detects: soils that react to magnetic field, such as midden

Typical Application: Mapping midden distribution/activity areas in American Indian sites (often in plow zone) and Historic period farmsteads; taking measurements on excavation floors to help define features

Pros: Fast, portable, some systems can be linked to GPS/GNSS, plow zone maintains magnetic enhancement

Cons: Data can be low density, system only detects down somewhat less than the diameter of the sensor

Minimum Recommended Data Density: depends on target, 10-20 meter interval good for locating areas with possible midden in plow zone

Type: Downhole field sensor

Data Collection Modes: Manual or timed logging

Use Areas & Conditions: 1-inch diameter core hole, wooded or open sites

Detects: Reaction of sediment to applied magnetic field; works well for detecting buried midden and A horizons (i.e., paleosols)

Typical Application: Distinguishing/following out layers identified in profiles, mapping buried midden layers across areas, further testing anomalies detected with other techniques

Pros: Can test deeper deposits (down to 2-3 meters, or more) without excavating, can detect thin layers (down to 1.25 cm thick) because sensor is relatively small, data collection in ground quick and can be automated

Cons: Sensor can only be used in core holes about 1-inch wide, need many core holes to map out large areas, must be regularly corrected for drift during data collection

Figure 5. Examples of magnetic susceptibility meters and sensors.

Metal Detecting: Metal detectors are a type of geophysical survey instrument somewhat similar to electromagnetic conductivity meters (Figure 6). Metal detectors create an electromagnetic field at a particular frequency range and measure the response to this field from nearby objects. They can detect all types of metal, and most can be used to differentiate (aka, discriminate) between metal types. Most metal detectors have the ability for attaching sensors (aka, loops, detector heads, and coils) of different shapes and sizes that allow for changing the depth sensitivity of the system. In archaeology, metal detectors are best used for conducting systematic surveys within lanes/swaths of set width. When possible, surveys at a site should be conducted twice, in lanes running perpendicular to one another (e.g., running lanes north- south for the first survey and then east-west for the second). Once detected, metal targets typically are excavated with small holes to limit ground disturbance. The locations of detected and/or excavated targets are then mapped using tape measures or a surveying instrument such as a laser transit or GPS/GNSS. In addition to locating objects of interest, a systematic metal detecting survey can result in maps useful for locating former buildings (e.g., a scatter of nails), activity and refuse disposal areas, and troop movements on battlefields, among other applications. For more on metal detecting, see Conner and Scott (1998).

Figure 6. Metal Detecting at the site of Pickawillany, Miami County, Ohio.

Where to Conduct Geophysical Surveys

Geophysical survey data can help locate archaeological features and answer many other questions on Section 106 projects in Ohio. Five common contexts in which to employ geophysics include : Pre-contact Period American Indian Sites, Post-Contact Period Sites, Urban Settings, Cemeteries, and Deeply Buried Sites.

Pre-contact Period Sites

American Indian sites of the Pre-contact period are some of the most widely surveyed and studied archaeological sites in Ohio. These sites can be divided into settlement/occupation sites and earthworks. Occupation sites consist primarily of small debris scatters (usually once acre or less), most represented by flint debit age and fire-cracked rock, in a wide array of settings on soils of varying type. The primary types of features present at these sites include sheet midden, pit-type features (e.g., storage pits and earth ovens), and structure remains. Earthworks consist of earthen enclosure and burial mound sites. Some of the enclosure sites are quite large, covering hundreds of acres. Enclosures consist of embankments or paired ditch-and- embankment constructions, often in geometric shapes. Mounds are accumulations of soil typically heaped over a prepared surface or floor, which is sometimes surrounded by postholes (i.e., it was inside a building or wood enclosure). Large and small pit features can extend down below mound floors; areas of intense burning on the floors is common. Many earthwork sites have been plowed flat but their remains are still present in the plow zone and just below.

Geophysical survey instruments are well suited for detecting Pre-contact period features. The following notes outline the most appropriate approaches for detecting common Pre-contact period feature types in Ohio.

Pit Features: Pits are the most common type of subsurface feature found at Pre-contact period archaeology sites, which can have one or many hundreds of pits. Most pits range from 75-150 cm in diameter and can extend down to 1-2 meters below surface. Pits often contain refuse or midden debris, and pits used for cooking can be heavily burned and contain large amounts of fire-cracked rock (e.g., igneous, sandstone, and/or limestone). Magnetometry is the best instrument for detecting pits in Ohio, assuming data are collected at a rate of at least 8 samples per meter along transects spaced 50 cm apart. The pit features appear as small, monopolar positive magnetic anomalies generally between 2 nT and 20 nT in magnetic strength in magnetic gradiometer data (Figure 7). When used for cooking, especially if heavily burned or laden with fire-cracked rock, pits often produce a distinctive dipolar magnetic signature with negative values ringing a central positive area. The magnetic strength of earth ovens can be two or three times as much as other pit features. While magnetic survey is the best way to detect pit features, sometimes pits are visible in radar, earth resistance, and electromagne t ic conductivity data. Detectability in these other instruments will depend on data density and feature content. For example, pits excavated into soil and filled with more soil are difficult to detect in radar data unless they contain large numbers of rocks or mussel shells.

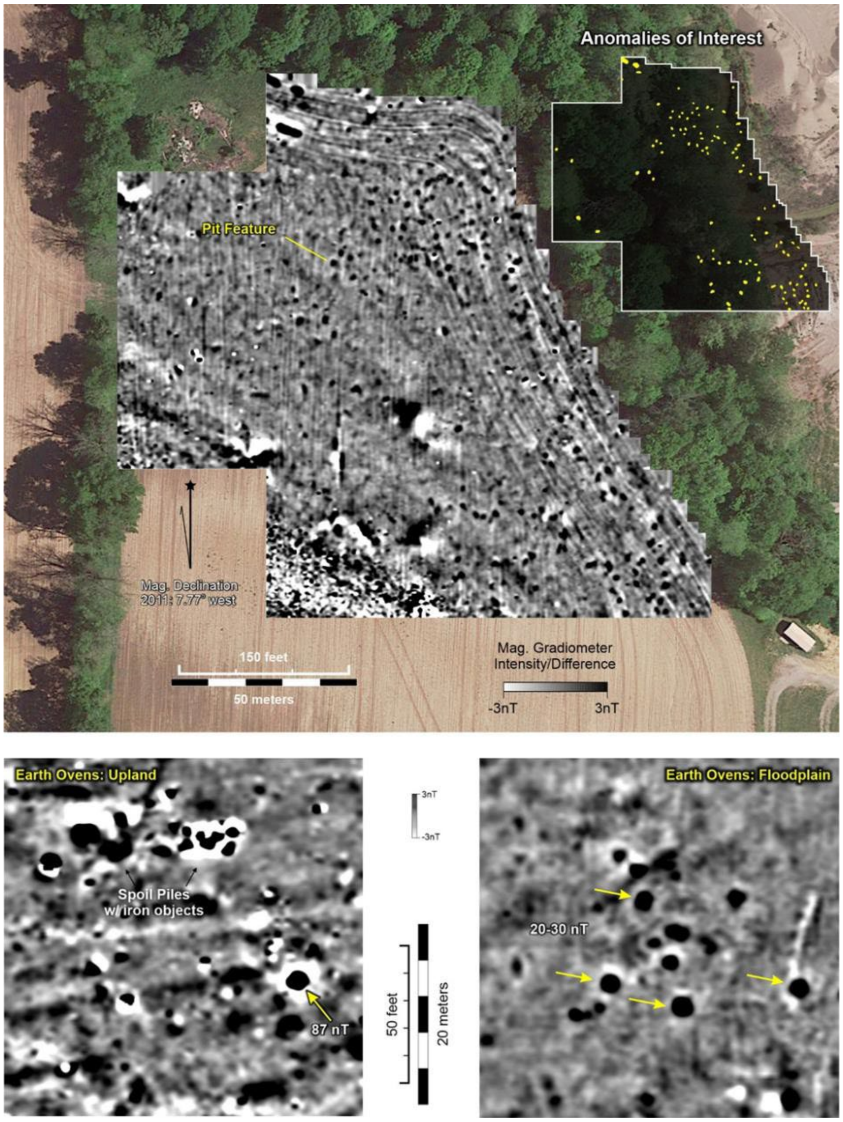

Figure 7. Pit features in magnetic data.

Structures/Houses: Detecting Pre-contact period structures is rare for geophysical survey in Ohio primarily because the structure floors have been plowed away and the postholes that extend down below the floors are very small. To be detected, posts need to be large and/or contain igneous rock or burned material. In floodplain or unplowed settings, floors may be intact. Most, if not all, structures detected in geophysical surveys to date have appeared in magnetic surveys (Figure 8). In some cases, individual posts are detected, while in others it is the structure floor or magnetically enhanced materials on it that are detected (e.g., Gold Camp and Guard sites in Figure 8-Guard is just across the state line in southeastern Indiana).

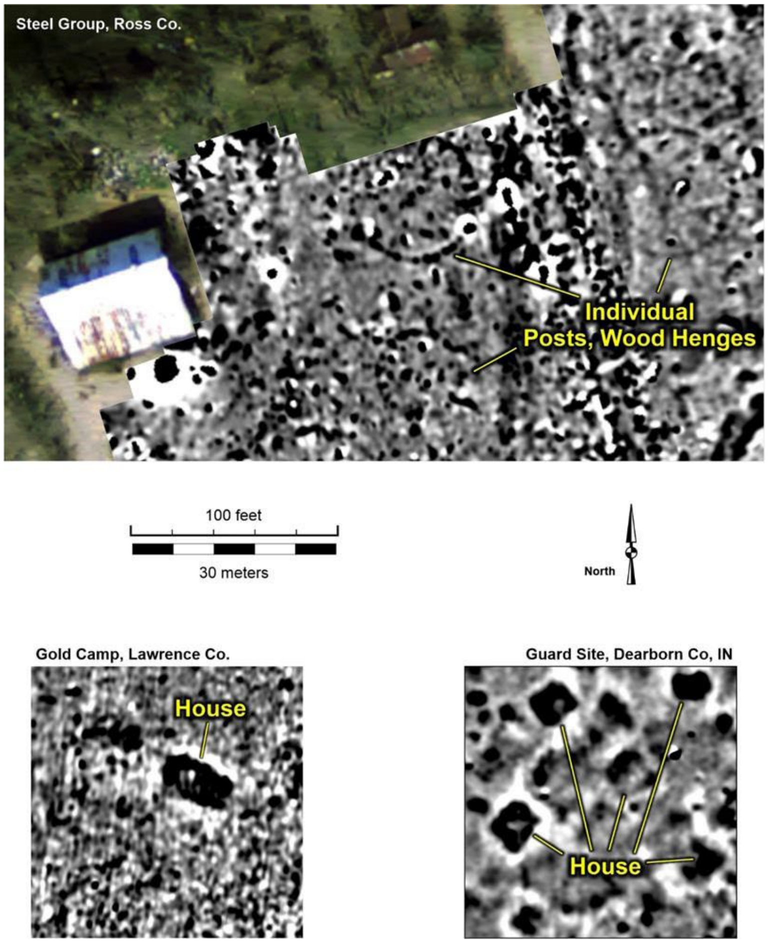

Figure 8. Structures and postholes in magnetic data.

<u>Mounds and Enclosures:</u> There are hundreds of enclosure sites in Ohio and thousands of mounds. Individual enclosures range from about 20 meters to as much as nearly 400 meters across. Mounds are smaller and can be from a few meters to 150 meters wide. When looking for features of this size, it is important to survey large areas if possible. All across Ohio, earthworks have been detected in magnetic survey data (Figure 9).

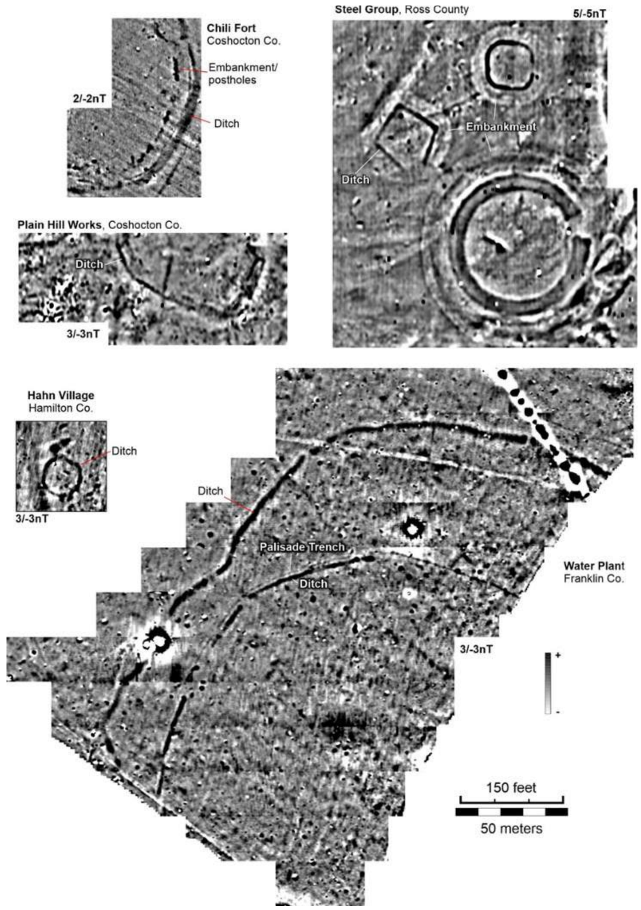

Figure 9. Enclosures in magnetic data.

Ditches typically appear as positive anomalies while embankments can be positive or negative. In some cases, earthworks can be hard to detect in magnetic data but are readily visible in earth resistance or radar data (Figure 10). Starting with a magnetic survey is recommended at earthwork sites. If the expected enclosures are not evident in the magnetic data, it may be necessary to collect earth resistance data. When attempting to identify a plowed down mound, be sure to use radar in addition to magnetic survey, as the mound floor may be detectable below the plow layer. Since earthworks and mounds are large, wider survey transect spacing can be used (e.g., 1 meter for magnetometer and resistance surveys). However, a 50 cm transect interval is always better and may be needed to detect post circles and other small features.

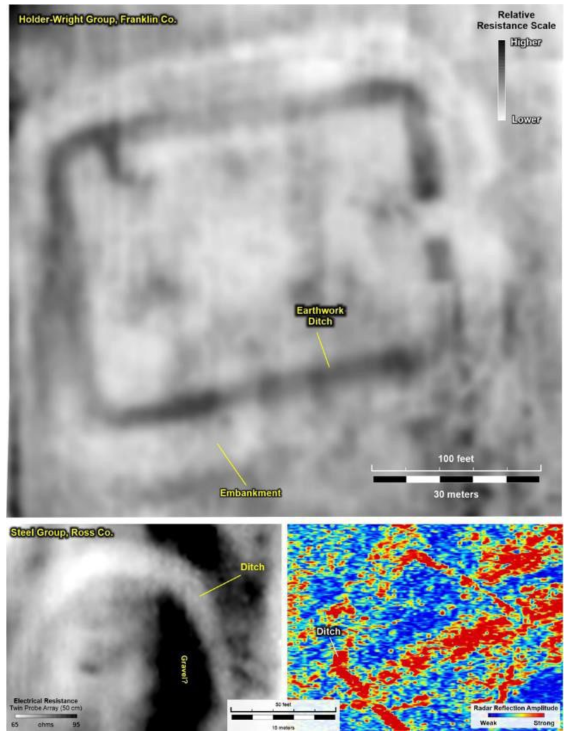

Figure 10. Examples of enclosures in resistance and radar data.

<u>Midden:</u> Pre-contact period settlement/occupation sites sometimes are associated with distinctive midden deposits. Midden contains higher levels of organic matter and the detritus from many fires. Such material is magnetically enhanced and therefore can be detected in magnetometer and magnetic susceptibility surveys. Though magnetic gradiometers tend to filter out layer-like deposits such as midden, variability in the thickness of magnetically enhanced layers, typically from plowing, can be visible as more distinctive plow marks (Figure 11).

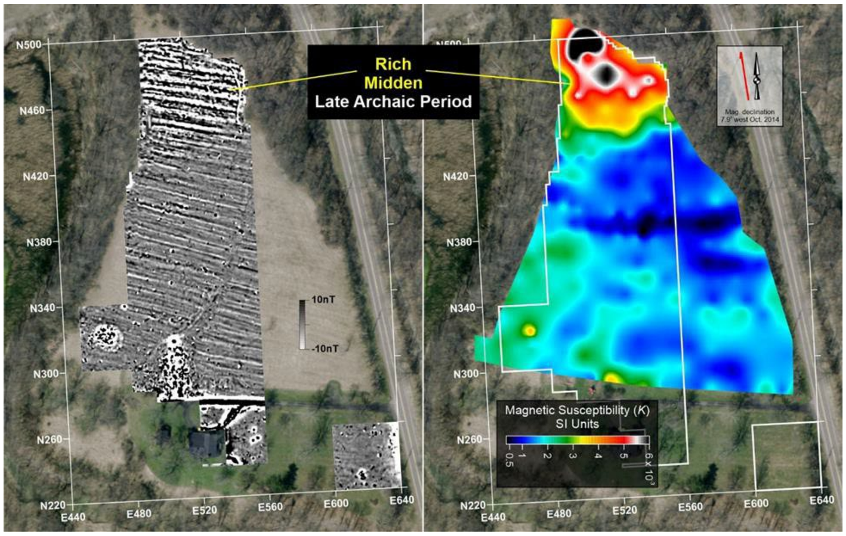

Figure 11. Detecting midden in magnetic gradiometer data as more distinctive plow marks (left) and the same site in magnetic susceptibility data (right) without plow marks.

Post-Contact Period Sites

Ohio contains many Post-Contact period rural sites, including cabin sites, farmsteads, mines, and industrial complexes. Post-Contact sites consist of building foundations, shaft-type features (wells, cisterns, and privies), massive debris scatters, and large-area earth moving. These are high contrast, relatively easy to detect geophysical anomalies for most types of instruments. Unless a specific feature is being targeted (e.g., a particular foundation), it is best to use at least two different instrument types when surveying rural Post-Contact sites. Three of the major feature types encountered include building locations/foundations, shaft-type features, and midden.

<u>Foundations:</u> The easiest way to locate buildings on Post-Contact period sites is by identifying their foundations. In Ohio, as in many other regions, building foundations were made of rubble core (fist-sized rock and sometimes brick fragments), brick, stone, or concrete. Foundations made with these durable materials can be detected by radar, magnetometers, resistance meters, and conductivity meters. Radar systems will provide the highest resolution images if 25 cm transects intervals are used (Figure 12). Typically, it is possible to determine if a foundation contains a cellar or not in radar data—those with cellars tend to have solid internal fill, as with the “House” in Figure 12. Building locations also can be identified by locating the scatter of metal (predominantly iron) hardware once

associated with them. Systematic metal detector surveys work for this, or sometimes discrete scatters of iron objects can be identified in magnetic data (Figure 13).

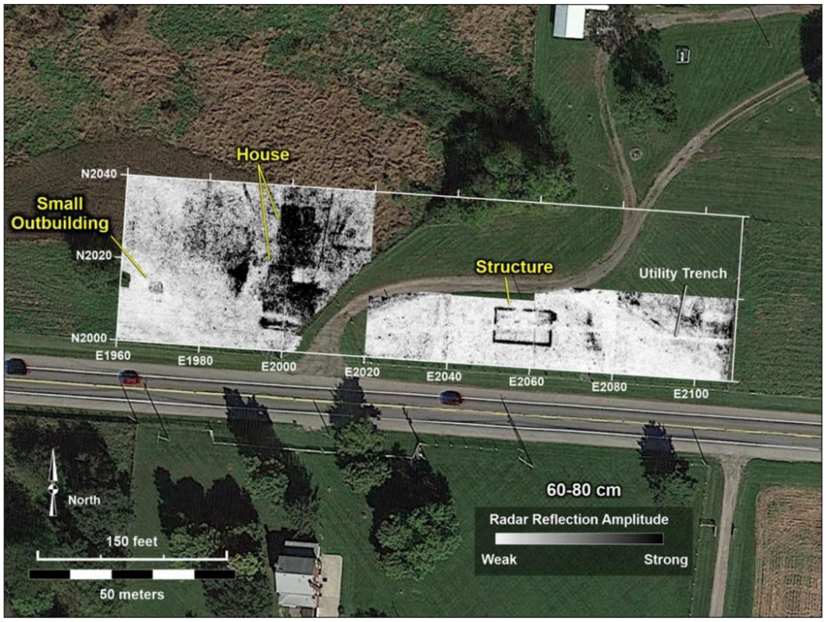

Figure 12. Radar amplitude slice map from 60-80 cm below surface showing building foundations and a modern-era utility line that has cut through them.

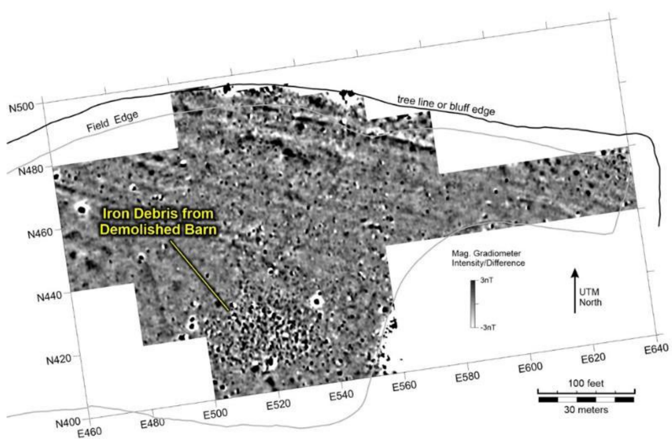

Figure 13. Detecting building locations as debris scatters in magnetometer data.

Shaft-type Features: Shaft-type features are some of the more sought-after features on Post- Contact period sites—especially privies. Their sealed, often stratified, fill is quite useful for studying the lives of people who lived at the sites. Shaft-type features include privies, wells, and cisterns, as well as other deep, steep-sided excavations. While some extend down quite deep (many meters), these features tend to have a narrow footprint (1-2 meters across), which makes them difficult to find. Ground penetrating radar surveys are the best tool for finding shaft-type features because of their ability to detect deeper into the ground than other instruments (Figure 14). Ideally, the radar data would be collected along transects spaced at 25 cm intervals (for single channel systems). Lower frequency antennas may be useful for increasing depth penetration. However, sometimes the rubble filling shaft-type features scatters the radar energy, making the features difficult to detect for the radar. For this reason, it can be useful to use a second instrument when searching for shaft-type features. They sometimes appear in magnetic data, if they are constructed with brick or filled with magnetic debris. They can also be detected by resistance meters and conductivity meters.

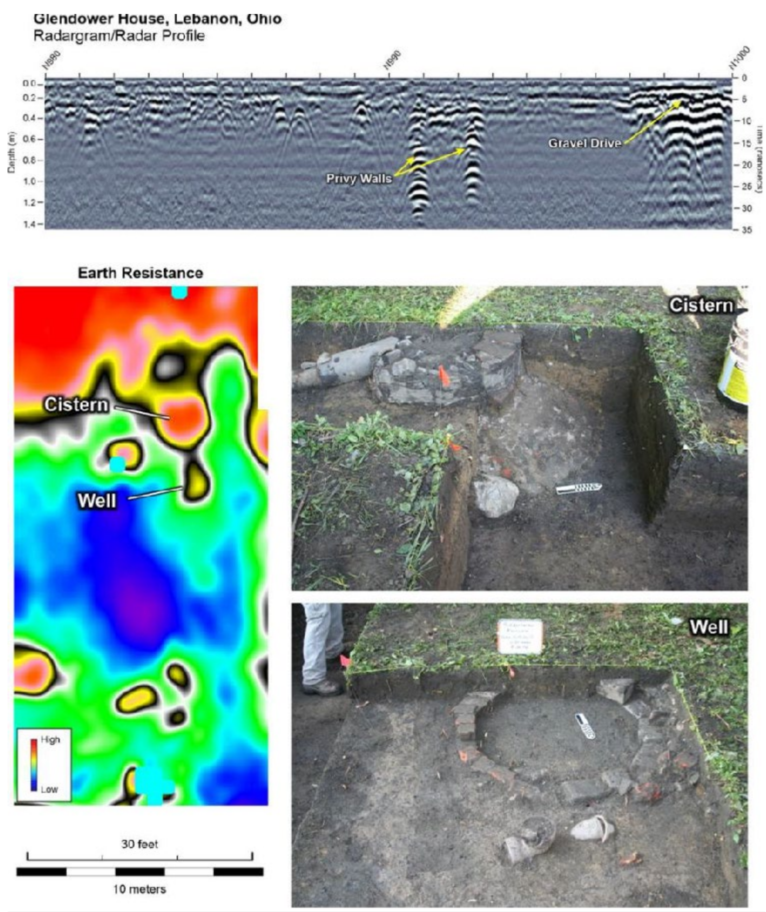

Figure 14. Shaft-type features near Post-Contact period houses.

<u>Midden:</u> Locating Post-Contact period sites in rural settings is generally straight-forward, since they tend to be ringed by refuse that is readily visible at the surface. But when the surface is obscured by vegetation, as in hay fields or wooded areas, shovel testing may be needed to locate these midden deposits. Geophysical survey is a much faster alternative. Magnetic susceptibility survey is perhaps the quickest way to locate and map the extents of Post-Contact period middens around cabin sites and farmsteads (Figure 15). Readings can be taken at the surface at very low densities (e.g., one reading per 10-20 meters over large areas) and mapped out using GPS/GNSS. The results tend to correlate well with higher artifact density areas.

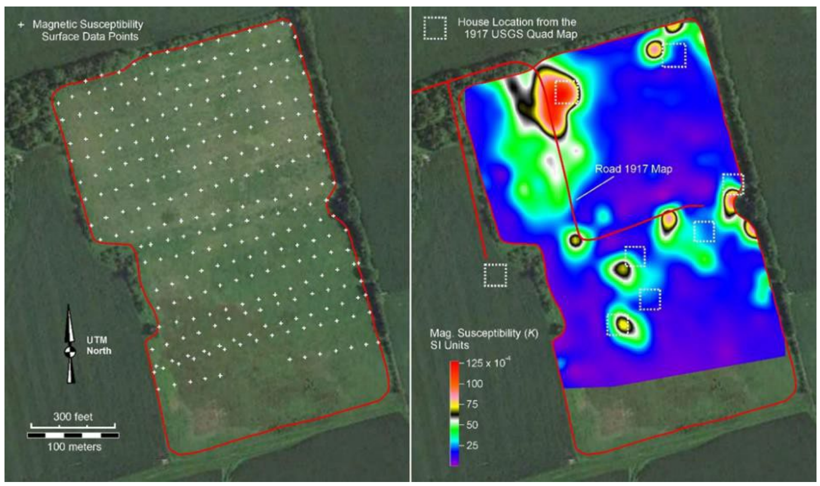

Figure 15. Magnetic susceptibility survey to locate midden related to rural houses (19th-early 20th century).

Urban Settings

Urban sites are typically complicated settings, with numerous fill layers, demolition debris, utility lines, pavement, and above-ground obstacles. They are a challenging context for geophysical survey—especially if one is looking for subtle earthen features such as older graves. However, larger, high-contrast features can still be readily detected by a range of instrument types. Most often, archaeology projects need to locate buried building foundations, shaft-type features, and roads/sidewalks. Urban project areas are located in paved areas such as parking lots, in the yards around houses, and in vacant or occupied larger building or industrial lots.

Because of its ability to penetrate pavement and achieve depths of 1-2 meters, ground penetrating radar is most often used in urban settings (Figure 16). Radar is not the only instrument that can detect features in these settings or through pavement—magnetometers and conductivity meters can, as well. However, asphalt is sometimes magnetic, which tends to overwhelm the magnetometer. Also, concrete can contain iron rebar, which the radar may be able to penetrate (or detect around—radar energy cannot penetrate metal) but the other instruments cannot.

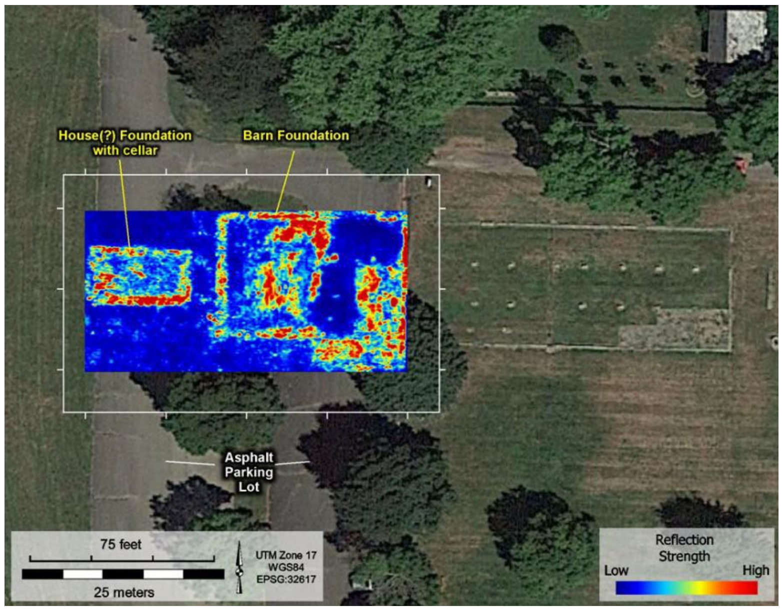

Figure 16. Radar slice map showing building foundations beneath an asphalt parking lot.

Urban house lots are also good places for geophysical survey. Using at least two instruments is recommended, as with rural farmstead sites. Radar data collected along transects spaced at 25 cm intervals is preferred, if features such as subtle shaft-type features (e.g., wood lined privies) and foundation piers are to be detected (Figure 17). Because of the many trees that are usually present on urban house lots, geophysical surveys in these settings will in most cases need to be grid-based rather than GPS/GNSS guided. As part of the survey, a map of existing features (e.g., structures, utility lines, sidewalks, trees, etc.) should be made so that the locations of these features can be compared to the geophysical survey results. Sanborn Fire Insurance maps are useful comparative material for understanding the possible construction dates for geophysically detected buildings in some urban settings.

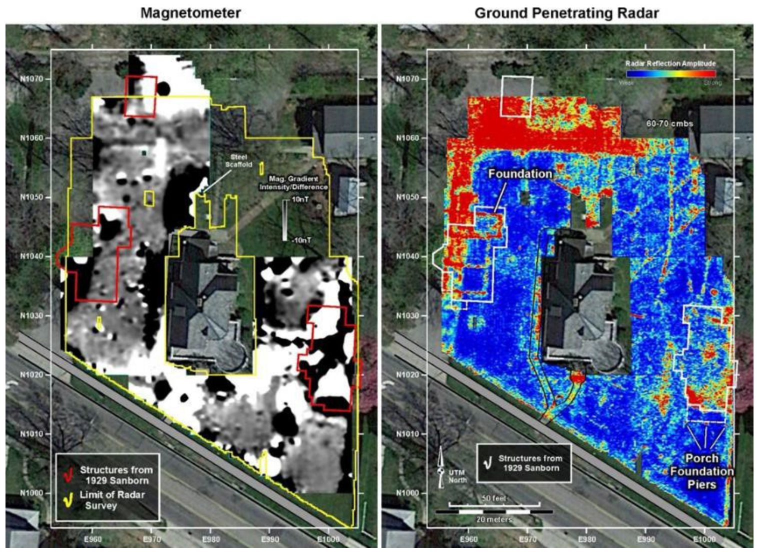

Figure 17. Magnetometer and ground penetrating radar survey results in an urban lot around the Warren G. Harding home, Marion, Ohio.

Cemeteries

Cemeteries are one of the more challenging contexts in which to conduct geophysical surveys. The soils are highly disturbed, from grave excavation, and they often contain numerous obstacles (e.g., headstones, trees, bushes, fences) to collecting data. Many cemeteries also have experienced considerable landscaping and the installation of irrigation lines. While not all graves are detectable in geophysical data, no matter the type of instrument used, geophysical surveys can locate many useful features in cemeteries to help identify individual graves and reveal the general cemetery layout.

Three instruments are commonly used to survey cemeteries in Ohio: ground penetrating radar, magnetometer, and earth resistance meter. Though radar is typically the instrument of choice for detecting graves, if at all possible, cemetery surveys should include data from at least two instrument types (e.g., radar and magnetometer, or radar and conductivity meter). There are at least three important factors, or steps, to consider when setting up a cemetery survey: (1) if possible, the data collection transects should run perpendicular, or at an angle, to the long axes of the graves—avoid paralleling the long axes. In most cemeteries in Ohio this means collecting the data along north-south lines; (2) the project should include mapping the locations of existing headstones and other features in the cemetery (e.g., trees, large rocks, and other things that will appear in the data); and (3) if possible, grave-side offerings (e.g., flowers, wreaths, etc.) and moveable markers (e.g., veteran markers) should be temporarily moved to facilitate data collection. If grave-side offerings are not moved, these may be some of the only things detected in the survey data—they may block out the signals of the graves below ground. Be sure to have permission to move objects before doing the survey work, and always conduct yourself in a respectful way while working in the cemetery.

Specific survey parameters for doing cemetery work will depend on the instrument and the soil conditions within the cemetery, but there are a few instrument-specific guidelines for minim um standards:

<u>Ground Penetrating Radar:</u> All radar surveys in cemeteries should involve the collection of radargrams and the later processing of that data into three-dimensional volumes for creating amplitude slice maps (Figure 18). Graves can appear in radar data as positive or negative (gaps in an otherwise strong reflector) anomalies. Real-time flagging of hyperbolas in radargrams visible on the radar system display screen is highly discouraged if it is the sole survey result because tree roots (among other things) look very much like graves in radar profiles; furthermore, grave shafts might be located between hyperbolas, which is only visible in amplitude/time slice maps. Because graves are relatively small, radar data in cemeteries should be collected along transects spaced no more than 25 cm apart. Radar antennas with central frequency ranges from 200-700 MHz are recommended. Lower frequency antennas may be too low in resolution to differentiate side-by-side graves. Most soils in Ohio rapidly attenuate radar energy, so depth penetration typically does not exceed one meter, unless soils are sandy. Radar surveys in cemeteries typically detect grave shafts (the soil within the grave), roads/paths, building and wall (outer walls, plot boundaries) foundations, utility lines (e.g., irrigation), and burial containers (coffins and vaults) if the depth of penetration is sufficient.

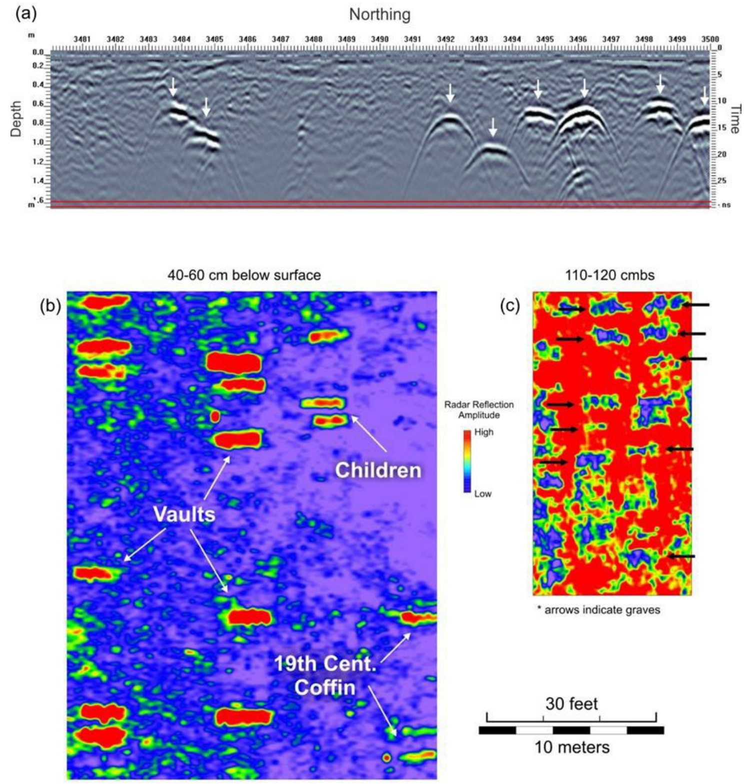

Figure 18. Examples of graves in radar data (a) a radargram, (b) when graves appear as positive anomalies (i.e., the grave or something in it is detected), and (c) when graves appear as negative anomalies (i.e., gaps in a reflective layer).

Magnetometer: Post-Contact-era cemeteries in Ohio typically have many of iron objects that show up in magnetic data—sometimes to the point of overwhelming magnetic survey results. However, magnetometers can detect a range of useful features in cemeteries, including grave shafts, iron coffins and vaults, the subsurface remains of iron fences, utility lines (e.g., iron irrigation lines), and buried marker stones (if a magnetic material, such as igneous rock, is used) (Figure 19). In some cases, individual graves will not be identifiable, but indications of rows may be evident. Modern grave-side offerings, such as plastic flowers with steel stem inserts, can be problematic. Magnetometer data should be collected in cemeteries at a minim um of eight samples per meter (in line) along transects spaced 50 cm apart. Scanning (walking about with the instrument turned on but not collecting data) may be useful for locating suspected iron coffins and vaults.

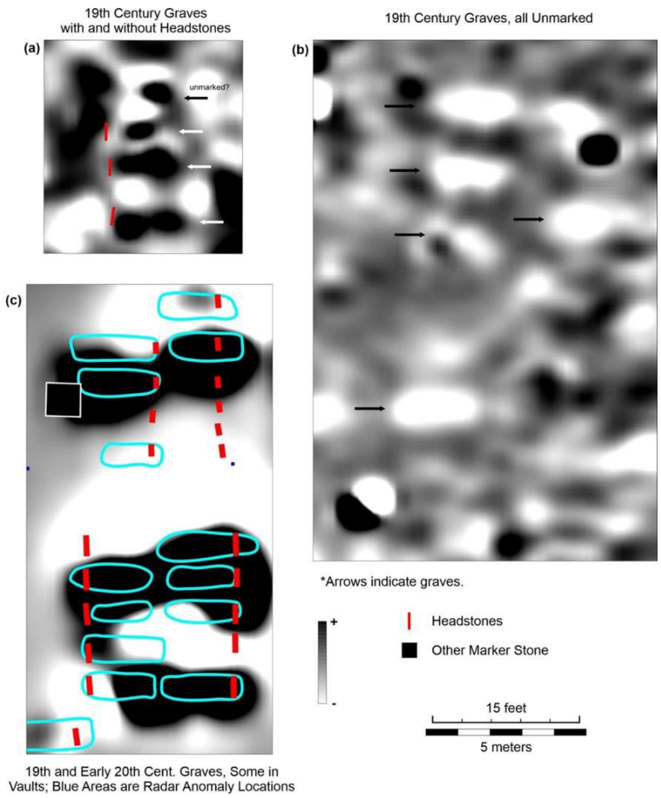

Figure 19. Examples of graves in magnetometer data.

<u>Earth Resistance:</u> Resistance surveys are a good, independent type of data to collect in cemeteries. The resistance meter, typically using a twin probe array, can detect moisture differences in the grave shaft but the data are unaffected by metal objects on or in the ground (Figure 20). The biggest challenge for resistance surveys and finding graves is data density. Because resistance survey is slow, it can be hard to collect enough data to detect something as small as a grave. Survey transect intervals of at least 50 cm are necessary, with two data readings per meter along those transects—four samples per meter would be better. A mobile probe spacing of 50 cm can work, if the ground moisture is adequate near surface for there to be a difference between the grave shaft and the surrounding matrix.

Collecting data with one meter mobile probe spacing can work as well if ground moisture is adequate, but this is a less sensitive configuration (it measures a bigger volume of soil) and therefore requires higher contrast between the grave shaft and its matrix. Individual graves may not be visible, but this technique can pick up on the positioning of rows of graves, as well.

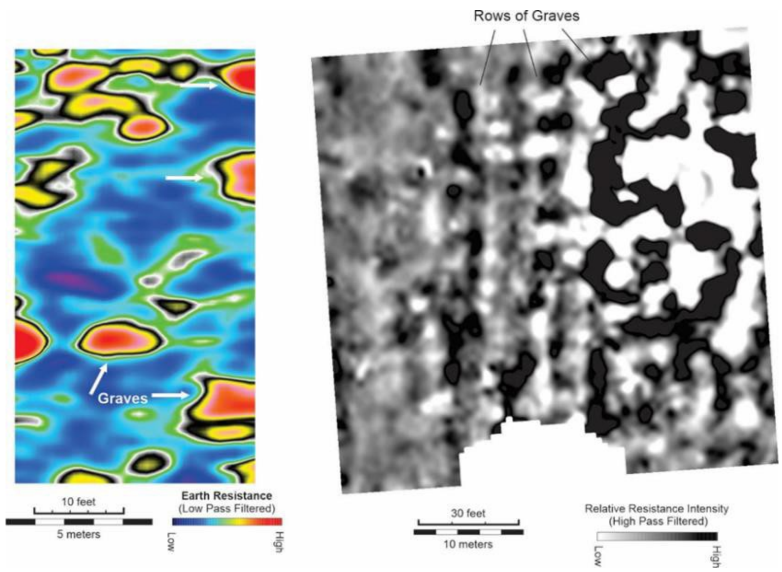

Figure 20. Examples of individual graves and rows in earth resistance data from two Ohio cemeteries.

Deeply Buried Sites

Deeply buried sites are the most challenging for geophysical survey devices. With most instruments, increased depth means decreased resolution—such as using a lower frequency radar system to achieve better depth penetration or widening the space between electrodes on a resistance meter to detect deeper. Every depth estimate comes with several caveats and conditions. For example, magnetometers can detect Pre-contact period features down to about 120-140 cm below surface, as long as (1) they are intensively burned or contain large amounts of fire-cracked rock, (2) the soil has sufficient iron oxides to be magnetized, and (3) there are no other stronger magnetic anomalies that extend into the area.

Perhaps one of the most common archaeological projects involving deep testing is looking for buried Pre-contact period layers in floodplain settings. This is often achieved through bucket augering or backhoe trenching. Another, geophysical option is magnetic susceptibility survey. Buried archaeological sites often are (a) located on/in buried topsoil or (b) have distinct midden layers. Midden and topsoil are both magnetically enhanced and therefore can best be detected by magnetic susceptibility meters. This can be achieved in the laboratory with loose or solid - core soil samples collected from varying depths across the survey area, or it can be performed in the field with a downhole susceptibility sensor. In addition to using this approach to locate buried sites, downhole susceptibility also is an effective way to map the extents of buried archaeological horizons identified through trenching. Rows of auger or core holes radiating outward from a known buried deposit can quickly define the deposit's limit.

When considering using geophysical survey to look for deeply buried archaeology, it is best to discuss your goals with an archaeological geophysics specialist. They can help you decide if your features of interest can be detected at specific depths. Table 1 provides general information about the depth of detection for various survey techniques.

Table 1. Estimates for detection depth with buried archaeology in Ohio soils.

Instrument	Configuration/Setup	Max Depth	Comments
Magnetometer-Fluxgate Gradiometer	50-100 cm sensor separation in probe	Pre-contact Period: 120-140 cm Post-Contact Period: perhaps 2 cm	Requires limited magnetic clutter; Post-Contact period feature must contain large amounts of brick or iron
Ground Penetrating Radar	~100-800 MHz	80-120 cm	Depth of penetration for radar depends on soil type and soil moisture. Dry, sandy soils provide the best depth penetration, with 2-3 meter penetration possible, or more with lower frequency systems
Earth Resistance	50-150 cm mobile probe separation, twin probe array	ca. 40-130 cm	Depth penetration for resistance arrays depends on mobile probe separation. Most surveys are conducted with the probes set between 50-150 cm (50-100 most common) apart. With wider probe separation, features must be larger to be detected
Electromagnetic Conductivity	GF Instruments CMD Mini Geonics EM38 MK2	50, 100, 180 cm 75, 150 cm	Most EM instruments have multiple receiver coils at varying distances from the transmitter coil, which allows for multiple, simultaneous measurements at different depths
Magnetic Susceptibility Meter	Varies with loop/sensor diameter	1.5-45 cm	Dedicated susceptibility meters are either small, compact units with limited (1-2 cm) depth potential or larger systems have various attachments that allow measurements to varying depth
Bartington's Downhole Magnetic Susceptibility MS2/MS3 Meter	MS2 or MS3 meters with MS2H downhole sensor	Expandable in 1-meter extensions	The Bartington downhole susceptibility system can be lowered down into a 1-inch diameter borehole to as deep as needed— up to 100 meters. In most handheld archaeology coring, this means down to about 150 cm below surface. For vehicle- mounted coring systems, this could be much deeper. Measurements can be taken at 1-2 cm intervals within the borehole.

When to use Geophysics: Common Applications

Geophysical survey can be a useful part of NHPA/Section 106 projects at all phases of investigation. Instruments and computers are now fast enough to allow for quick surveys of very large areas, while sensor and electronics miniaturization have resulted in instruments that can be used in excavation units or down boreholes. Decisions about when and how to use geophysical survey in your project must be weighed against project goals and costs. Because most geophysics requires expensive equipment and specialists to operate the equipment and interpret the results, it is important to work geophysical survey into your project design early in the process. Adding geophysics on to the end of a project should be avoided. The following sections explore some of the ways in which geophysical survey is and/or can be integrated into the NHPA/Section 106 process.

Phase I: Finding Cultural Resources

Section 106 projects often begin by surveying a select area to look for cultural resources. In Ohio this frequently means conducting pedestrian surface surveys or shovel test surveys to locate artifacts. However, this may not be the quickest way to locate cultural resources and determine if they are significant. For example, magnetometers are now fast enough that a single person can push a cart-based GPS/GNSS guided system around for a day, covering 6-10 acres. Large towed magnetometer arrays can cover as much as 25-50 acres per day, depending on surface conditions and survey speed. Radar systems are also quickly becoming capable of such coverage rates. As the speed of geophysical survey systems increases, along with data capacity, their use at the Phase I level to search for cultural resources has now become an option in Ohio, where much of the archaeological record below ground consists of small, low-contrast features. While they may not be able to completely replace traditional Phase I search methods, geophysical surveys can greatly speed up certain tasks. This is especially true in two scenarios:

> <u>Working in High Probability Areas:</u> Archaeological resources are distributed across the landscape in somewhat predictable ways. For example, relatively dry, floodplain terraces tend to contain concentrations of artifacts and subsurface features while low, wet areas have very little. If avoiding archaeological sites with numerous subsurface features in these settings is paramount, a magnetic gradiometer survey can quickly locate pit-type magnetic anomalies in open agricultural fields and guide project planning away from these features (select soil coring can determine if anomalies are features without the need for extensive excavations). Lower density techniques, such as magnetic susceptibility might also be used to cover large areas quickly to identify high probability areas for archaeological midden, which should produce elevated susceptibility values. These areas could then be targeted with costlier techniques such as shovel testing. If an earthwork or mound is located within or adjacent to the project area,

geophysical survey should be considered at the Phase I level to locate additional enclosures, mounds, and/or feature clusters (Figure 21). Distinct features at earthwork sites are not typically accompanied by concentrations of artifacts and therefore they cannot be found with surface survey or shovel testing, nor can the earthworks themselves.

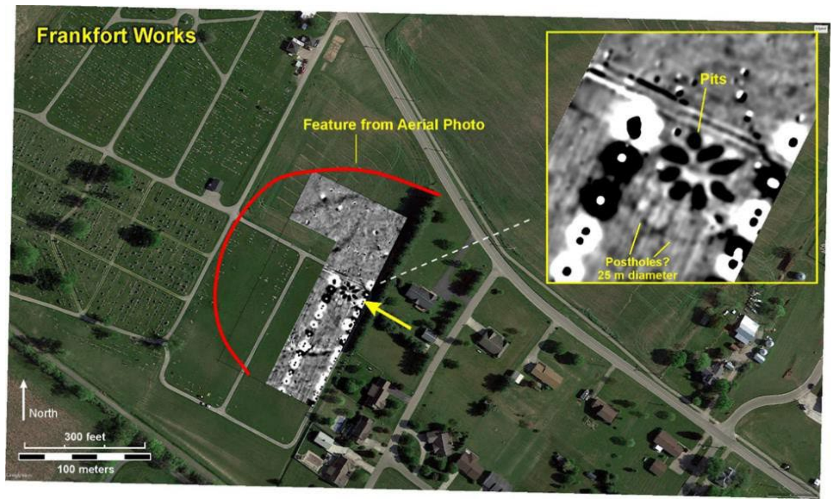

Figure 21. Patterned cluster of pit features located at west edge of Frankfort, Ohio in the general area of the Frankfort Works Hopewell earthwork site.

Looking for known Targets: In some cases, known or suspected features are present within survey areas but their exact locations have yet to be determined. House and cabin sites shown on nineteenth century township atlases are a prime example. While they are clearly shown on these atlas maps, their locations sometimes shift from map to map, due to imprecise mapping (Figure 22). A quick, low density magnetic susceptibility survey with a surface sensor can locate the midden associated with the house site and help to more specifically determine its location prior to the arrival of a shovel test crew. Or, the magnetic susceptibility survey could be the end result of the Phase I work, with future construction work within the project area retailored to avoid the area of high susceptibility. Scanning with a magnetometer or a ground penetrating radar can also quickly locate known, high contrast features such as pottery or brick kilns. In these cases, even a single probe magnetometer could be rapidly walked back forth while watching or listening to the detected values—high- fired features such as kilns will likely be one of the most magnetic features on a site. Soil coring at targets found while scanning could quickly reveal the presence or absence of burned material. A similar approach can be used to look for many other types of targets (e.g., large building foundations, cellars, buried roads, etc.).

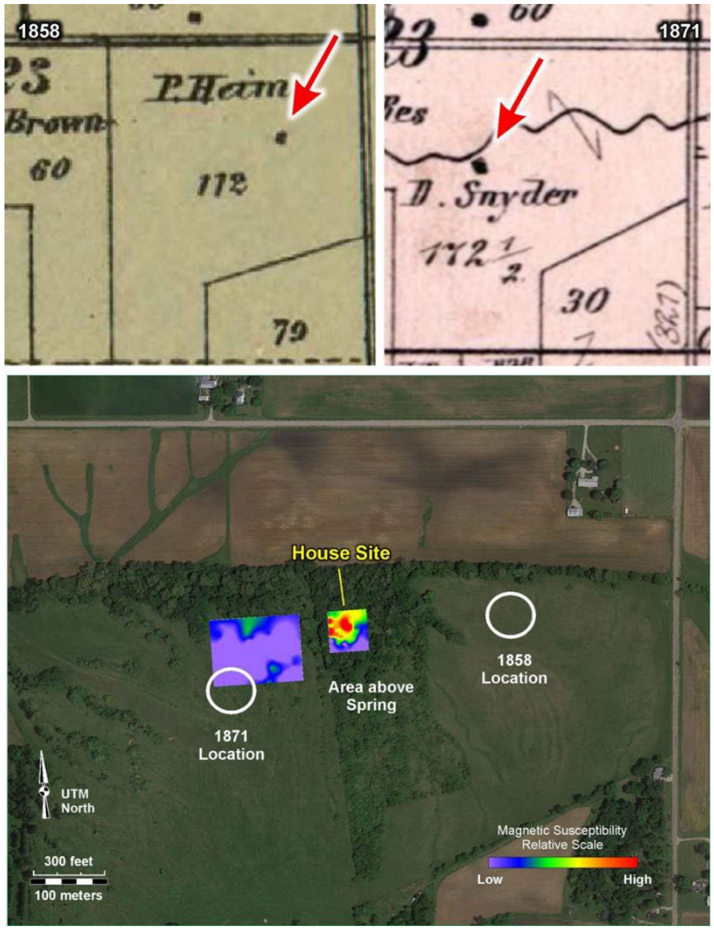

Figure 22. Quickly identifying the location of a house/cabin site using a low-data-density technique such as magnetic susceptibility to locate midden.

Phase II: Assessing Sites

Phase II projects, which frequently involve further delineating the boundaries of a site and assessing its potential for listing on the National Register are the typical point in the Section 106 process when geophysical survey is employed.

<u>Delineating Site Boundaries:</u> The boundaries of a site traditionally are defined as the extent of the site's midden or its subsurface features. Both of these tasks can be completed, or at least enhanced, using geophysics. On Pre-contact period American Indian sites, magnetic susceptibility survey can be used to define the limits of the major midden deposits and a magnetometer survey can reveal the distribution of pit-type features. Pit features and midden are often, but not always, co-located on larger archaeology sites. At Pre-contact villages such as the Hahn

Village site in Figure 23, pit distribution and areas of high susceptibility indicate the boundaries of the settlement; the lack of pits and high susceptibility values suggests the presence of a plaza near the middle of the village. In fact, there may be more than one, suggesting the possible presence of overlapping villages.

<u>Locating Subsurface Features:</u> As in the Hahn site example in Figure 23, locating pit-type features on American Indian sites is relatively simple with magnetic gradiometer surveys. On smaller sites, there may only be one or two pit-type features present within a 0.5-1-acre site.

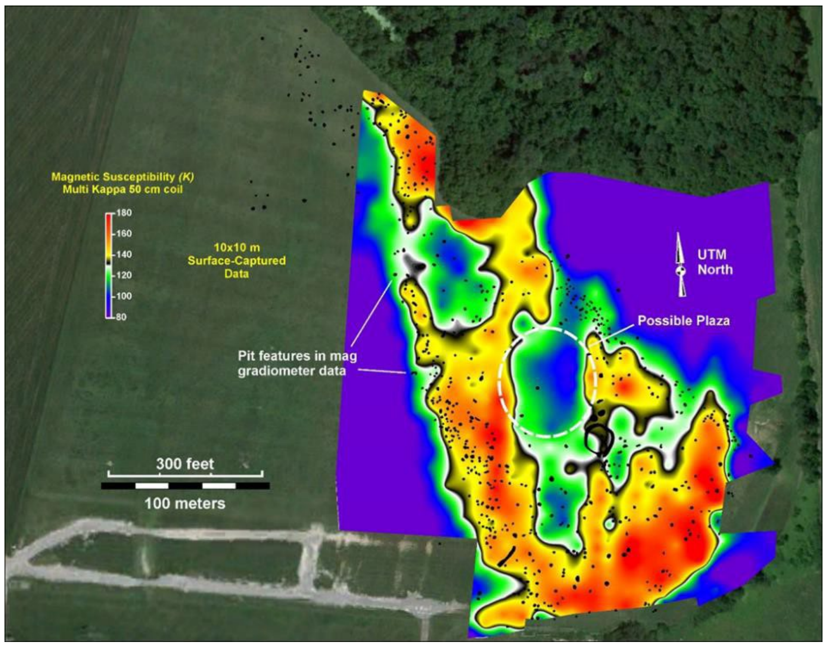

Figure 23. Delineating site boundaries at the Hahn Village site in Hamilton County; note how the magnetic susceptibility values and pit feature density fall off toward the edges of the site.

If finding sparse, widely scattered pits is important to determinations of eligibility, it would be nearly impossible to do this without removing the plow zone from most of the site—thus destroying it. A magnetic gradiometer survey can quickly locate those pit features and allow for much less excavation in the search for features. When considering this application of magnetic gradiometer survey, be sure to survey a large enough area since pit-type features are not always co-located with high-density artifact deposits at small sites. On Post-Contact period sites, especially those suspected of having buried foundations or shaft-type features, a ground- penetrating radar survey can be used to locate and map building foundations without the need for trenching. This can allow for more strategic placement of excavation units. Urban sites can be so complex that finding undisturbed places to excavate and look for earlier deposits can be nearly impossible, even with good Sanborn Fire Insurance maps. A radar and magnetome ter survey in complex urban settings will not only find features of interest, they will also help locate minimally disturbed areas lacking later utility lines and building disturbances. This approach was used to good effect in Fort Defiance, Ohio to identify less disturbed areas in which to search for remains of the late eighteenth-century fort.

Phase III: Data Recovery

When important sites cannot be avoided, large, costly excavations may be required. Even at the Phase III level, most excavations cannot uncover an entire site. Therefore, sampling must be used. Identifying anomalies of interest in geophysical data is an excellent way to help develop a sampling strategy. Anomalies of interest can be grouped by inherent clusters into sampling strata, as in the case of the Brown's Bottom site in Ross County (Figure 24). A large magnetic survey identified dozens of anomalies (probable pit features) that appeared to occur in three clusters. Sample excavations would need to target each of these clusters to achieve a representative sample in excavations. In this case, the anomalies within clusters were also classified by their magnetic strength and then random samples of anomalies from each magnetic strength class were excavated to ensure that a more representative sample within sites was also examined, rather than excavating only the most obvious and strongest anomalies in the magnetic data. Similar surveys on Post- Contact period sites (Figure 25) can reveal the locations of buildings, features, and refuse disposal zones—all of which could be sampled as part of a Phase III data recovery.

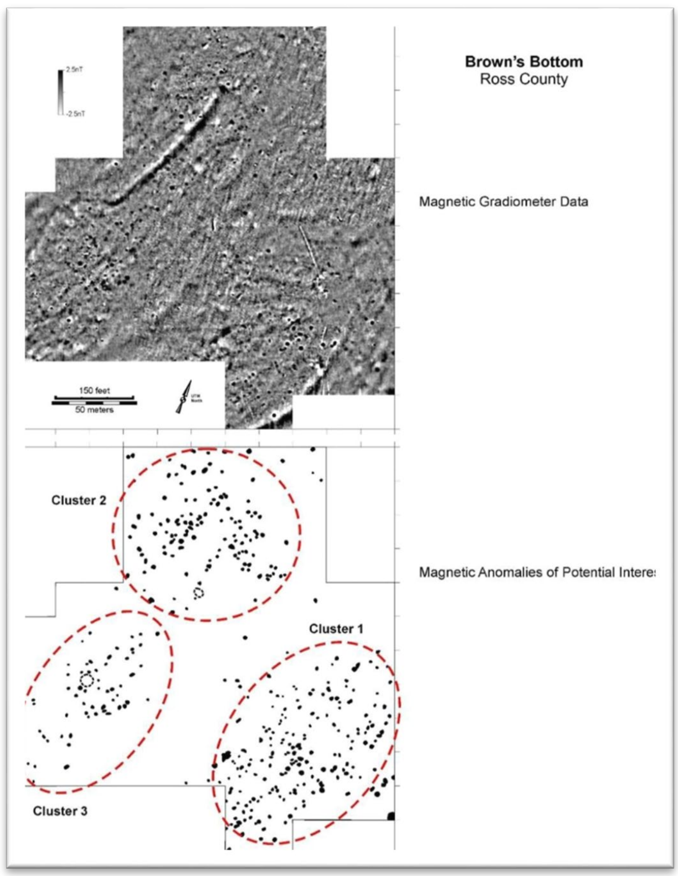

Figure 24. A site with numerous probable features detected in magnetic survey that has been divided into clusters for sampling.

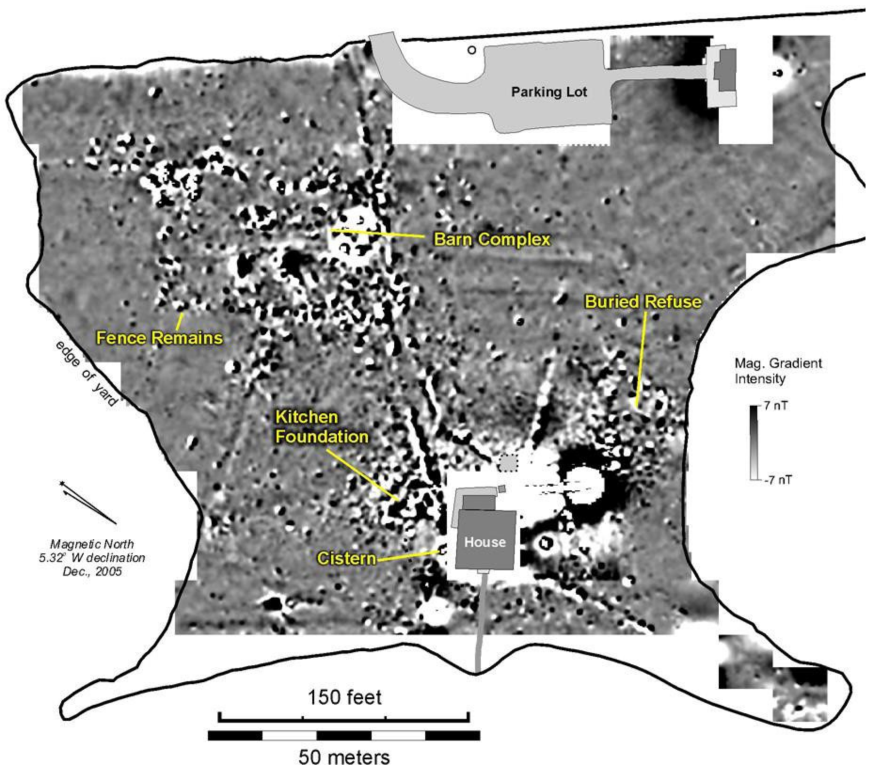

Figure 25. Different building and artifact clusters identified in a magnetic survey that can be used to guide excavation strategies.

Expectations and Best Practices

Instruments to Use: How Many and Which?

How many and which instruments to use for a project is an important question. Sometimes there is an easy answer—use the one instrument you have availab le. In other cases, archaeologists simply use all the major instrument types to see which works best. Both approaches can backfire, especially with projects on a fixed budget. Use the wrong instrument and you may not detect features that can be otherwise readily detected; use a whole suite of instruments and you may end up spending much of your budget on something that just one instrument can adequately do. Therefore, it is important to first answer the question of what is or are the project objectives before deciding which instrument(s) might work best. For example, if finding pit-type features on a Pre- contact American Indian site is the goal, then a magnetometer survey is the best solution since pit- type features are readily detected in magnetic surveys and rarely show up in radar surveys, for example. Table 2 outlines survey strategies and instrument parameters for a number of common geophysical survey projects that might occur in Ohio. Adding additional instrument types to each of the scenarios can of course result in additional types of information, but it is not always practical or cost effective to use more instruments than are necessary to achieve the primary objectives. In the future, instruments and objectives likely will change, so tables like this will need to be updated as technologies and research questions evolve.

Table 2. Common projects for geophysical surveys with suggested instruments and parameters.

Project Type	**Expected Features**	**Instrument Type (s)***	**Data Density**
Pre-contact American Indian	Pit features, houses	Magnetometer	In-line: 8-10/m Transect Spacing: 50 cm
"	Earthworks	Magnetometer+Earth Resistance	Mag: 8-10/m, 50 cm transects Res: 2/m, 1 m transects
Post-Contact Farmstead	Building foundations, shaft-type features, artifact scatter	GPR, Magnetometer	GPR: 40-50 traces/m, 25-50 cm transects Mag: 8-10/m, 50 cm transects
Urban Lot	Building foundations, shaft-type features, complicated fill	GPR	GPR: 40-50 traces/m, 25 cm transects
Cemetery	Graves, roads/paths, fences, building foundations	GPR, Magnetometer/ Conductivity	GPR: 40-50 traces/m, 25 cm transects Mag/conductivity: 8/m, 50 cm transects
Industrial (Brick/Pottery)	Kiln, building foundations, clay pit, waster piles	Magnetometer/GPR	GPR: 40-50 traces/m, 50 cm transects Mag: 8-10/m, 50-100 cm transects Scanning also useful
Charcoal Making Site	Burned area, broad filled pit	Magnetic Susceptibility	5-10 meter data sample interval
Midden (Post-Contact or Pre-contact)	Layer with artifacts, organic debris, and burned materials	Magnetic Susceptibility	10-20 meter data sample interval

* Assumes fluxgate gradiometer (magnetometer), 400-600 MHz radar system, twin probe resistance array, dedicated magnetic susceptibility system with surface sensor (25 cm loop).

Size of Area to Survey

The size of survey areas is an important topic for geophysical survey as it impacts the interpretation of the geophysical survey results. A survey area that is too small will make it impossible to determine what has been detected, especially with large features, as in the case demonstrated in Figure 26 where magnetic data from Hopewell Mound Group and Serpent Mound both produced serpentine-shaped anomalies. Imagine if only the small areas outlined in red had been surveyed. It would be impossible to know what had been detected. Since both surveys covered considerable ground, it was easy to show that the probable old stream channel at Hopewell Mound Group was not a serpent effigy. Much of geophysical survey data interpretation hinges on pattern recognition. When not limited by narrow project corridors, surveying slightly larger areas can greatly enhance interpretations and may show that what has been detected is more significant than just what is present within the smaller project footprint.

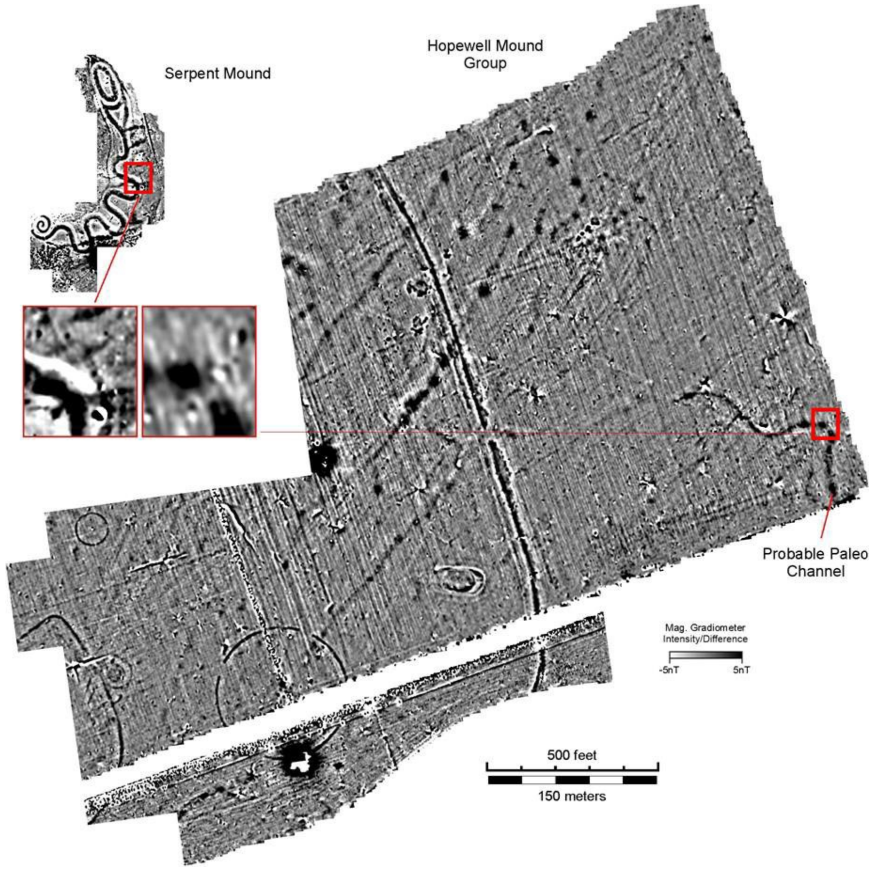

Figure 26. The importance of survey size and site scale, with a comparison of Hopewell Mound Group and Serpent Mound in magnetometer data.

The problem of survey size goes beyond large earthwork site features. It is also an issue in cemeteries, where changing soil types and drainage patterns can make it hard to detect graves in one area and easy in another. Being able to better understand the background geophysical variability in a site—the site's geophysical context—can also aid in understanding what has or has not been detected in a smaller project area. Therefore, in sites like cemeteries it is important to gain a good understanding of differences in the geophysical context in order to determine what is present within a small survey area.

When collecting additional geophysical data is not an option, comparing the existing survey results to other remote sensing data is especially important. Aerial photographs from a range of years, high-resolution topographic data, and Post-Contact maps all provide important context for interpreting geophysical survey results.

Data Density

Data density is the second most important survey parameter to decide on next to picking the appropriate instrument(s) for achieving a project's objectives. Collecting too much data is never a bad thing, except for the impact it has on time and budget. However, collecting too little data can result in failing to locate the targets of interest. For magnetometer and radar surveys, as well as other instruments that can detect in continuous or timed mode, in-line data density is no longer an issue today. Survey instruments should be able to collect more than sufficient in-line data. The more important variable today is the between line, or transect, interval. Table 2 provides recommended transect intervals for various types of projects and instruments. For any surveys aiming to detect pit-type or shaft-type features in magnetic data, 50 cm transect intervals are necessary. For detecting larger features, such as earthworks and mounds, 1 meter transect spacing works well. Variability in transect interval is most notable in radar data. An interval of 25 cm or smaller (this would be difficult for a single channel system) is required for graves and is desirable when looking for shaft-type features. With larger features, such as foundations, a 50 cm radar transect interval is often sufficient, though a one-meter interval is too wide for most archaeology in Ohio unless one is scanning for very large features. For reference, new multichannel radar systems that are becoming available in the United States have a 6.5-8 cm separation between transects. This is the future of radar survey.

Reporting

Geophysical survey reports should include method and results sections, with a discussion of the site setting (e.g., soils and ground cover) as well as other factors that might influence the results of the survey (weather, radio noise, instrument malfunctions, etc.). Presentation of data should occur in ways that help situate the results on the survey site, for example, with an aerial photograph or map in the background (Figure 27).

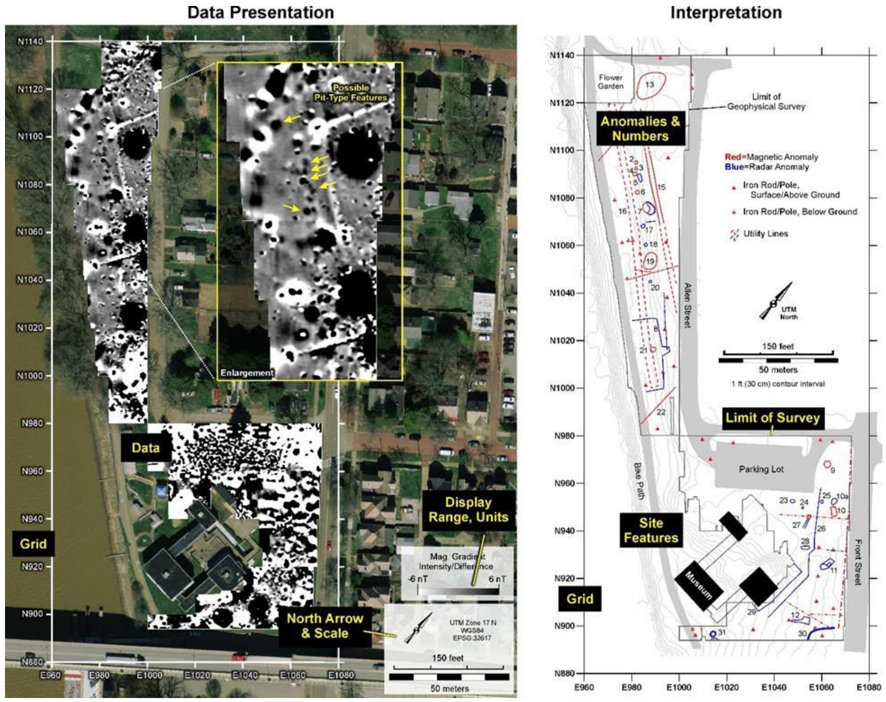

Figure 27. Presenting survey data and interpretation results.

Data maps should include spatial referents such as the site survey grid, a scale, and a north arrow. Consider appropriate color palettes that best highlight the archaeological features of interest. For all instruments except magnetometers (which typically are displayed as grayscale images with black to the positive), color or grayscale palettes are optional since anomalies of weaker or stronger amplitude may be archaeological.

Data interpretation results are best presented on a map separate from the data (Figure 26). Anomaly shapes and/or locations should be displayed as polygon and line features, along with symbols for some anomaly types and a legend. Anomalies should be numbered for ease in referring to them in the results text and/or in anomaly tables that record details such as center point coordinates, anomaly type, and interpretation comments, among other possible things. To be useful for the client and other archaeologists, the survey grid and anomaly coordinates should be tied to site datums, the geographic coordinates (e.g., UTM) of which should appear in the report. Interpretation maps also benefit from showing other features present on the site, such as buildings and roads/sidewalks; indications of topography (e.g., contour lines) also can be useful. Basic topographic data is available for the entire state as [LiDAR](#) data. It may also be useful to include larger versions of data and interpretation maps in report appendices.

Archiving

A final important topic for consideration is archiving geophysical survey results and data. While maps in reports typically are archived at the Ohio State Historic Preservation Office (SHPO), practitioners should consider archiving the data, as well. At the moment, there is no venue for storing the geophysical data within the SHPO. But when such archiving capacity becomes available, practitioners should consider submitting the data in raw and processed forms. Supporting documents and information (i.e., metadata) must accompany the data, including maps showing survey grid arrangements and descriptions of data processing software and steps, along with finished products/images for reference. Most geophysical survey instruments come with proprietary software for downloading and processing the resulting survey data. When possible, data should be provided in generic formats that can be opened by a wide range of software packages. For example, processed data can be turned into georeferenced geotiffs for opening in GIS software. Many different software packages can read XYZ file formats, as well. For a lengthier discussion of archiving geophysical survey data, see Schmidt (2013).

FAQs: Frequently Asked Questions

(1) How many instrument types should be used for a survey, and is one instrument enough?

One instrument may be sufficient if the target of interest is readily detected by the instrument. For example, a magnetometer is the best instrument to detect large iron objects or earth ovens. With subtle features, such as graves, using two or more complimentary instruments is highly recommended.

(2) I am looking for a grave, so why do I have to survey a bigger area?

Identifying features of note in geophysical data requires contrast between the feature and the background signature of the site. This means surveying an area that is significantly larger than the feature. And with subtle features such as graves, it may be necessary to detect multiple graves in one or more rows before it is possible to identify a single anomaly as a grave. When possible, avoid grave-related surveys smaller than 20x20 meters in extent and/or make sure the survey area is at least 3-5 times wider than a single grave.

(3) Can I detect features beneath a parking lot or other pavement?

Yes, most instruments (except for an earth resistance meter) can collect useful data in parking lots. Asphalt parking lots often produce the best results, especially in radar data. Some asphalt is magnetic, which can inhibit magnetometer surveys. Likewise, concrete pavement is often reinforced with steel rebar. The rebar will "blind" a magnetometer and other metal-sensing instruments such as conductivity meters, but a ground penetrating radar may be able to detect around the rebar depending on the frequency of the radar and the spacing of the rebar.

(4) Is it possible to detect bones?

Yes, with radar but only in very rare circumstances. Surveys attempting to locate burials typically detect the hole (i.e., the grave shaft) containing the remains or the container (i.e., coffin or vault) placed into the hole.

(5) About how much ground can be surveyed in a day?

This depends on instrument type (and number of channels/sensors), data density, and surface conditions. Single channel/probe instruments can cover about one acre per day. Higher density surveys, such as needed in cemeteries will cover less ground per day. Certain instrument types, such as magnetometers, can be configured with multiple probes and can be towed behind vehicles, allowing for dozens of acres per day.

(6) Can wooded areas be surveyed?

Yes. However, in almost all cases the undergrowth will need to be removed in a way that minimally disturbs the ground. Dense clusters of small trees may need to be significantly thinned.

(7) Are ground conditions important to a geophysical survey?

Yes. Always ask the geophysical survey specialist before making any changes to the ground surface ahead of a geophysical survey. Flat ground with low or no vegetation is ideal. Overly wet ground with standing water is not good for earth resistance and radar surveys while ground that is too dry at the surface can impede resistance surveys, as well.

(8) Will the instruments work in the rain or cold?

Yes, but in some cases weather conditions will negatively impact results. Muddy, wet surface conditions can produce bad radar results, while frozen or partially frozen ground is bad for earth resistance surveys. This is something that should be assessed on a case by case basis.

(9) Will geophysical survey work in urban areas or around power lines?

Yes. Most of the instruments should have no or few problems working in urban settings or around power lines. However, sources of interference are more common in these settings, and this interference may reduce the utility of some instrument types.

(10) When should a geophysical survey be done?

Geophysical data can be useful in all stages of archaeological investigation: Phases I-III. Ideally, it should be completed before any excavations or other ground disturbance. What role the survey results play in the project will depend on the project objectives. It may be that the geophysical survey results are the primary and only objective, or the results are needed to help determine the locations of excavations. When possible, avoid adding geophysics on to the end of projects.

(11) Must one record geophysical survey data (for later processing) and make maps of the results?

Yes, in nearly all cases. The great strength of geophysical survey in archaeological contexts is being able to collect and process data to refine the results of the survey. There are many things in the ground that look very similar to archaeological features in geophysical data. Having well processed data that can be used to compare to other kinds of remote sensing data, such as aerial photographs, topographic data, or artifact distribution data from surface collections or shovel test surveys will help improve the usefulness of the geophysical survey results.

Glossary

Amplitude Slice Map. Also known as time slice map or slice map. A horizontal plan map of radar survey results showing weak and strong reflections from above. Slice maps are created with special software that aligns adjacent radargrams, fills in the intervening space, and allows the user to “slice” the data at any depth within the radargram. While many modern dataloggers can create slice maps, most lack the full range of desktop data processing options needed to produce final slice maps. Data for creating slice maps should be collected in the field and processed on a computer.

Anomaly. Area of notably different values against the background geophysical signature of a survey area or site. Ideally, archaeological features and sediments create anomalies, but there are many other sources, including natural phenomena (e.g., rocks, animal burrows, lighting strikes, and soil changes), recent land modification, and signal interference.

Attenuation. A condition that affects radar data. When the soil is too conductive, it absorbs the radar energy rather than allowing it to continue down into the ground and bounce back to the instrument. Attenuation limits depth penetration in radar surveys. Certain types of clay, when moist, lead to attenuation, while sandy soils (because they typically are well drained) have less attenuation and permit greater penetration depth. Attenuation affects all frequencies.

Block. A unit of data collection and file storage. Many geophysical survey instruments collect data along parallel transects of a set length within a block. During most surveys, the block corners are laid out across the survey area with a fiberglass tape measure (for small surveys) or a more precise instrument (e.g., laser transit or RTK GNSS) for larger surveys. Blacks range in size, but 20 meters by 20 meters is common or many instruments.

Clutter. Geophysical anomalies not of interest to the objectives of the survey. These often are natural features such as rocks, tree roots, or animal burrows.

Data Density. The number of data points collected per unit space. This count has two important components: the number of data values recorded along the survey line (usually reported as the readings or samples per meter) and the spacing between sample lines (also known as the transect interval). In most cases, collecting higher density data takes longer, but it may be necessary for detecting the targets of interest.

Equifinality. In the case of geophysical surveys, when two separate and distinct things in the ground produce anomalies that look very similar or identical. For example, the magnetic anomalies associated with igneous boulders can sometimes look like the signatures of cooking pits. Equifinality is a challenge when attempting to interpret geophysical survey data to identify archaeological features.

Fluxgate Gradiometer. One of the most common magnetometer types used in archaeology. These magnetometers have two fluxgate sensors arranged one atop the other within a tube. Sensor spacings of 50-100 cm are typical. While fluxgates are somewhat less sensitive than other sensor types (e.g., cesium vapor), they work quite well in Ohio for detecting buried archaeologica l features.

GNSS. Or global navigation satellite system; sometimes referred to as GPS. GNSS includes satellite systems for mapping, navigation, and precision timing services from several differe nt countries, including for example the United States (GPS), European Union (Galileo), and the Russian Federation (Glonass).

Ground Truthing. The process of testing geophysical data interpretations. While some anomalies and interpretations are quite obvious, there are a range of things that can create anomalies similar to those expected for archaeological features. Additional testing, with a second or third type of geophysical instrument or through targeted excavation, can help sort out which anomalies are archaeological features and which have other sources. Ground truthing by excavation can include coring, hand excavation units (e.g., 2x2 m unit), or careful (and monitored) stripping/trenc hing with heavy machinery.

Radargram. A profile view of radar survey results, with the ground surface at the top and deeper reflections toward the bottom. Most radargrams show two travel time on one side and estimated depth on the other. A wide range of color palettes can be used for display. While grayscale displays are common, color can sometimes help highlight features of interest.

Transect. Also known as a traverse. A line along which survey data are collected. Whether collecting data in a gridded block or using instruments connected to a GNSS, it is important to consider transect spacing when designing a survey. Widely spaced transects may miss smaller features, while tight transect spacing can increase the cost/time of a survey and may not be necessary for the targeted features of interest.

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