Ground Penetrating Radar (GPR), Electromagnetic Induction, and Magnetic Gradiometry Surveys

Gunston Hall Plantation

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INTRODUCTION

Purpose

Geophysical surveys were conducted in two subareas at George Mason's Gunston Hall Plantation in June 2005 to demonstrate the possible usefulness of non-invasive techniques in archaeological searches for fence post-hole locations and unmarked graves. One subarea is part of the southwest side-yard of the mansion; the other subarea is the Mason Family Cemetery, about 300 yards southwest of the mansion (**figures 1 and 2**). Ground-penetrating radar (GPR) surveys were conducted June 7, after establishment of mapped grids for each subarea the previous day. In-phase electromagnetic induction (EMI) surveys were made June 17, 23, and 24. Quadrature-phase EMI surveys were made June 17 and 23. Vertical magnetic-gradiometry surveys were conducted June 17 and 24. The identification of subsurface posthole locations is important for helping to delineate the original gardens and fenced outlying areas. The discovery of unmarked graves is important for helping to understand the 18th- and 19-century demographics of the region with respect to Euro-American and Afro-American occupation.

Gunston Hall's original owner, George Mason IV (1725-1792), has been described as one of the least known and most influential of America's Founding Founders. Among his many Colonial and Revolutionary accomplishments, he wrote Virginia's Declaration of Rights and its Constitution, both of which influenced Thomas Jefferson's composition of the Declaration of Independence. Gunston Hall was occupied almost continuously by many owners throughout a period of nearly 250 years; one owner in 1875 constructed a cupola atop the mansion to house his telescope. Today, Gunston Hall is a 550-acre National Historic Landmark owned by the Commonwealth of Virginia and administered by a Board of Regents appointed from The National Society of The Colonial Dames of America.

Geographic Setting

Gunston Hall Plantation is located in Fairfax County, Virginia, about 14 miles south of Alexandria, on a cove of the Potomac River at geographic coordinates 38.6641° N, 77.1603° W, and elevation 123 ft (GPS and Fort Belvoir 7.5-minute USGS topographic quadrangle). Gunston Hall was constructed mainly during the period 1755-1759 with a probable permanent occupation no later than 1760. Contemporary plantations on or near the Potomac River included Mount Vernon and Marshall Hall to the northeast and Rippon Lodge to the southwest. Gunston Hall has a mailing address of 10709 Gunston Road, Mason Neck, VA 22079 and a worldwide web site of "gunstonhall.org". It is accessed from the Richmond Highway (U.S. Route #1) by traveling about 3.6 miles southeast along Gunston Road (Route 242) and turning left onto the well-marked entrance road.

Geologic Setting

Gunston Hall Plantation is situated on the Atlantic Coastal Plain physiographic province. It is underlain by unconsolidated sediments of the Potomac Formation, Cenozoic upland gravels, and Quaternary alluvium. The Potomac Formation consists of medium to coarse sands, silty sands, silty clays, and gravelly sands. The soil surrounding the mansion, including our southwest side-yard survey area, has been labeled "manmade" on a soils map; this term indicates that the soil here is largely introduced fill. The coarse, brown soil at the family cemetery, which has a fragipan at about 2 ft depth, is labeled "Beltsville loam, undulating phase" and has developed from Coastal Plain sand, silt, and clay. Soils topographically higher than the mansion typically consist of a mantle of silty and sandy materials over older river terrace deposits that overlie sedimentary beds of the Potomac Formation. Soils topographically lower than the mansion typically consist of alternating strata of sands, silts, and clays with some river-deposited cobbles and boulders. The presence of clay is relevant to our GPR surveys in that significant quantities tend to attenuate the signal and thus impede the passage of radar energy into the subsurface.

Posthole detection

This investigation was initiated by a communication of Dave Shonyo to W. F. Hanna in January 2005 at the suggestion of our friend, Fairfax County Archaeologist Michael Johnson. Shonyo inquired about the feasibility of using remote-sensing techniques to locate subsurface postholes. Hanna was aware of the sometimes-successful use of magnetic methods to detect postholes, and Hanna's colleague, C. E. Petrone, claimed success at Shuters Hill, Alexandria, Va., using GPR for this purpose. Thus, we decided to include GPR with more conventional remote-sensing techniques in a demonstration project.

We first remind ourselves of a typical formation of a posthole/postmold feature: (1) A hole is cut (often nearly square in plan view) into the soil; (2) a wooden post, often pre-charred to enhance its protection against insects and decay, is inserted into the hole; (3) the hole is in-filled with redeposited soil that may also contain solid objects, such as brick fragments; (4) over a sufficient period of time, the wooden post decays and additional layers of soil and topsoil are deposited over the feature; and (5) removal of the topsoil and other layers reveals the posthole feature as a darker fill that intrudes the undisturbed soil.

Acknowledgments

Staff archaeologist Dave Shonyo and archaeology volunteers Molly Brisendine, Bob Heuser, Dan Ryan, Don Ward , and Ann Oliver observed the GPR surveys and helped with measurement tapes. Shonyo and archaeology volunteers Carol Boland, Marge Budd, and Gretchen Wendelin later participated in setting up measurement tapes for the southwest side-yard grid and were briefly introduced by Hanna to presentations of EMI and magnetic gradiometry data. Shonyo also marked a line where his previous archaeological investigations indicated that an old fence line approached the mansion in the southwest yard. He also provided Hanna with a copy of a 1998 Gunston Hall geophysical report by Bruce W. Bevan.

Gunston Hall Director, David L. Reese, visited our field sites several times and kindly offered his

support. Staff librarian Kevin Shupe also visited our field site and answered several of our questions about the history of the plantation.

Among our GPR team, Pete Petrone, owner and operator of the GPR system, monitored signals received during the surveys, used his custom-made pole-cam digital camera to supply overhead photographs, and, with Molly Brisendine, provided other photography John Imlay announced the GPR line numbers and distances for audio/video recording, managed antenna cables, and tested soil conditions at a few locations using a steel probe. Bill Hanna pulled and timed the antenna passage and analyzed and interpreted the GPR data. Hanna also conducted the EMI and magnetic gradiometry surveys, analyzed and interpreted the data, and composed this multi-disciplinary report.

EXACTLY WHAT PHYSICAL PROPERTIES WERE REMOTELY SENSED?

Subsurface objects, structural features, or disturbed soil of possible archaeological interest can be remotely sensed by several geophysical techniques. Those most frequently used are GPR, EMI (or, alternatively, galvanic resistivity), and magnetic methods. Each technique senses a different property or combination of properties of a material *if and only if the property appears as a sufficiently strong contrast to that of surrounding material.* The properties sensed in our surveys include induced and remanent magnetization, electrical conductivity, dielectric permittivity, and magnetic viscosity. We have used three primary instruments and three secondary instruments. The primary tools were the GPR system, an EMI instrument capable of measuring in-phase or quadrature-phase signals, and a vertical magnetic gradiometer. The secondary tools were a handheld magnetic susceptibility meter, a fluxgate magnetic locator, and a phase-sensitive metal detector. The GPR system mainly sensed dielectric permittivity or electrical conductivity. The EMI instrument, sensed magnetic susceptibility of soil or anti-phased high electrical conductivity of metal, or both, in its in-phase mode, and it sensed lower electrical conductivity of soil or anti-phased magnetic viscosity of soil, or both, in its quadrature-phase mode. The magnetic gradiometer sensed a combination of induced and remanent magnetization. Similar to the primary instruments, the secondary instruments measured various components of magnetization and electrical conductivity but generally at smaller depths or lower resolutions than the primary instruments.

GROUND-PENETRATING RADAR SURVEY

Instrumentation

GPR measurements were made by using a Subsurface Interface Radar system SIR-8, manufactured by Geophysical Survey Systems (GSSI), Inc. (**figure 3**). The antenna used with this system acts both as the transmitter and receiver of radar energy--this is called operating in "monostatic mode". The principle of operation is that pulses of multi-frequency energy are transmitted into the subsurface by the antenna which is pulled continuously along the ground surface. Where the transmitted energy encounters an interface of contrasting electromagnetic properties--an object or other feature--, some of the energy reflected (or back-scattered) from the interface will be received by the antenna. By noting the positions of signals on the radar record (or radargram), one can draw inferences about both the horizontal and vertical locations of an object or feature in the subsurface.

By carefully measuring the two-way time between the transmitted and received energy, one can infer the distance between the antenna and reflecting interface *if the average velocity of energy travel in the soil can be reasonably estimated.* It should be emphasized that one of the virtues of the GPR technique over other lower-frequency electromagnetic techniques (such as EMI) is that it is capable of sensing *non-metallic* targets as well as *metallic* targets.

On the basis of tests conducted using broadband antennas having central frequencies of 300 MHz and 500 MHz, we decided to use the 500-MHz antenna on the basis of its higher resolution performance. This antenna is shielded in order to effectively eliminate any upward generation of signal that might reflect from overhead tree limbs or wires. Thus, the antenna generates energy in a bandwidth of about 250 MHz to 1 GHz downward in the approximate shape of an elliptical cone. As a result of this conical shape, the antenna "sees" not only downward, but also a certain distance forward and backward as well as to either side. The transmitter generated pulses at a repetition rate of 50,000 times per second; reflections were recorded at a rate of 12.8 scans per second.

In these surveys, the antenna was continuously moved on the ground surface along parallel lines spaced 18 inches apart. The antenna was moved at a time-regulated rate of 50 ft/min. Time marks were inscribed on each GPR record at an interval of 5 ft. Two closely spaced time marks on the resulting record delineate the beginning and end of each line. The scan range (duration of recording of each scan line) was set at 36 nanoseconds (abbreviated "ns"; one ns is one-billionth of a second) on the basis of field tests. Filter settings were retained at low values to maximize the amount of returned signal. All of the data were displayed real-time on a GV-8 color monitor via a Model 38 Video Display Unit manufactured by GSSI, Inc. The color linescans were recorded on the GV-8 in 8-mm video tape format for further analysis.

Each recorded scan represents a wiggly reflected signal (not seen, except through use of post-surveying computer software) that has a variable amplitude greater or less than operator-set color thresholds. Thus, on the video screen, each scan takes the form of a skinny vertical line composed of many colored segments, each color corresponding to signal amplitude or "strength". The top of any scan line represents the start of the scan at the antenna; the bottom of the scan line represents the two-way travel time of the reflected radar energy (time required to travel from "antenna acting as transmitter" - to - "subsurface reflector" - to - "antenna acting as receiver"). The complete color linescan record seen on the video screen is the side-by-side ensemble of all of these skinny multi-color lines. In our records, bright whites, reds, yellows and greens usually represent large-amplitude positive signals and dark blues usually represent large-amplitude negative signals. Most moderately sized signals are various shades of gray.

The zero time mark and the duration of the near-field zone (where the transmitted signal is coupled to the uppermost part of the subsurface) was subjectively determined by comparison with other records previously acquired by this system under identical parameter settings. Each color linescan record shows (1) from left-to-right, distances at 5-foot intervals in the direction indicated on the radargram and (2) from top-to-bottom, the 2-way travel time (from transmitter-to-reflector-to-receiver) of the reflected signal in nanoseconds (ns), a total of 36 ns (vertical scale).

Our experience suggests that a reasonable estimate of the average velocity of radar energy in this soil is about 1/3 ft per nanosecond. Thus, we expect a reflection observed *halfway down* on the color timescan record (about 18 ns of 2-way travel time) to correspond to a reflector depth of about 3.0 ft; a reflection observed at the bottom of the record (about 36 ns of 2-way travel time) would correspond to a depth of about 6.0 ft. Where the soil velocity varies significantly in a lateral direction, the estimate of depth likewise varies.

GPR record analysis

After completion of field work, the data were analyzed by viewing and reviewing the video tape records on a Sony Trinitron 25-inch high-resolution NTSC television monitor. A transparent template with 36 major tick increments along its vertical axis was used to pick best estimates of first arrivals of primary reflections.

Ordinarily, the most conspicuous GPR reflections in a given area have the shape of a hyperbola or upward arch. This shape usually results from the reflection of radar energy from a single underground object--ideally a "point source". These signals resemble those of sonic echo-finders used by fishermen. Ideally, a well-formed hyperbolic echo in GPR work results when energy reflects from an object with a circular or curvilinear top, such as a horizontal cylinder (pipe or conduit), sphere, top of a tunnel--or in a graveyard, top of coffin. In practice, hyperbolic echoes are often broken, distorted, asymmetrical, or obscured by interfering signals from nearby objects or by other noise. A given reflector may be a rock, brick, tree root, animal burrow, conduit, utility line, tunnel, ditch, wall foundation, air- or water-filled void, or any metallic, ceramic, glass, or plastic object. Within a graveyard, a reflector may be any feature of a burial container or its contents--such as a knotty portion of a pine box, coffin hardware, a viewing pane, more massive bones, or a ceremonial object buried with the decedent.

A hyperbolic echo on rare occasions can underlie strong secondary reflections from a V-shaped trench ("bowtie" signature); can be produced from the "velocity pullup effect" associated with a large subsurface void--also applicable to some graves; and can be generated from constructive wave interference patterns. Other conspicuous GPR reflections can take the form of horizontal to sub-horizontal bands, corresponding to flat subsurface features (such as a buried root cellar) or soil facies, or conspicuous columns of reverberations caused by multiple reflections from metallic objects.

GPR presentation of results

The color linescans are examined and notes are taken on the location, two-way travel time, and relative strength of hyperbolic echoes. For plotting purposes, the hyperbolic echoes are separated into 4 categories: "shallow & weak", "deep & weak", "shallow & strong", and "deep & strong". The break between "shallow" and "deep" is made at the 18 ns two-way travel time mark. Thus, if the average soil velocity is 1/3 ft per ns, "shallow" reflectors are those less than 3 ft deep. Those taken to be "weak" are those of amplitudes 1 and 2; those taken to be "strong" are those of amplitudes 3, 4, and 5. In a cemetery setting, we also commonly note, in a subjective manner based upon our experience, those signals that seemed likely to represent graves. The notes also include some abbreviated descriptive comments.

IN-PHASE AND QUADRATURE-PHASE EMI SURVEYS

The EM measurements were made with a Model EM-38 Conductivity Meter manufactured by Geonics Limited (top of **figure 4**). The principle of operation is that, after a small transmitter coil at one end of the elongate instrument generates a magnetic field downward into the soil, this field induces a magnetization in the soil or induces eddy currents within electrically conductive material, or both, that can be detected by a small receiver coil at the opposite end of the instrument. This signal will contain both in-phase and quadrature-phase components, that are respectively "in step" and 90 degrees "out of step" with respect to the transmitting signal. This device operates at a frequency of 14.6 kHz (much lower than frequencies used in GPR) and was designed to detect magnetic susceptibility to a depth of about 2 ft or metallic conductivity to a depth of about 4 ft. Measurements were made in walking mode at a 12-inch station interval along lines spaced 18 inches apart. At each field location, measurements were made on the ground surface with the long axis of the instrument parallel to the traverse line. All of the data were recorded real-time on a data logger--the Omnidata 720 Polycorder. The Polycorder data were later downloaded to a computer for processing, analysis, and display.

It is conventional to express in-phase results when using the Polycorder in units of "ppt"--that is, parts-per-thousand of the ratio of in-phase secondary field to in-phase primary field. It is customary to express quadrature-phase results in units of conductivity--millisiemans per meter (mS/m). It should be noted that the Geonics EM-38 device was designed to be calibrated in conductivity units over one-dimensional or half-space models of soil of low induction number. In practice, the induction number varies widely and the instrument predictably responds in a nonlinear fashion, also yielding negative as well as positive values. This operation is in accordance with the physics of the instrument and its environment. For archaeological purposes, the in-phase and quadrature-phase units can be simply and conveniently expressed as "IP units" or "QP units".

A conductivity measurement is sometimes made in an area where a GPR survey is planned to be made. This preliminary measurement must be made in an area devoid of subsurface conductive objects. A general rule is that, if the conductivity of soil is less than 35 mS/m, the GPR energy will penetrate to a depth of more than 3 ft.

MAGNETIC GRADIOMETRY SURVEY

A Model GSM-19 Overhauser-effect magnetic gradiometer, manufactured by GEM Systems, Inc., was used to make measurements of the earth's magnetic field and of its vertical gradient (bottom of **figure 4**). This gradiometer consists of two sensors mounted on a vertical pole; the sensors are connected by wires to a computerized console worn around the neck. Each sensor contains a liquid that is rich in both protons and free electrons. The basic principle of operation is that, after the spins of protons within the liquid are purposely disturbed from their "random" alignment, they precess (or "wobble" like a spinning top) about the direction of the earth's ambient magnetic field with a frequency directly proportional to the earth's magnetic field. Because the constant of this proportionality is accurately known, when one measures the precessional frequency, one determines the magnitude of the magnetic field. The free radicals contained in the liquid guarantee the presence of free, unbound electrons that couple with protons, resulting in a two-spin system. When the strong radio-frequency magnetic field is used to disturb the electron-proton coupling, the free-electron resonance lines are saturated and the polarization of protons in the sensor liquid is greatly increased. This phenomenon is known in physics as the Overhauser effect.

The two sensors of this gradiometer are mounted 22 inches apart on a nonmagnetic pole such that the lower sensor is 38.5 inches above ground level. The instrument simultaneously measures and records the total magnetic-field intensity of the lower sensor and the vertical gradient of the total magnetic-field intensity between the two sensors, assuming that the pole to which the sensors are attached is held upright. The total magnetic-field intensity shows the local behavior of the Earth's magnetic field and is especially convenient for purposes of numerically modeling the magnetic objects that may cause the magnetic anomalies. The vertical gradient is valuable for highlighting the shallowest buried magnetic objects or anomalously magnetized soil and is critical for canceling time-varying regional magnetic fields that appear as noise. Measurements of the total field in nanoTeslas (nT) and its vertical gradient in nanoTeslas per meter (nT/m) were made in stop-and-go mode at the same locations as the EMI measurements–that is, a 12-inch station interval along lines spaced 18 inches apart (**figure x**).

SOUTHWEST SIDE YARD

Coordinate system

For descriptive purposes, it is convenient to consider the mansion to be aligned along geographic cardinal directions, with the front door facing "north" and our survey area to be in the "west" yard.

Our rectangular survey area in the west yard of the mansion is centered on a line marked by Dave Shonyo (**figure 5**) where his previous archaeological investigations suggest that an old fence-line approaches the mansion. This line was marked so that the several geophysical systems might cross one or more subsurface post-holes, which are 10 ft apart and nearly aligned in the area Shonyo and his volunteers previously excavated. Our rectangular area thereby is aligned with the orientation of the mansion and in size is just over 50 ft east-west and 30 ft north-south. The easternmost north-south line (the one closest to the mansion) abuts against two brick-paved gutters that extend 7.5 ft from the west side of the mansion, flush with and on either side of a small, roofed side entrance. The origin of the coordinate system is 5.5 ft north of the northern edge of the north brick-paved gutter.

All geophysical measurements were made by moving north-to-south along each line, with each succeeding line west of (farther from the mansion than) the previous one (**figure 6**). The 18-inch-spaced GPR lines are symmetrically located within each alley created by two adjacent measurement tapes so that the dragged GPR antenna would not disrupt the tapes. The 18-inch-spaced EMI and magnetic-gradiometry lines coincide with the measurement tapes and are thus offset 9 inches relative to the GPR lines.

Results

GPR echoes and lateral discontinuities are shown in **figure 7**. Among the 104 echoes noted (**Appendix A**), 9 (~ 9 %) are "shallow & weak", 4 (~ 4 %) are "deep & weak", 90 (~ 90 %) are "shallow & strong", and 1 (~1%) is "deep & strong". Examples of these GPR echoes are outlined in yellow in **figure 8**.

In-phase and quadrature-phase EMI anomalies are shown in **figure 9**.

Total-field magnetic anomalies measured by the lower gradiometer sensor are shown in **figure 10**. Vertical magnetic gradiometer anomalies are shown in **figure 11.**

MASON FAMILY CEMETERY

Coordinate system

The Mason Family Cemetery [Fairfax County Cemetery #FX144 (Conley, 1994)] is enclosed by a brick wall 50 ft true north-south by 40 ft true east-west that, according to Dave Shonyo, probably was constructed in the 1920s. This wall orientation is congruent with the grave-marker orientation within it–that is, the traditional Judeo-Christian burial pattern of the decedent resting in a supine position oriented west to east with the head to the west.

We established the coordinate system parallel to the cemetery walls with the origin near the southwest corner–specifically 1.9 ft east of the inside edge of the west wall and 6.0 ft north of the inside edge of the south wall (**figure 12**). The location of GPR lines is shown in **figure 13** and the location of EMI and magnetic-gradiometer measurement points is shown in **figure 14.**

Inscribed stones

The cemetery contains markers for 8 east-west oriented graves:

(1) George Mason IV of Gunston Hall
(2) Ann Mason, wife of George Mason IV
(3) George Mason V of Lexington
(4) Elizabeth Mary Ann Barnes Graham, wife of George Mason V of Lexington
(5) William Mason, son of George Mason IV
(6) George Mason, son of William Mason and grandson of George Mason IV
(7) Eleanor Ann Clifton, wife of George Mason VI
(8) "L. G.", presumably unidentified. [W.F. Hanna note: This repaired, footstone-size marker is very similar in shape and composition to the gravestones of Elizabeth Mary Ann Barnes Graham (#4 above) who was the daughter of Gerard and Sarah Hooe of Barnesfield. Could this "L. G." correspond to a Graham not known in genealogical records? Alternatively, it is of passing interest, because of several coincidences of names, that a descendant of George Mason IV, Lucy Grymes, who died in Barnesfield, married a Hooe, and provided each of her three Hooe children the middle name Barnes. Although Lucy was interred in St. Paul's Episcopal Cemetery, could it be that this gravestone somehow commemorates her name–perhaps having been "saved" and placed within the family cemetery?]

Written accounts imply that others are buried in the Mason Family Cemetery, including:

Richard and James Mason (both d.1772, one day old), twin sons of George Mason IV and Ann Eilbeck

John (d. 1811, 6 years old) and Richard (d. 1814, an infant) Graham, sons of George Graham and Elizabeth Mary Ann Barnes (widow of George Mason V)–both claimed on an inscribed slab to "lie beside her".

John McCarty Mason (d. 1837, 20 years old), son of George Mason VI and first wife Elizabeth Thomson Mason

Richard Barnes Patten Mason (d. 1847, 23 years old), son of George Mason VI and second wife Eleanor Ann Clifton

It is unlikely that the gravestones within the walled family cemetery bear an accurate spatial relationship to their corresponding burials, including the marble box tombs commemorating George Mason IV and his first wife Ann. We see from J. Harry Shannon's 1905 glass-negative image "Jefferson Walnut Tree at Gunston Hall" that, as noted by authors Connie Pendleton Stuntz and Mayo Sturdevant Stuntz, "not far from the black walnut tree is a grave marked by a simple granite headstone inscribed 'George Mason, Author of the Bill of Rights and the First Constitution of Virginia 1725-1792'." We also learn from Bertha Louisa Robinson's 1910 article "Pilgrimages to American Landmarks–Gunston Hall" (Journal of American History) that the grave of George Mason IV "is *unmarked*, but tradition tells us that his body was interred beside that of his wife." In more recent times, the cemetery has gone through the cyclic process of becoming overgrown and then cleared, like many–if not most--others of its age in this part of the country. We have discovered through our work in very old cemeteries elsewhere in northern Virginia that, over time, gravestones have been inadvertently (or sometimes intentionally) moved, broken, repaired, replaced, removed, or naturally buried for any number of reasons, including planned re-interments, accidents during caretaking, vandalism, passive neglect, plowing, and the natural forces of frost-heaving followed by settling. Just as some burials exist in an unmarked state, some gravestones remain in place where no burials exist–notably where re-interments have occurred .and where inscribed stones have been purposely "saved" from anticipated destruction and re-emplaced at another burying ground.

Results

GPR echoes and lateral discontinuities are shown in **figure 15**. Among the 131 echoes noted (**Appendix B**), 31 (~ 23 %) are "shallow & weak", 43 (~ 33 %) are "deep & weak", 43 (~ 33 %) are "shallow & strong", and 14 (~ 11 %) are "deep & strong". Examples of GPR echoes are shown in **figure 16.**

In-phase EMI anomalies are shown in **figure 17.**

Quadrature-phase EMI anomalies are shown in **figure 18.**

Total-field magnetic anomalies measured by the lower gradiometer sensor are shown in **figure 19.** Vertical magnetic gradiometer anomalies are shown in **figure 20.**

AREA IMMEDIATELY WEST OF CEMETERY

Coordinate system

All coordinates of the region west of the cemetery area are referenced to the same coordinate system as that used for the cemetery itself (origin inside of the cemetery and close to its southwest corner). Although only 4 GPR lines were surveyed, 18 lines of in-phase EMI data were acquired (**figure 21**). The locations of the 4 GPR lines and 18 lines of in-phase EMI measurement points are shown in **figure 22.**

Results

GPR echoes and lateral discontinuities are shown in **figure 23**. Among the 35 echoes noted (**Appendix C**), 4 (~ 11 %) are "shallow & weak", 4 (~ 11 %) are "deep & weak", 26 (~ 75 %) are "shallow & strong", and 1 (~ 3 %) is "deep & strong".

In-phase EMI anomalies are shown in **figure 24** with some high-amplitude anomalies outlined in ~~blue.~~ RED.

CONCLUSIONS

Southwest side yard

All five geophysical data sets clearly show at least one major ferrous conduit that emanates westward from the mansion, directly below the northern of two ground-level brick gutters next to the roofed side entrance (**figure 25**). After a distance of 5 ft, the major conduit is intersected by another ferrous conduit leading north. After a distance of about 18 ft, the major conduit turns nearly 90^{O} south, toward the garden. If this conduit line were projected southward, it would cross beneath the boxwood hedge and pebble walkway and enter the westernmost component of the garden.

This major conduit may be a main water pipe that feeds or fed an iron-pipe irrigation system in the garden. In these regions of conduit intersection and conduit turn, large magnetic anomalies suggest the presence of additional buried iron or brick, or both. Among other possibilities, these anomalies could mark the presence of an old cistern or well. It also is possible that, during the 250-year period of the mansion's habitation, this area was used septically. Other mansions, such as York Hall, has septic drainages that intersected the formal garden. However, the proximity of the conduits to the mansion suggests to us the likelihood that these are water pipes.

Cutting diagonally across the side yard is a non-magnetic but highly conductive linear feature that intersects in plan view the major ferrous conduit near the southern boundary of our survey area. This linear feature may be a subsurface cable laid in a trench and may have connected with a long-ago-removed house that was once located not far from the present-day school house. If this line were projected southward, it would cross the backyard central path just a few feet south of the porch steps. The geophysical maps suggest that this diagonal feature may have been cut by emplacement of the subsurface iron pipe; however, our survey map area terminated where evidence of this possible crosscutting could have been more clearly viewed.

Another less well defined south-trending linear feature was detected on the magnetic-gradient map; its source may be a small-diameter conduit or a narrow trench where the soil has been disturbed.

The main objective of determining the feasibility of using geophysics to detect the locations of subsurface postholes predictably is yet to be realized because only future topsoil removal can definitely prove the existence or non-existence of such a feature at a given location. However, we have the advantage of archaeological knowledge (from Dave Shonyo) that a fence line trends toward the mansion, with the projected line intersecting the mansion at the southern ground-level brick gutter next to the side entrance. Where this fence line has been excavated far from the mansion, the postholes are 10 ft apart and in near alignment (indicating a straight fence, rather than a zig-zagging worm fence). Looking at geophysical anomalies on or near this projected fence line, we discover one cluster consisting of a magnetic-gradient anomaly near three strong GPR echoes. This cluster is our strongest candidate for a subsurface posthole. Two other groupings of major GPR echoes appear on or near the projected fence line closer to the mansion and we simply label them on the map with question marks.

It is clear, however, that it is *not* economical to conduct conventional geophysical surveys in this kind of terrain for the *sole* purpose of detecting subsurface postholes. Such detection depends greatly on the presence of in-filled magnetic objects, such as bricks or mafic stones, or upon significant contrasts of induced magnetization between the disturbed and undisturbed soil. In this area, other subsurface features give rise to large anomalies that tend to mask smaller ones, such as those associated with postholes. The tool of choice for this specific purpose may be a magnetic susceptibility meter, although such a device is extremely limited in the distance (depth) that can be sensed.

Mason Family Cemetery

The geophysical data reveal one very significant discovery. Inside of the walled cemetery resides a single, unmarked, relatively rare, cast-iron coffin–possibly of the type that was first patented in 1848 to Almond J. Fisk, who produced three models before 1854. Other companies, in particular the Crane, Breed, and Co. of Cincinnati, obtained licences to produce Fisk coffins early in the 1850s and introduced several modified versions. Prior to the Fisk versions, "metallic" versions were produced by the late 1840s in eastern United States. One notable U.S. site of metallic coffins was discovered in archaeological investigations at another Mason Family Cemetery in Giles County, Tennessee. At this cemetery, excavations exposed 39 burial containers, among which 31 were hexagonal wooden, 2 were rectangular wooden, and 6 were metallic or iron--some for children. Such coffins, which were reserved for the wealthy, weigh in excess of 300 pounds and are sometimes invaluable for historical microbial analysis. If this iron coffin is of the Fisk type and if it correlates with one of the inscribed grave markers within the cemetery walls, the likeliest candidates are William Mason (d. 1856), ~~brother~~ son of George Mason IV, or George Mason (d. 1870), son of William Mason and grandson of George Mason IV. Time-wise, Eleanor Ann Clifton (d. 1867) would also be a candidate; however, we received GPR signals below her inscribed ground-level slab suggesting that she is interred beneath the slab.

Our analysis of the alignment of GPR echoes within the cemetery walls suggests that as many as 22 burials exist, most in the anticipated east-west orientation. We caution that these inferences based on geophysical data alone are subjective; greater proof can be realized by additional use of the stainless steel probe, soil-coring tool, and topsoil stripper. Burial containers of children usually are too small to easily identify. All of the inferred burials that are skewed relative to east-west are rotated several degrees *clockwise* in plan view. As expected from some historical documents and as known from our previous experiences at the nearby Wagener Family Cemetery [the many Peter Wagener's were contemporaries of the many George Mason's](Owsley and others, 2001), there is little spatial correlation of inferred burials with inscribed markers. It should be emphasized that our inferences of burials are based on (sometimes crude–sometimes perfect) alignments of GPR echoes in a generally east-west direction. Our previous experience in historic cemeteries indicates that echoes can emanate from any part of the 3-D volume of a grave shaft, regardless of whether the burial container and its contents are well preserved and intact or, more commonly, merely silhouettes less than an inch thick in the form of "shadow burials".

We also observed–but did not summarily outline–large-amplitude magnetic anomalies associated with the cemetery's iron gate and smaller-amplitude conductivity and magnetic anomalies associated with the brick walls. One large-amplitude conductivity anomaly near the northeast corner of the double-box-tomb slab appears to be caused by a metal plaque on the side of one of the box tombs. Two medium-amplitude, local magnetic anomalies in the south-central part of the cemetery do not have attendant conductivity anomalies and may be caused by some subsurface brick. More importantly, a large-amplitude magnetic anomaly with no associated conductivity anomaly at the southwest corner of the box-tombs slab may reflect the presence of a brick burial vault.

Our reconnaissance west of the cemetery indicates the presence of several local metallic objects and raises the possibility that some of these objects may extend eastward toward or into the walled cemetery. The GPR coverage was too restricted to note the possible presence of echo alignments that might signal the presence of east-west or skewed burials.

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Conley. B A., 1994, Cemeteries of Fairfax County, Virginia: A report to the Board of Supervisors, Fairfax County Public Library, Virginia Room, The City of Fairfax, Virginia [available online].

Owsley, D. W., Richardson, Malcolm, Hanna, W. F., and Imlay, J. H., 2001, Exhumation of graves associated with the Stisted Plantation–Wagener Family Cemetery: Report for the Colchester Land Development Company, L.L.C., 10406 Gunston Road, Lorton, VA 22079; Edwin W. Lynch, Jr., contact; [field work team of Owsley, Richardson, Hanna, Imlay, Dale Brown, Jackie Cuyler, Rebecca Redmond, and Claude E. Petrone], 33 p.

APPENDICES A, B, and C [see sheets following the color figures]

Data entries for GPR echoes

The column headings are: (1) “X-coord” or abscissa of plot, which is the location of the short axis of the antenna, in feet, to the right-hand-side of the coordinate origin, positive to the right; (2) “Y-coord” or ordinate of plot, which is the location of the long axis of the antenna upward from the coordinate origin, positive upward; (3) “2W_TT”, which is the 2-way travel time in nanoseconds for GPR pulses to transmit and return following reflection; (4) “Signal strength”, estimated as 1 (weakest) to 3 (strongest); (5) “Comment”; and (6) “Line#".

The comments, where added, contain informal abbreviations for characteristics of the signal. Examples are “brd” for broad; “nrrw” for narrow; “brkn” for broken; “Lhf” for left-hand flank of hyperbola; “Rhf” for right-hand flank of hyperbola; “assym” for asymmetrical; “reverb” for reverberation or ringing of signal; “chaot” for chaotic; “spot” for localized bright region; “dp” for deep; “chevr” for chevron shape; and “distort” for distorted.

Example

For example, the third entry of Appendix A shows that, along GPR Line Number 2, where the center line of the antenna is 2.25 ft to the right of the coordinate origin, an echo was noted at a distance of 6.5 ft upward from the origin–that is, 6.5 ft from the start of the line. The top of the echo was recorded at a two-way travel-time of 6.0 ns, or one-way travel time of 3.0 ns. If we assume a soil velocity of 1/3 foot per nanosecond, we multiply this velocity by 3.0 ns to obtain an estimated depth to reflector of approximately 1.0 ft. The relative amplitude of this echo was subjectively assigned a value of “2", meaning that it is moderately strong. The comment “rvrb” indicates that the echo shows as a multiple reverberation on the record.

APPENDIX D

What our experience has taught us about detecting old graves

In general, a grave site can be geophysically detected *directly* or *indirectly*. It can be detected *directly* by sensing the buried human remains, objects buried with the remains, or the burial container. It can be detected *indirectly* by sensing the soil characteristics of backfill in the grave shaft. Both *direct* and *indirect* detection of grave sites by GPR often involves sensing groups of reflectors that are just as likely to be located at the edges of the grave as at the center of the grave. We have discovered elsewhere that gravestones can be mis-placed by several feet relative to the burial, that gravestones and fieldstones mark only a small percentage of burials in some old cemeteries, and that burials, including burial containers, can be reduced to mere silhouettes or shadows in the subsurface. As expected, graves of children or infants are usually much more difficult to detect than graves of adults because of their smaller size. Also, as expected, of two extremes, it is most difficult to detect a shroud burial and easiest to detect a metallic-coffin burial.

Direct detection of grave sites may involve the sensing of more massive bones, such as the skull, femur, and tibia; coffin hardware (handles, finials, knobs, escutcheons, glass viewing panes); objects attached to the interred (jewelry and favorite possessions), and knotty sections of pine boxes, which are much more resistant to decomposition than other woody parts. The cloth of shroud burials occasionally escapes decomposition, especially if it has been in contact with a brass or copper-based metal object–button, pendant, or buckle--, which protects it from bacterial decay. Environmental factors detrimental to preservation include extremely acidic or extremely alkalic soil and poor drainage resulting in alternating wet-dry subsuface conditions.

Indirect detection of grave sites may involve the sensing of disturbed soil in the grave shaft (a chaotic GPR pattern as compared to a stratified pattern or a sharp GPR lateral discontinuity representing the side of the grave shaft) and objects contained in the backfill, such as rocks or metallic items.

Not unexpectedly, we have discovered that *direct* detection of early and mid-19th-century graves in the Piedmont usually is difficult (compared to late-19th-century graves and those more recent), regardless of methods used, because of dissolution of the buried remains, attached objects, and burial containers, if any. *Indirect* detection also is more difficult because the older the grave, the more compacted the soil surrounding the burial, and the less contrast of disturbed soil relative to undisturbed soil. Preservation conditions are usually much better in the Atlantic Coastal Plain where Gunston Hall Plantation resides.

The most effective ways to delineate these old graves are

(1) by using a steel probe with custom-made bulbous tip, supplemented by using a spoon-tipped coring tool, in the hands of an experienced archaeologist or soil scientist in order to ascertain whether or not the soil is disturbed--as it must be if it is part of a grave shaft. This probing is sometimes difficult or impossible to accomplish if the soil is frozen, dry-hardened, or exceptionally stony.

(2) by stripping the topsoil in order to visually detect the presence and exact location of a grave shaft on the basis of contrasts in soil color and texture.

It is prudent beforehand or concurrently to use remote-sensing techniques, such as GPR, to help establish where to probe and where to excavate the topsoil. The interred remains themselves often are reduced to "shadows", merely a fraction of an inch thick.

In general, we find that most 19th-century burials are surprisingly shallow--often less than half of the traditionally assumed 6-ft depth. Fortunately, even in adverse soil conditions, it is not necessary for the radar energy to penetrate much below the topsoil in order to detect some characteristics of the grave-shaft soil. It also is our experience that graves sometimes can be detected by reflections from subsurface tree roots and groundhog burrows that invade old grave shafts, following the path of least resistance.

Users of GPR data should recognize that neither this technique nor any other remote-sensing technique can *unambiguously* detect the presence of very old graves in normal circumstances. It is important to remember that GPR signals associated with *a single grave* can be shallow and/or deep; can be weak and/or strong; and can emanate from any part of the grave--from center to edges or top to bottom of the grave shaft.

Dimensions of graves

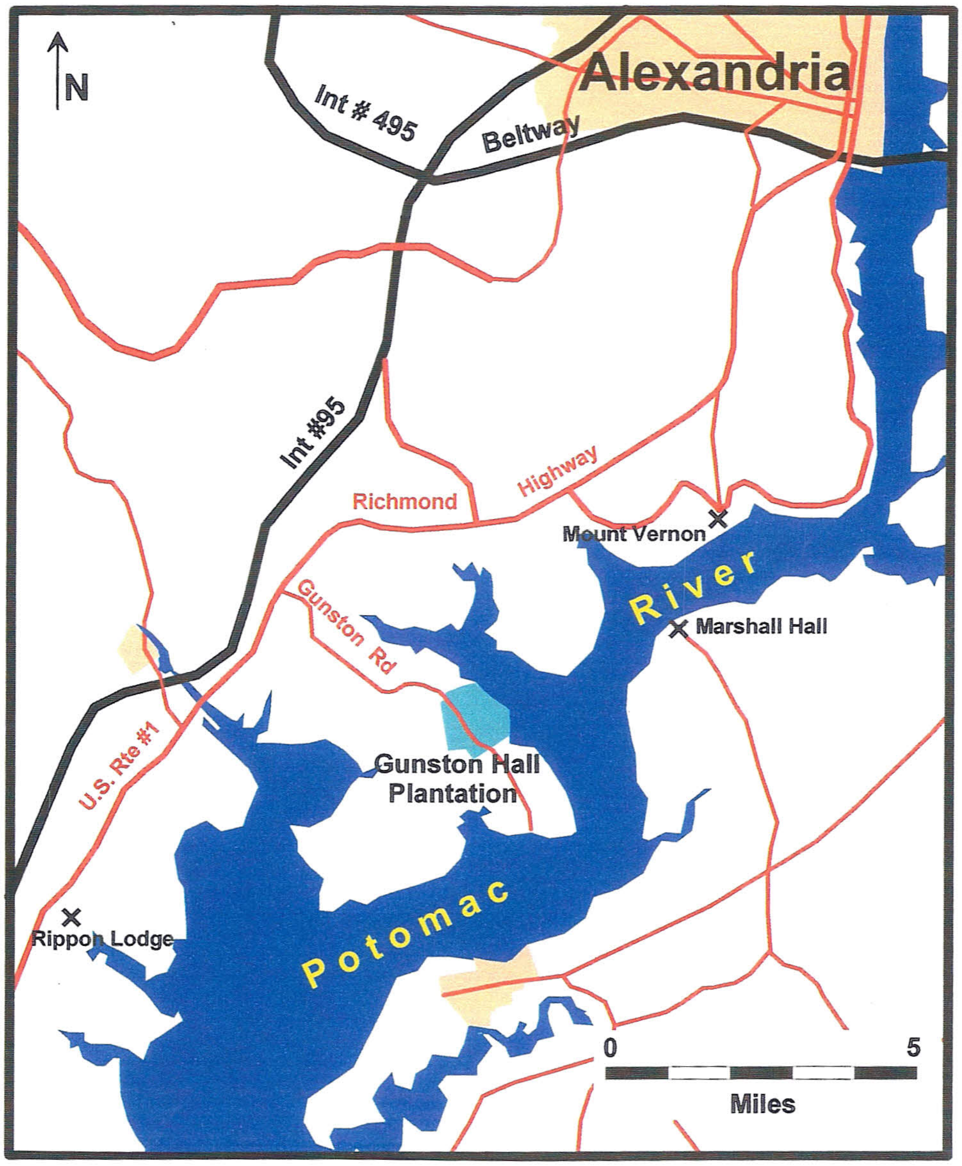
Today, the average size of a modern casket for adult burial is 84 inches long, 28 inches wide, and 23 inches high. A medium-size grave liner (an unsealed receptacle into which the casket is optionally placed) is 86 inches by 30 inches by 24 inches. A medium size burial vault (a sealed receptacle into which the casket is optionally placed) is 86 inches by 29 inches by 25 inches. Although receptacles may be larger or much smaller (for children), the dimensions of most caskets, liners, and vaults are similar. The rectangular (in plan view) grave shaft, usually dug by use of a backhoe but dug by hand where backhoe access is denied, must be a few inches greater in length and width than the largest container emplaced. These rectangular dimensions also approximately apply to the hexagonal toe-pincher coffins commonly used in the 18th, 19th and early 20th centuries.

About the Author [W. F. Hanna]

Bill is a geophysicist, earth scientist, and educator who for the past two decades has focused primarily on archaeological, forensic, and engineering applications of remote sensing. He is a specialist on conducting and interpreting ground-penetrating radar (GPR), electromagnetic induction, and magnetic-gradiometry surveys. His applications to historic archeology have included geophysical work in Washington, D.C. [U.S. Capitol and White House], Maryland [Antietam Battlefield N. P.; Harleigh Knoll; and Marshall Hall] , Delaware [John Dickinson Plantation], and Virginia [Monticello; Jefferson's Poplar Forest; Manassas Battlefield N. P.; Historic Christ Church Cemetery; Woodstock site (Aquia Creek); Ankerage mansion site; Bellwood Cemetery; Ash Grove mansion; Mount Zion Historic Church; Historic Aldie Mill; Oatlands Plantation, Tinner Hill, Historic Pole Green Church site; Oak Ridge Estate; Moor Green mansion; St. James Church site (Brandy Station); Blenheim mansion; Historic Annandale UMC Cemetery; and Historic Emmanuel Lutheran Church (New Market)]. His applications to Pre-columbian archeology have ranged from geophysical work at Mayan temples and plazas in Palenque, Mexico, to prehistoric sites on Pohick Creek near Lorton,Va. He has provided forensic support to the Fauquier and Spotsylvania County Police Departments (criminal weapons and murder-victim searches); to federal, state, county, and city law enforcement officials in Maryland (buried drugs and money search); to National Park Service Police (buried body-remains search); and to federal and state police in Virginia (Pulaski prison grounds search). He has advised DynCorp Meridian, Inc., on non-traditional techniques for detecting landmines and unexploded ordnance and has consulted for legal counsel of the Alabama Historical Commission on the validity of GPR data. He has presented geophysical demonstrations at Ben Lomond manor in Manassas on behalf of the Virginia Archeological Society; at the Peace homestead site, Aquia Creek, on behalf of the Fairfax County certification program; and at the Ankerage homestead site at Sterling, on behalf of the Northern Virginia Community College. He also coordinated the field phase of a short course "Geophysics in Law Enforcement" presented to forensics law-enforcement officials in Crystal City, at the direct request of the FBI headquartered in New York.

As an educator, he has assisted in teaching field geology, optical mineralogy, petrography, meteorology, and geophysics at Indiana University, served as a professor of geophysics at Stanford University, sat on archeology thesis committees at the College of William and Mary, and presented semester-long geophysical courses to scientists and university students in Bandung, Indonesia, and Rio de Janeiro, Brazil. He has authored or co-authored more than 125 published reports or books; has contributed to many publications of the National Academy of Sciences; has authored dozens of unpublished archaeological geophysics reports, and has served as a referee for scientific journals and National Science Foundation proposals.

Earlier, during a 30-year career as a research and supervisory geophysicist with the U.S. Geological Survey, he utilized magnetic, electromagnetic, gravity, and seismic techniques in airborne, marine, and land-based environmental and resources studies. While with the Survey, he geophysically analyzed the San Andreas fault system in California; fabricated a novel electronic instrument for measuring the magnetic characteristics of rocks; conducted marine magnetic and seismic studies in the Beaufort and Chukchi Seas, offshore Alaska and Siberia; served as proceedings editor for a national workshop on applications of modern magnetic surveys; analyzed sites of toxic wastes in Connecticut; studied rock magnetic problems in Montana (doctoral work was on paleomagnetism there); assisted in the assessment of the mineral resource potential of twelve western states; coordinated the development of magnetic and gravity anomaly maps of the United States and of North America for the Geological Society of America; analyzed sites for high-level radioactive waste disposal at the Nevada Test Site; conducted tests for the U.S. military on unconventional techniques to update inertial navigation systems; analyzed major land subsidence outside the East Wing of the White House; assisted the Charles Stark Draper Laboratory in developing a new aerogravity detection method; developed a new mathematical technique to measure 2nd-rank tensors; and served as Scientist Emeritus at the USGS National Center in Reston, Va. He has received many honors, including the Meritorious Service Award of the U.S. Department of Interior.



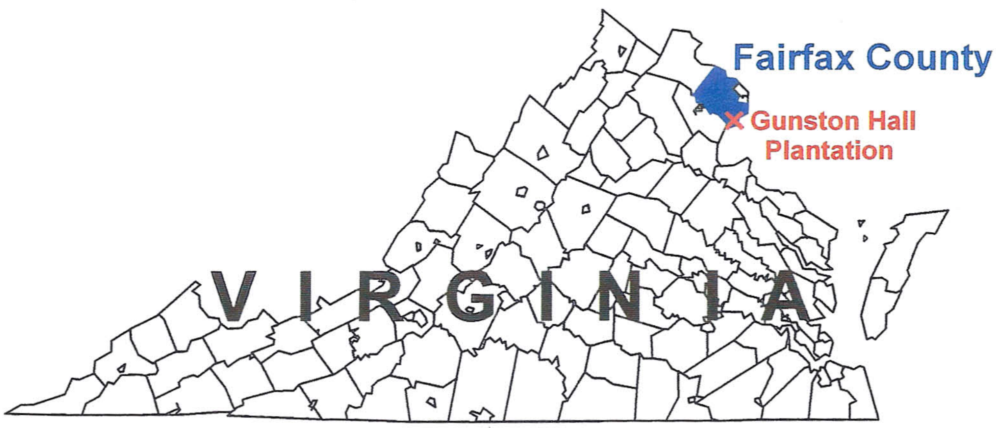


Figure 1. Regional map showing Gunston Hall Plantation.

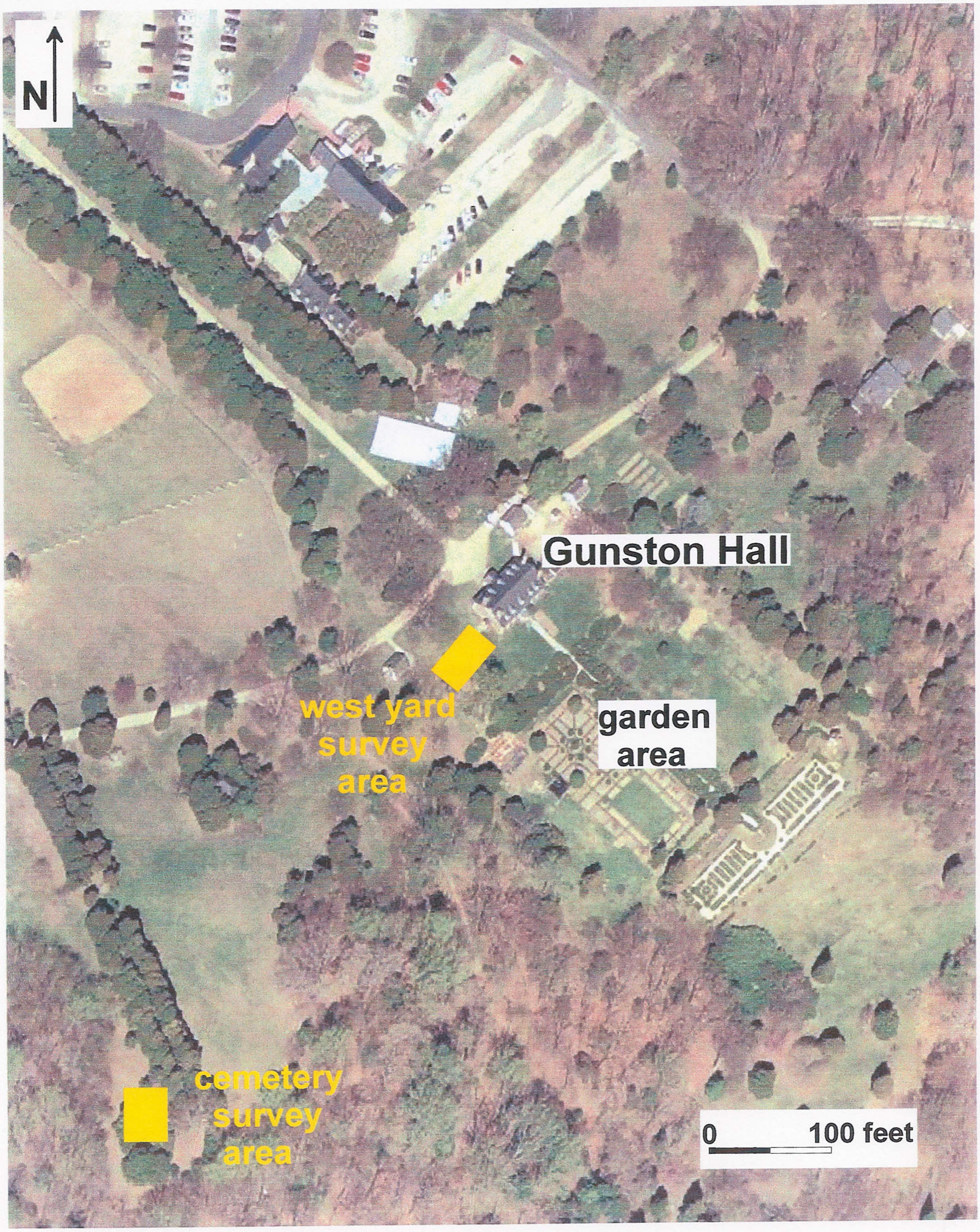


Figure 2. Aerial photograph showing our geophysical survey areas in relation to Gunston Hall and its backyard garden area.

Figure 3. Ground-penetrating radar equipment. Top: Pete Petrone operates GPR control units, monitor, and recorders at the back of his van. Bottom: John Imlay and Bill Hanna control movement of the GPR antenna.

Figure 4. Electromagnetic induction and magnetic gradiometer equipment. Top: Geonics EM-38 (orange) with attached microprocessor data logger (red). Bottom: Gem Systems Overhauser magnetometer console (sitting on top of wall) and two-sensor vertical pole (leaning against wall).

Figure 5. Survey area of southwest side yard of Gunston Hall mansion. Top: Measurement tapes forming coordinate system. Bottom: Petrone and staff archaeologist Dave Shonyo discussing GPR survey of yard.

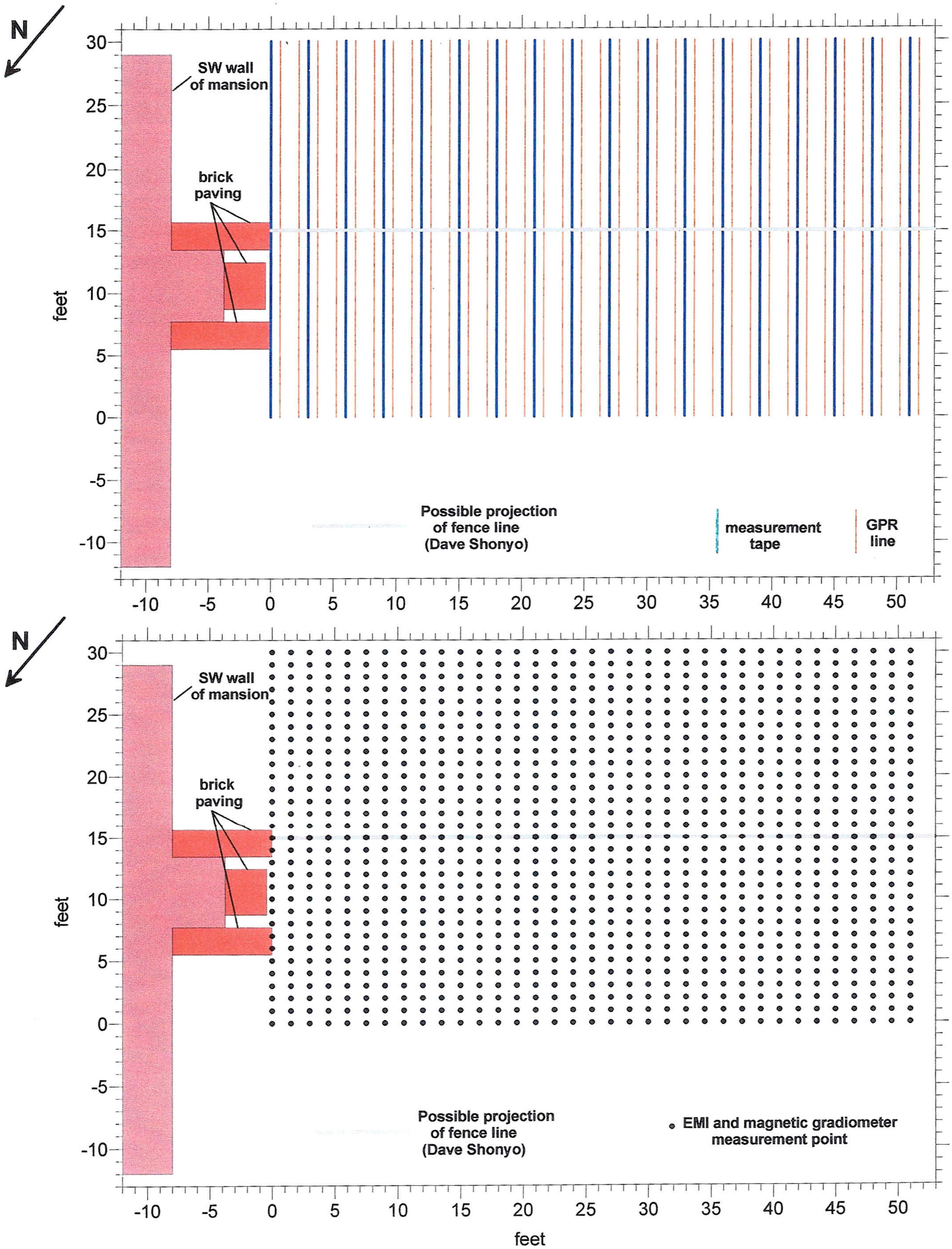


Figure 6. Top: Locations of GPR lines relative to measurement tapes. Bottom: Locations of EMI and magnetic gradiometer measurements.

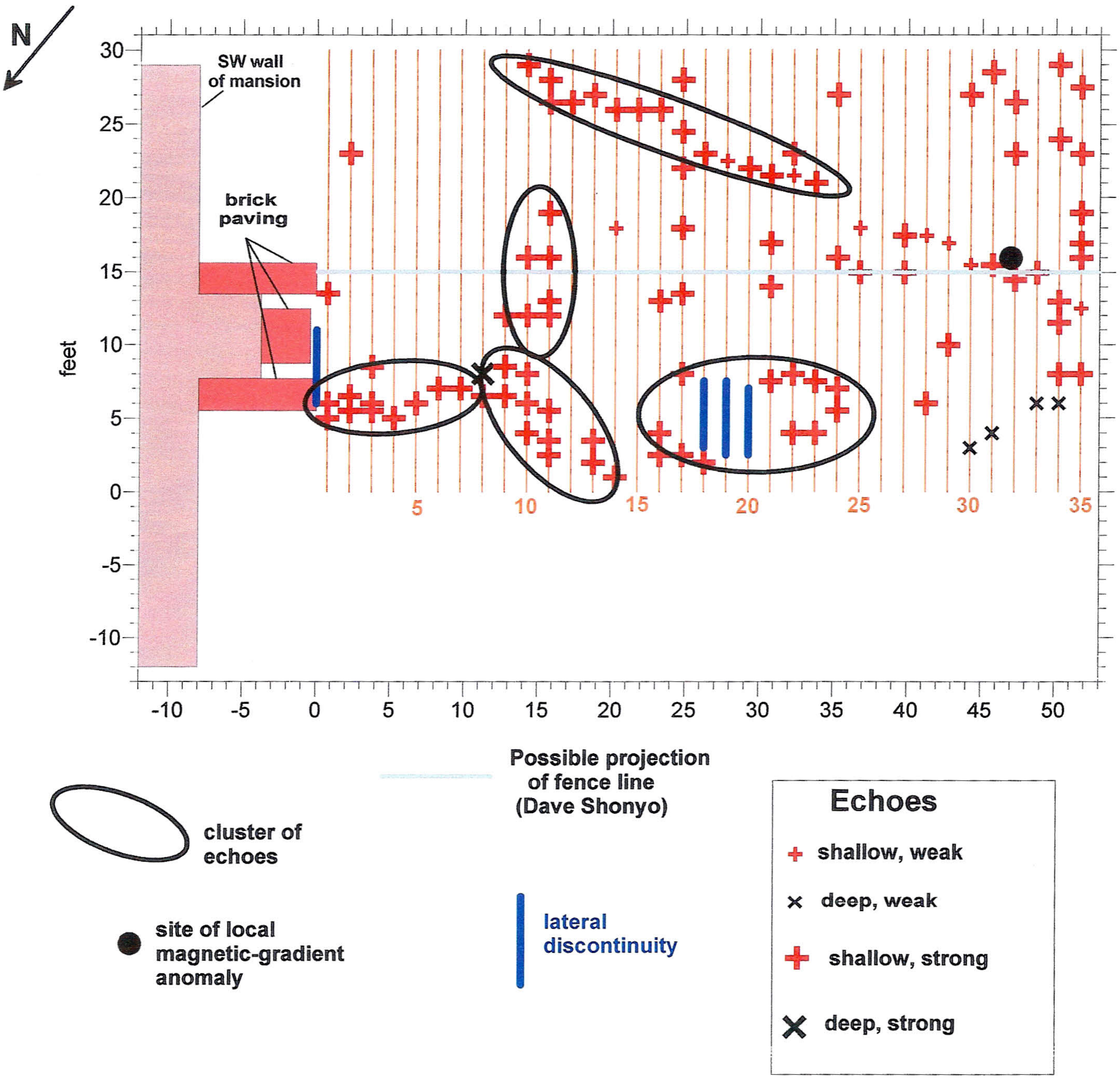


Figure 7. GPR echoes and lateral discontinuities, southwest side yard, Gunston Hall mansion. Note that strong echoes on lines 31, 32, and 33 correlate spatially with the local magnetic-gradient anomaly. These geophysical features are on Dave Shonyo's projected fence line, suggesting the possibility that they mark a subsurface post hole. Other strong echoes appear on this projected fence line.

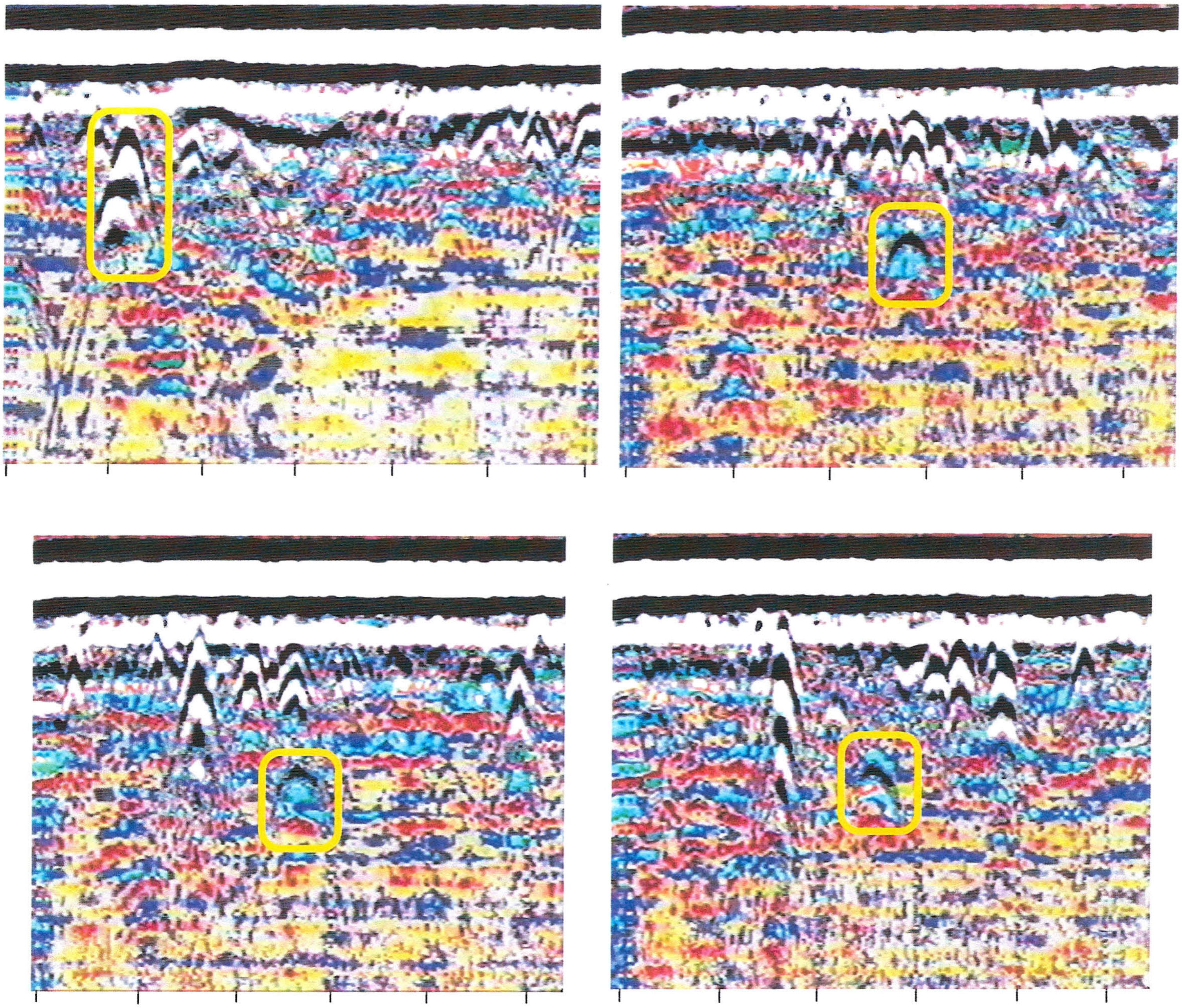


Figure 8. GPR record segments from the southwest side yard of Gunston Hall mansion. Upper-left: Line 3 showing a strong echo from a buried conduit known from other geophysical data to be strongly magnetic and highly conductive (probably a subsurface steel or iron pipe). Upper-right (Line 31), lower-left (Line 32), and lower-right (Line 33) records represent a tight clustering of echoes (outlined in yellow) at a site also marked by a localized magnetic-gradient anomaly. Because this clustering of anomalies (~2.5-ft depth) falls on or near a projected fence line based on archaeological data, the signals may be associated with a post-hole..

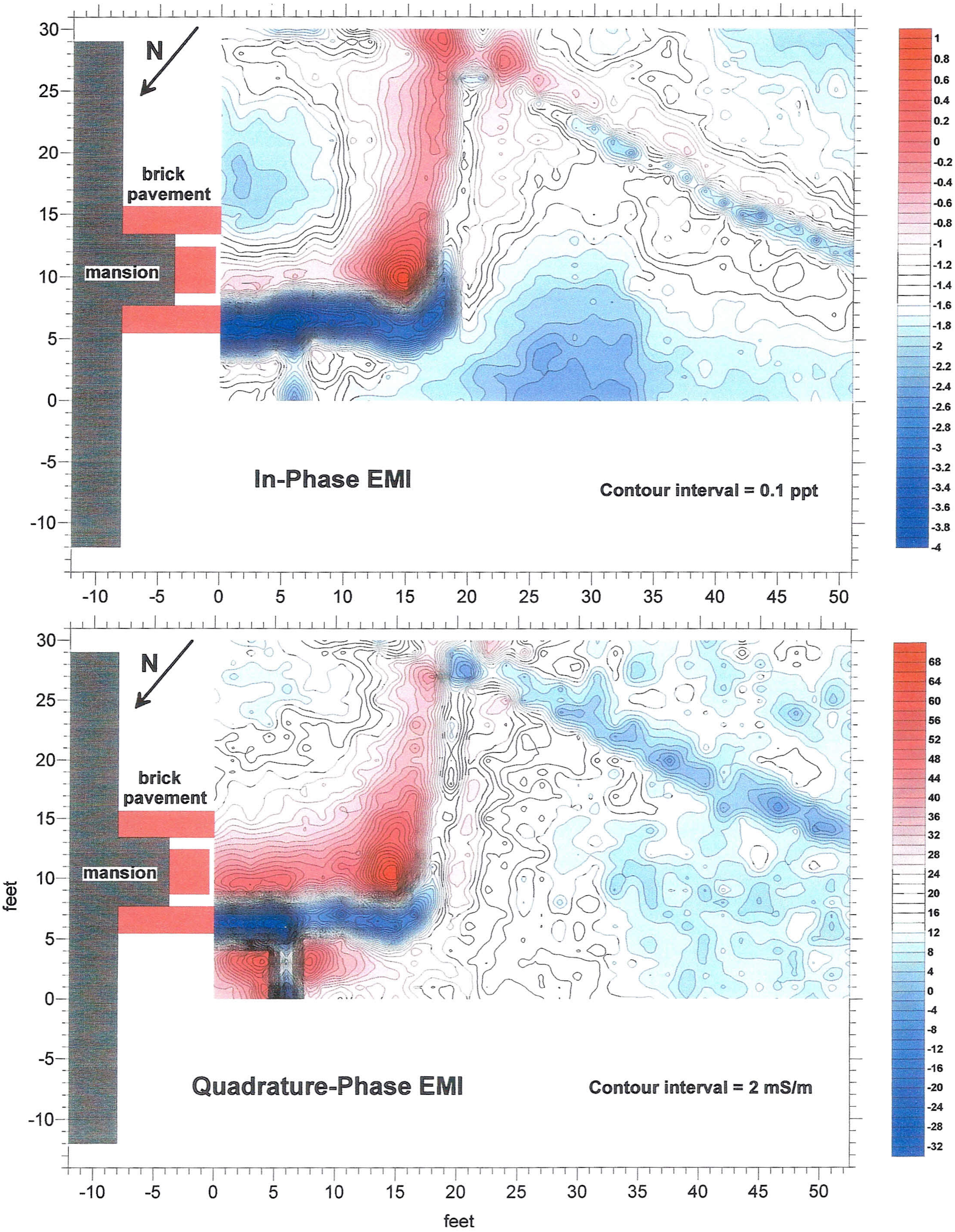


Figure 9. EMI anomalies, southwest side yard, Gunston Hall mansion.
Top: In-phase anomalies. Bottom: Quadrature-phase anomalies.

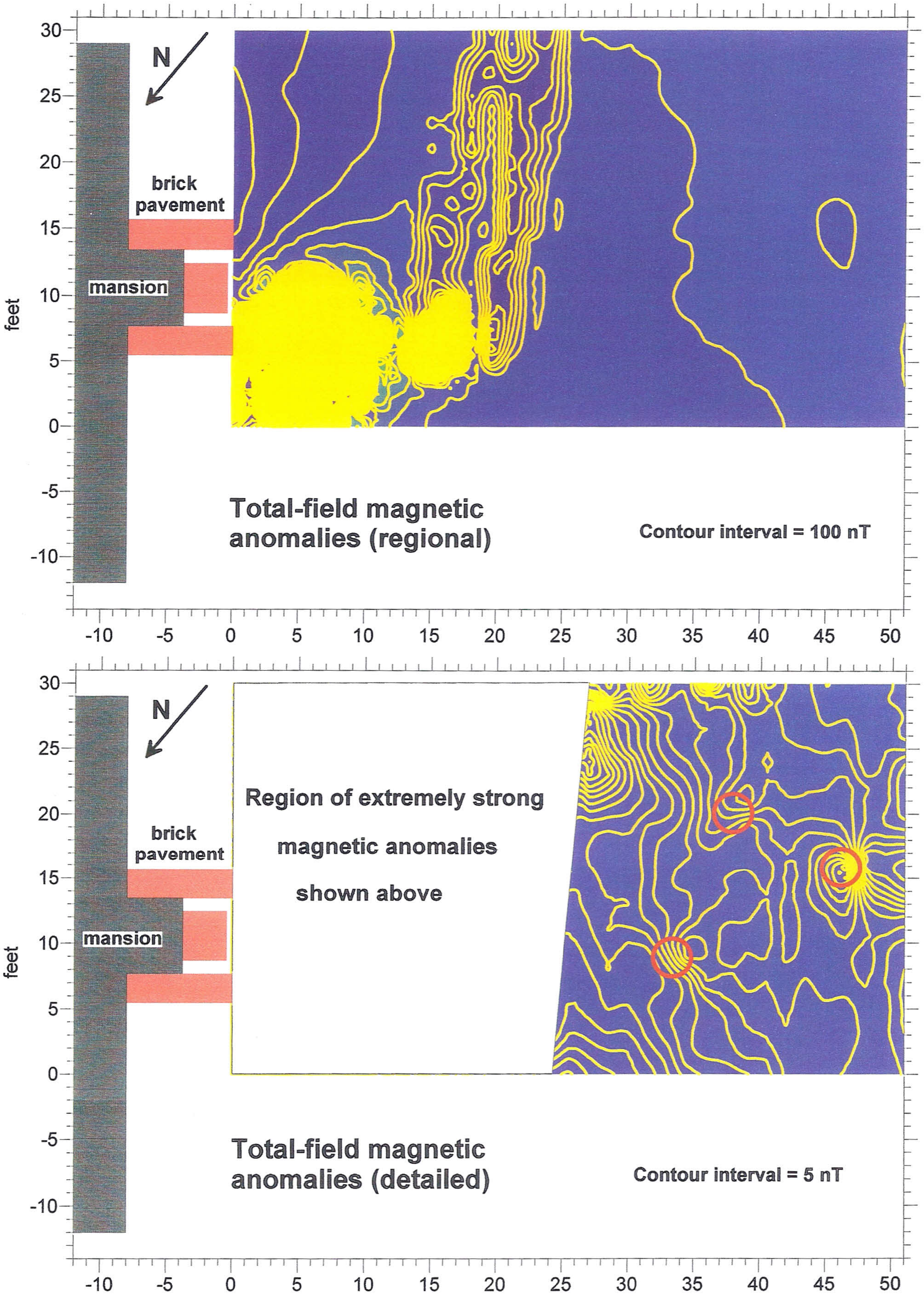


Figure 10. Total-field magnetic anomalies, southwest side yard, Gunston Hall mansion. Top: Regional anomalies. Bottom: Detailed anomalies southwest of extremely strong anomalies.

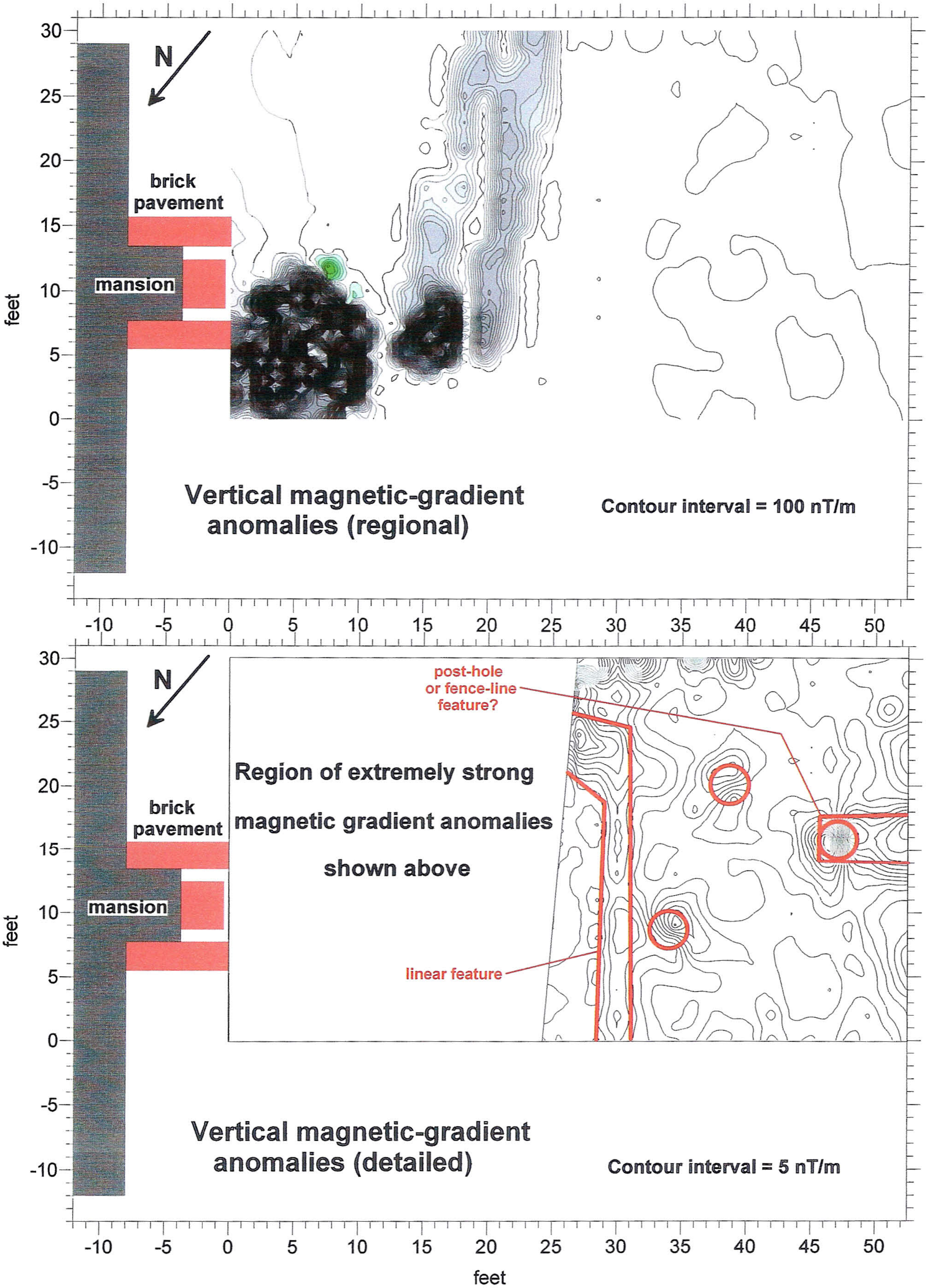


Figure 11. Vertical magnetic-gradient anomalies, southwest side yard, Gunston Hall mansion. Top: Regional anomalies. Bottom: Detailed anomalies southwest of extremely strong anomalies.

Figure 12. Mason Family Cemetery. Top: Measurement tapes forming coordinate system. Bottom: Dave Shonyo discusses cemetery with Hanna, Imlay, and archaeological volunteers.

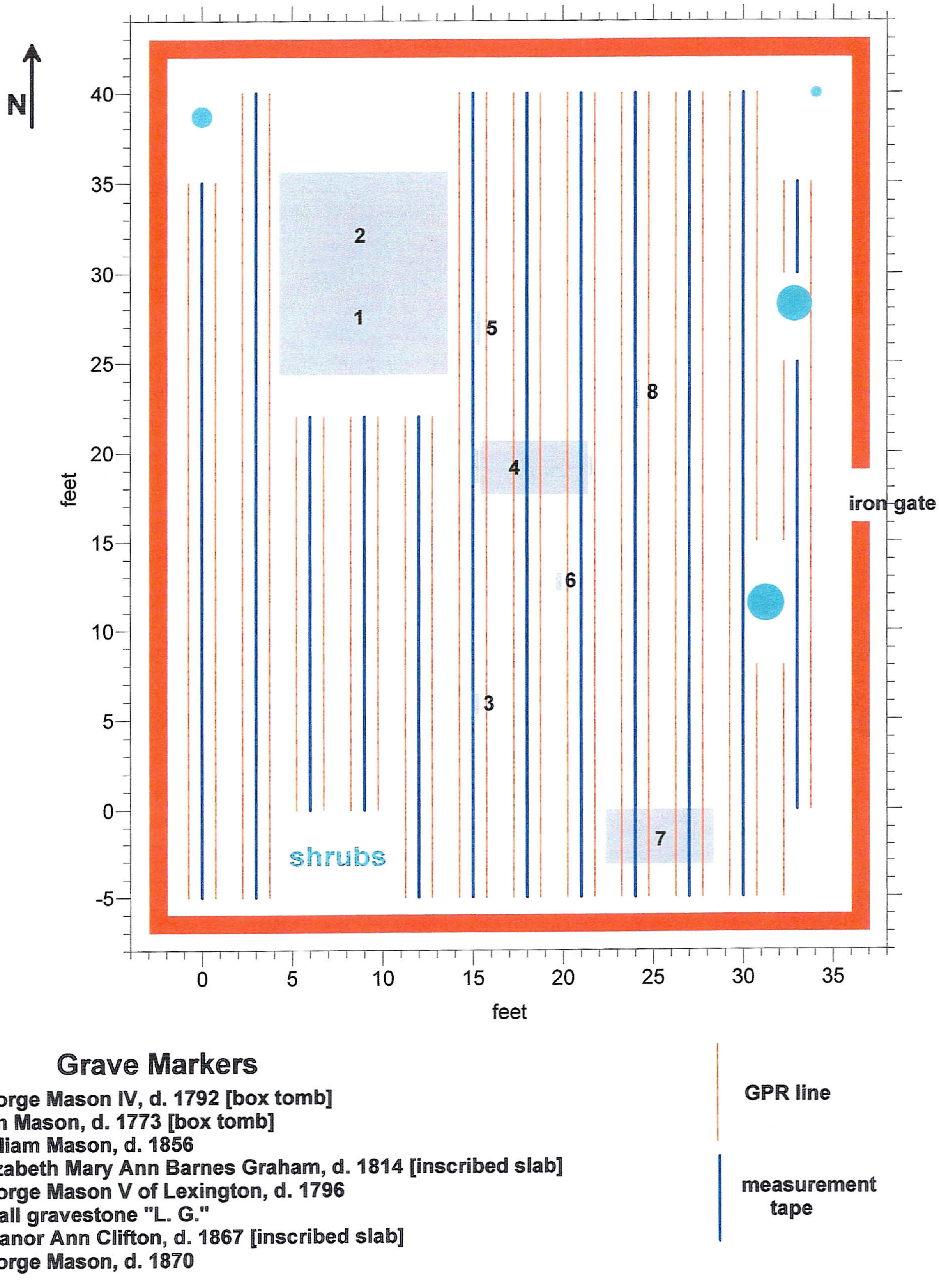
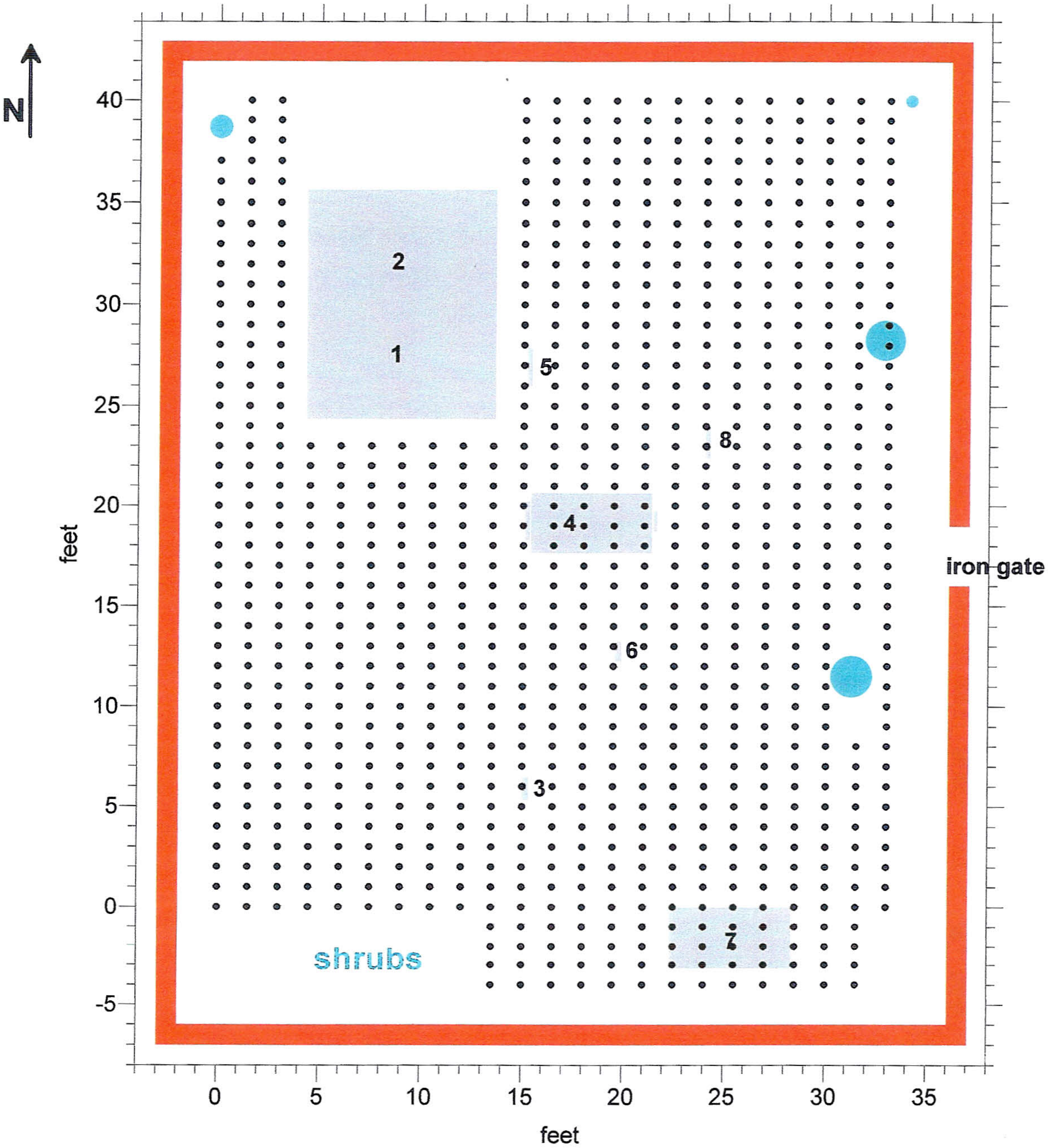


Figure 13. Locations of GPR lines within the Mason Family Cemetery, relative to locations of inscribed grave markers.



Grave Markers

1. George Mason IV, d. 1792 [box tomb]
2. Ann Mason, d. 1773 [box tomb]
3. William Mason, d. 1856
4. Elizabeth Mary Ann Barnes Graham, d. 1814 [inscribed slab]
5. George Mason V of Lexington, d. 1796
6. small gravestone "L. G."
7. Eleanor Ann Clifton, d. 1867 [inscribed slab]
8. George Mason, d. 1870

• EMI or magnetic gradiometer measurement point

Figure 14. Locations of EMI and magnetic gradiometer measurements within the Mason Family Cemetery, relative to locations of inscribed grave markers.

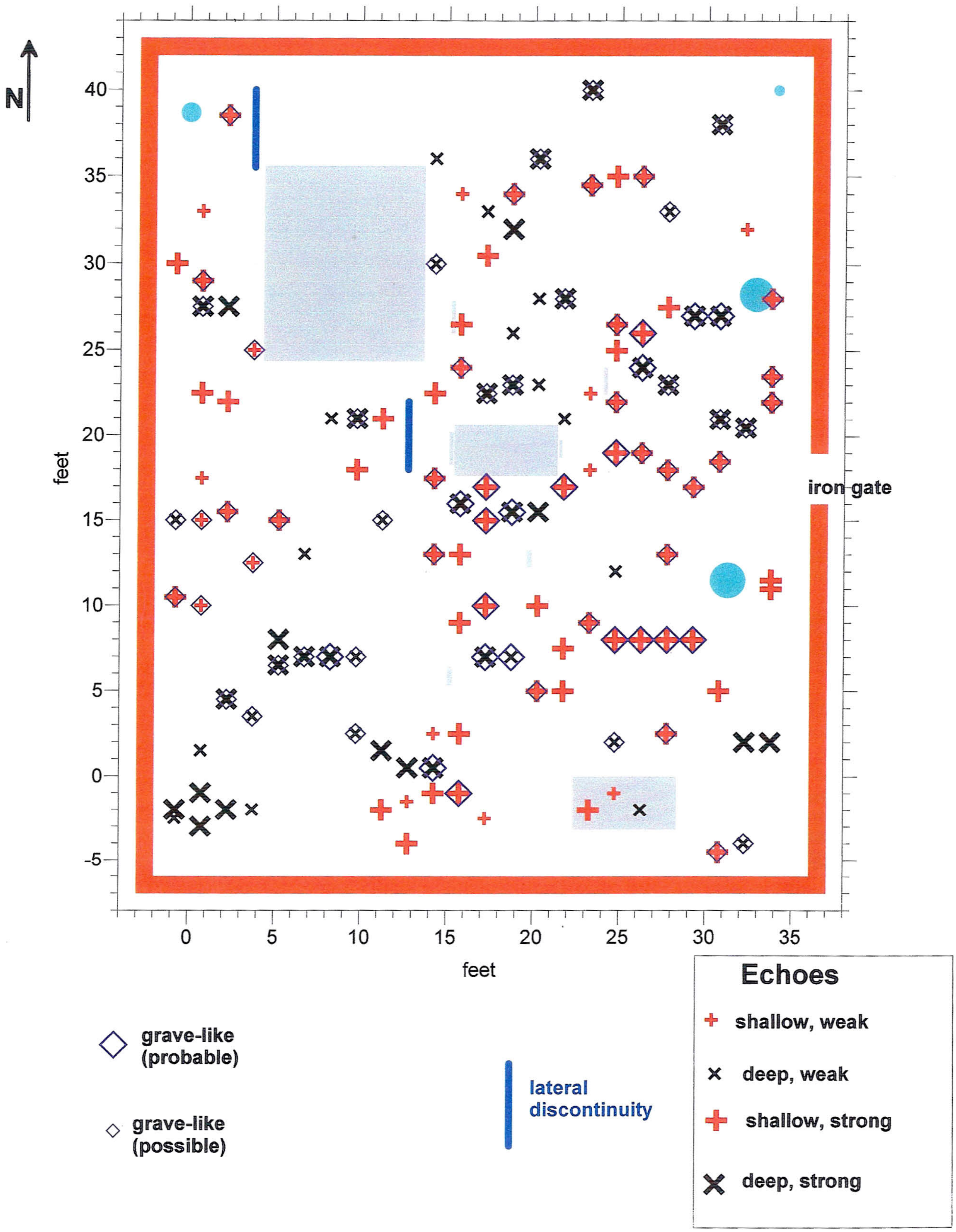


Figure 15. GPR echoes and lateral discontinuities within the Mason Family Cemetery. The "grave-like" icons denote those echoes that, on the basis of previous experience, suggest a probable or possible burial-type of GPR echo.

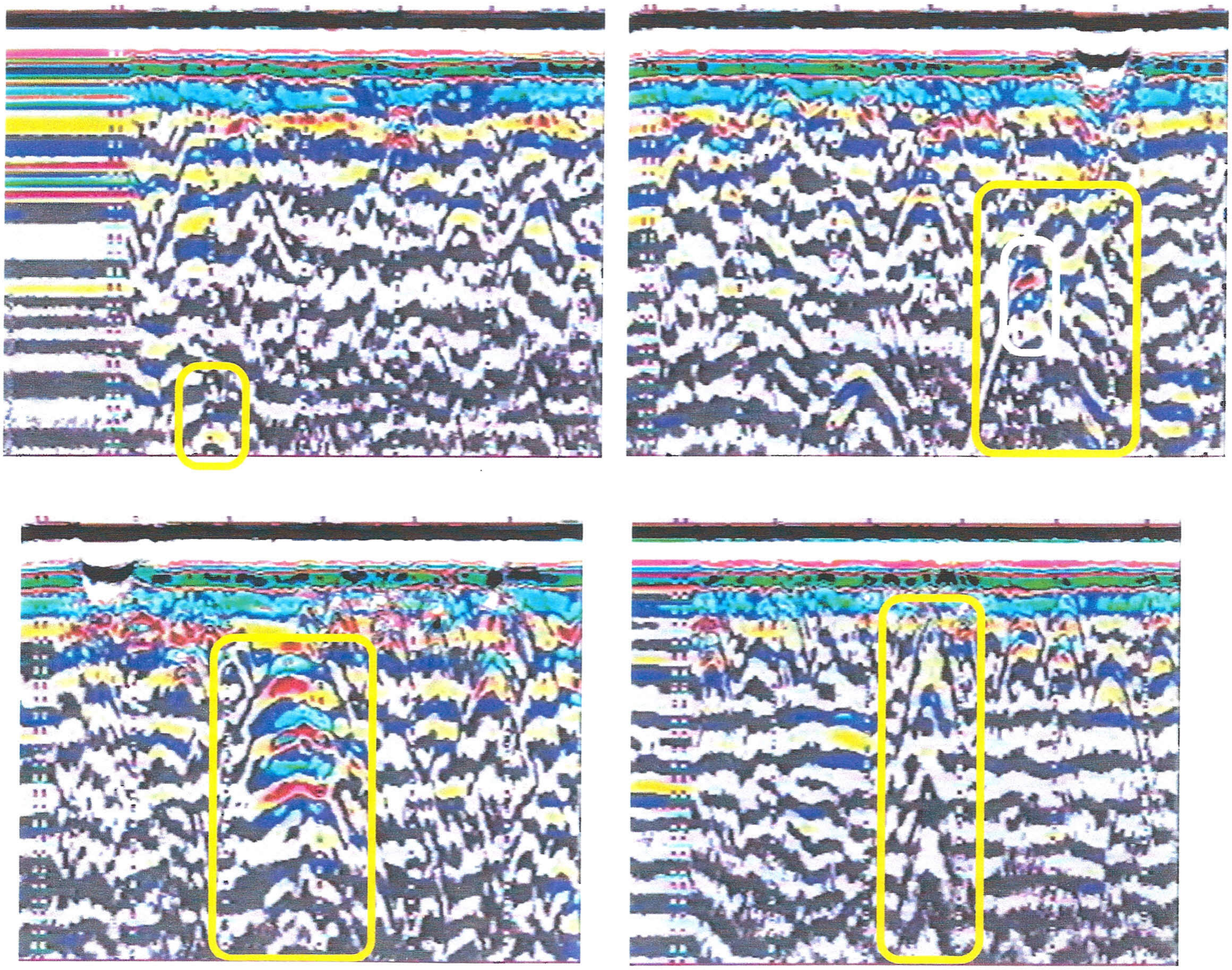


Figure 16. GPR record segments from the Gunston Family Cemetery area. Upper-left: Line 11, showing a deep probable burial. Upper-right: Line 13, showing a probable burial (yellow outline) in a coffin with attendant metallic hardware (white outline) . Lower-left: Line 19, showing the strong reflection from a cast-iron coffin, known also from 4 other sets of geophysical data. Lower-right: Second GPR line run west of the cemetery walls, showing a major echo.

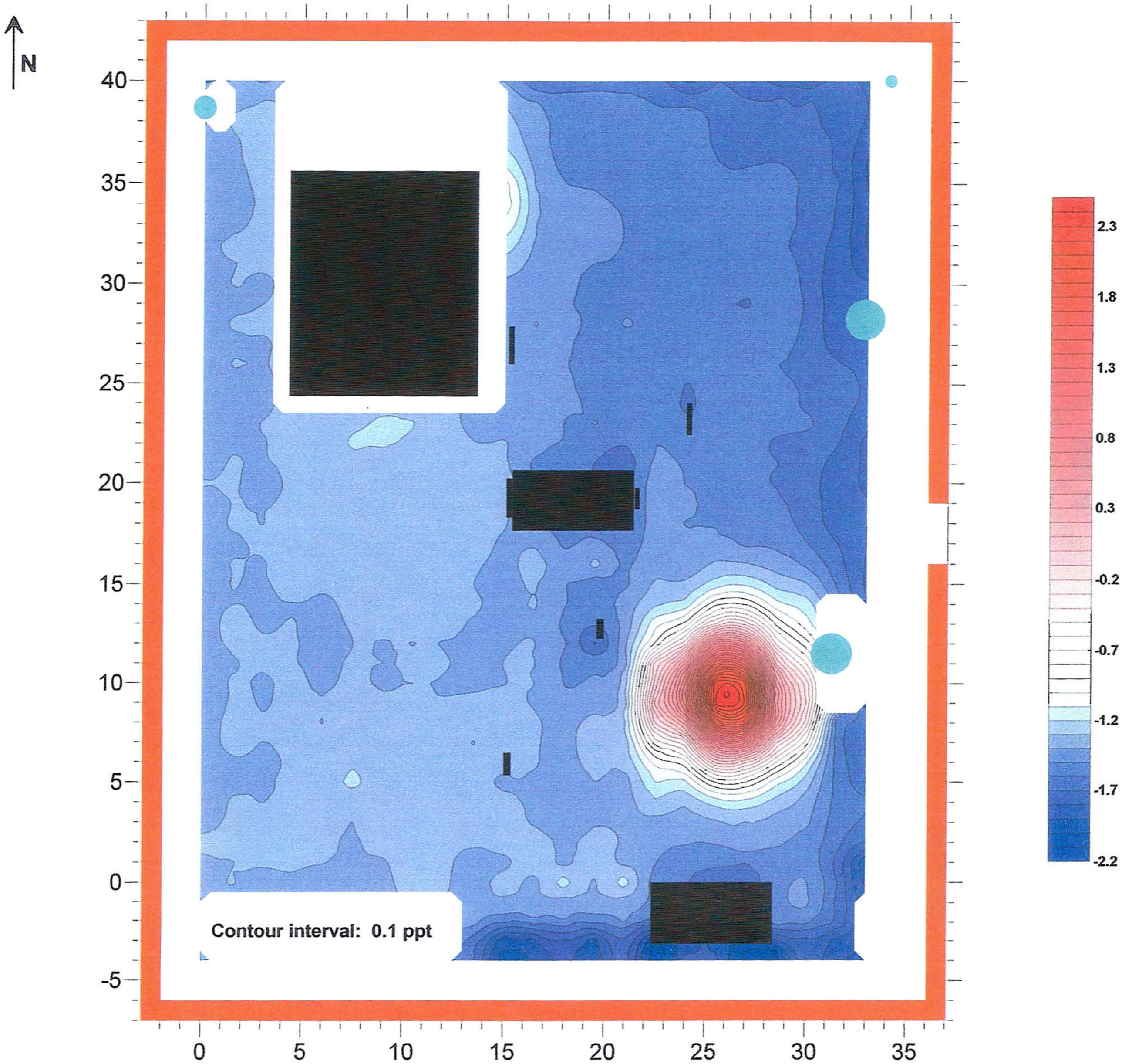


Figure 17. In-phase EMI anomalies, Mason Family Cemetery, Gunston Hall Plantation.

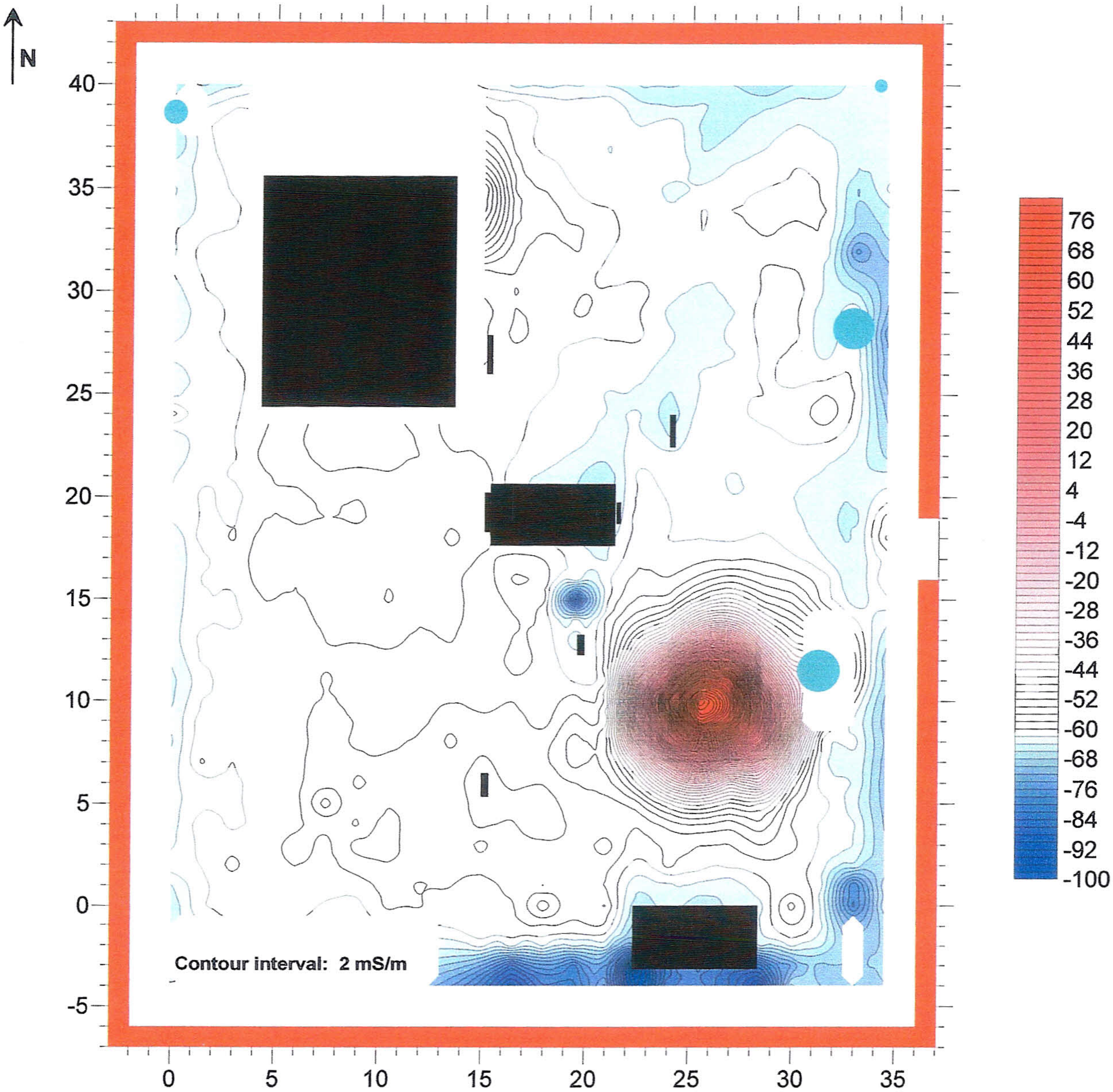


Figure 18. Quadrature-phase EMI anomalies, Mason Family Cemetery, Gunston Hall Plantation.

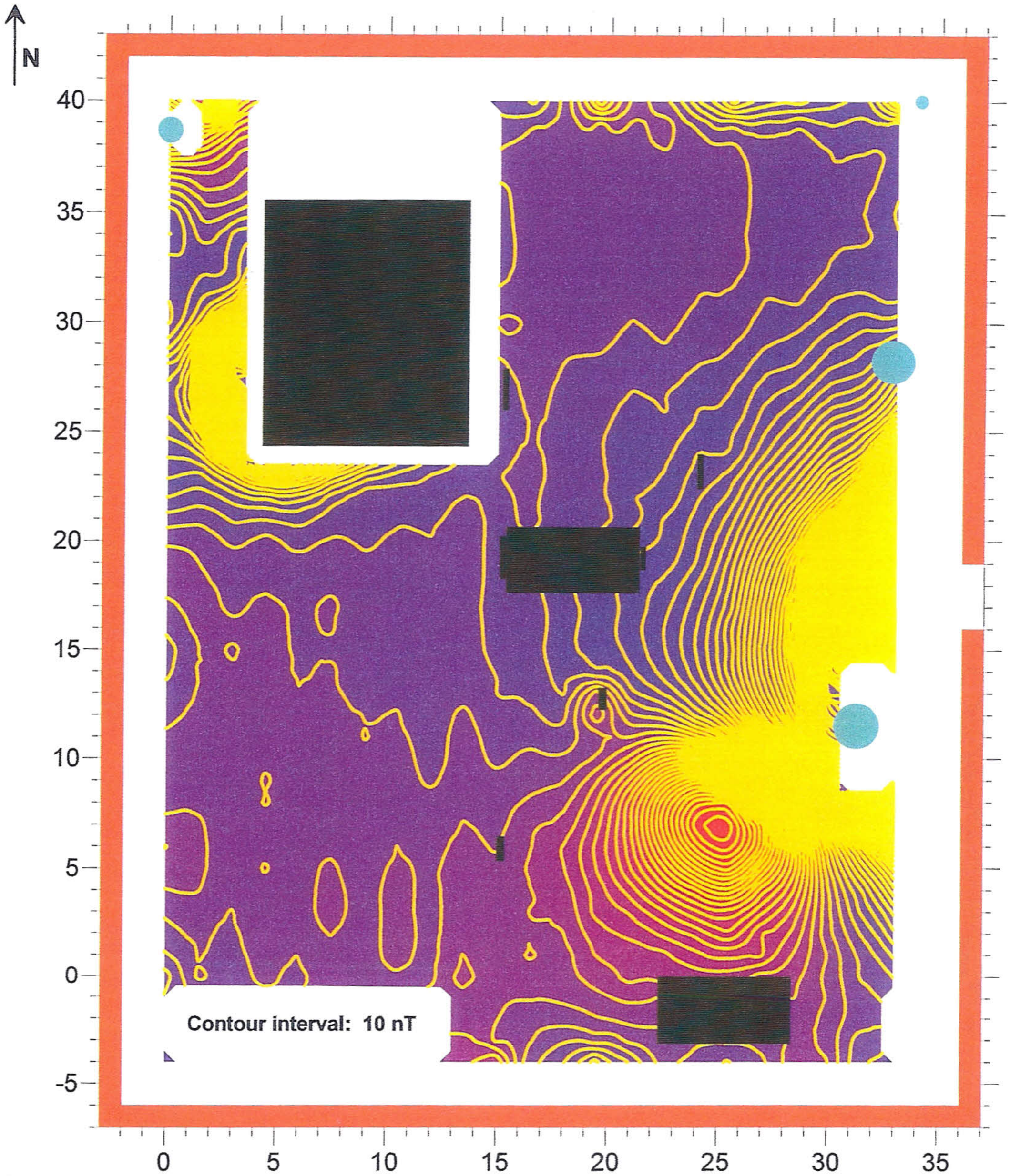


Figure 19. Total-field magnetic anomalies, Mason Family Cemetery, Gunston Hall Plantation.

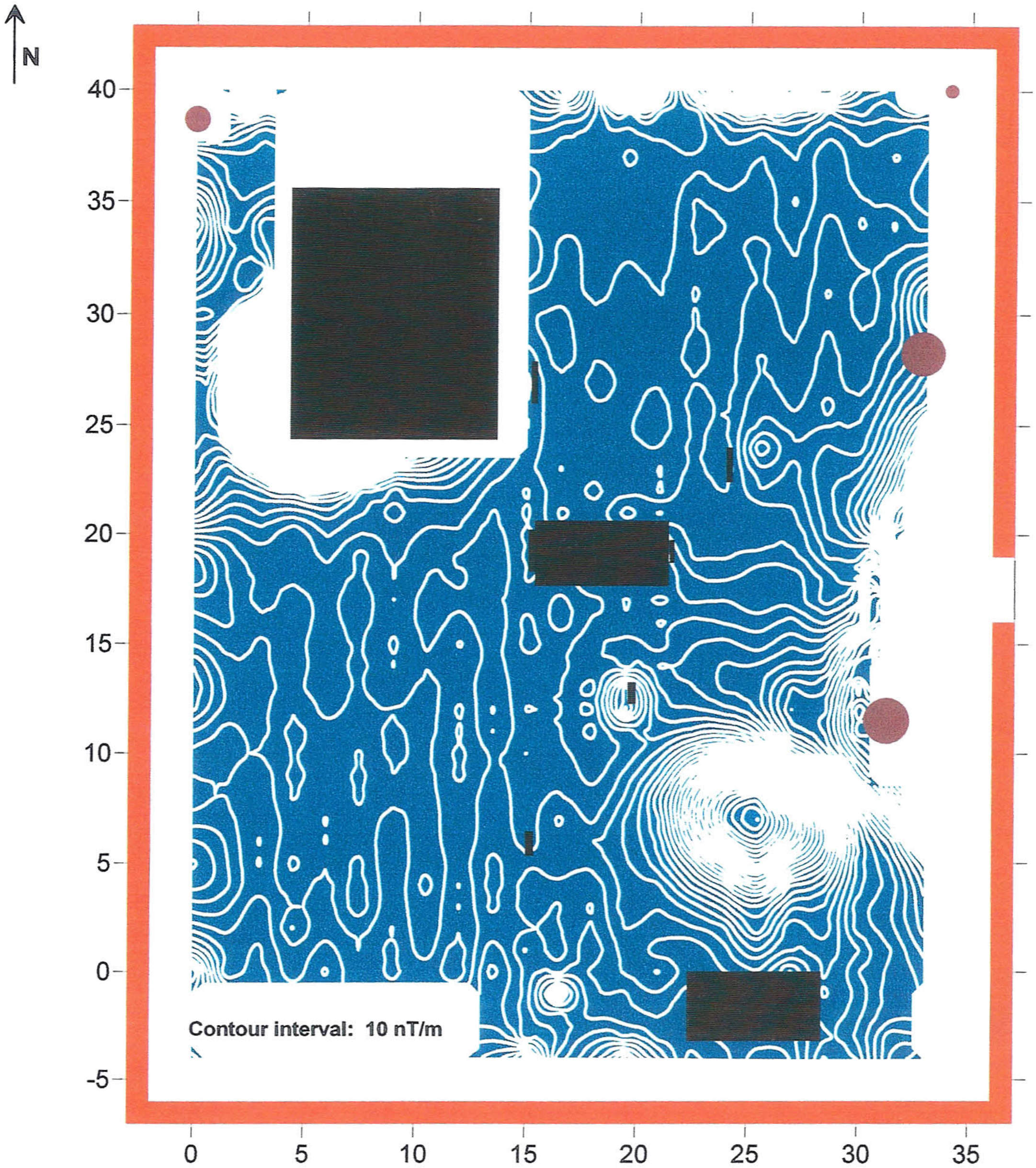


Figure 20. Vertical magnetic gradient anomalies, Mason Family Cemetery, Gunston Hall Plantation.

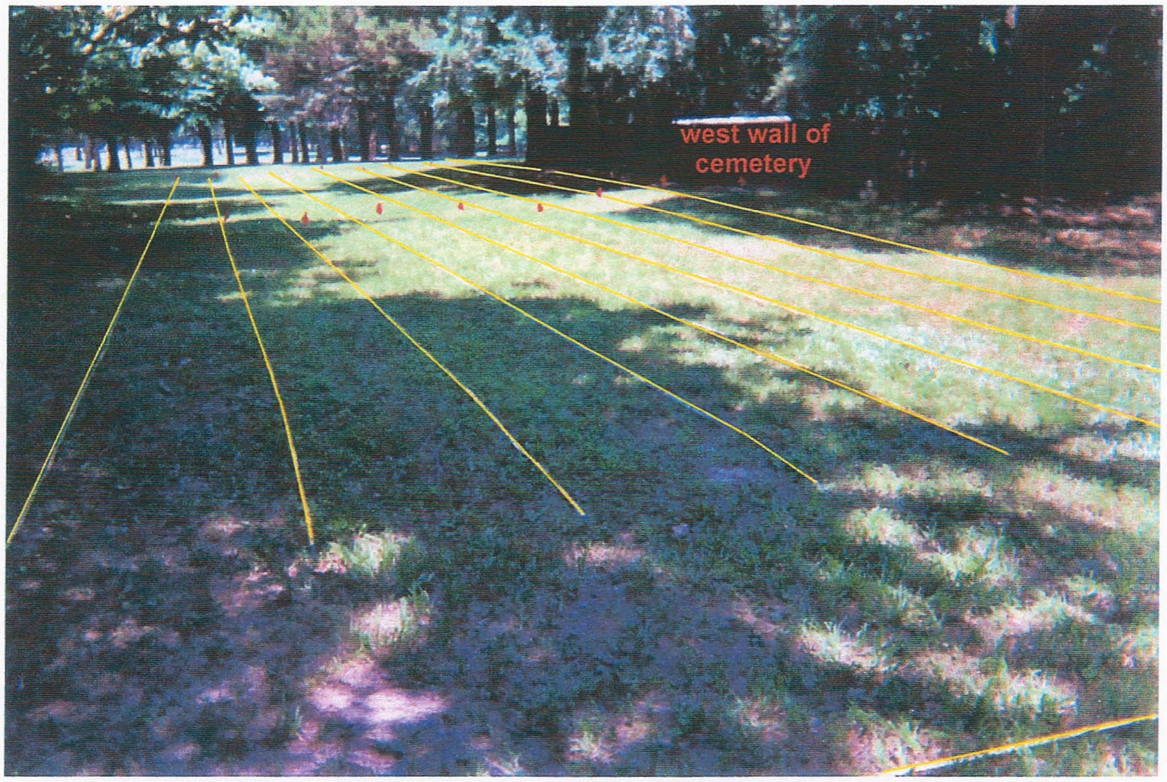


Figure 21. Survey area immediately west of west wall of mason Family Cemetery. Top: Measurement tapes in clearing. Bottom: Petrone discusses GPR results.

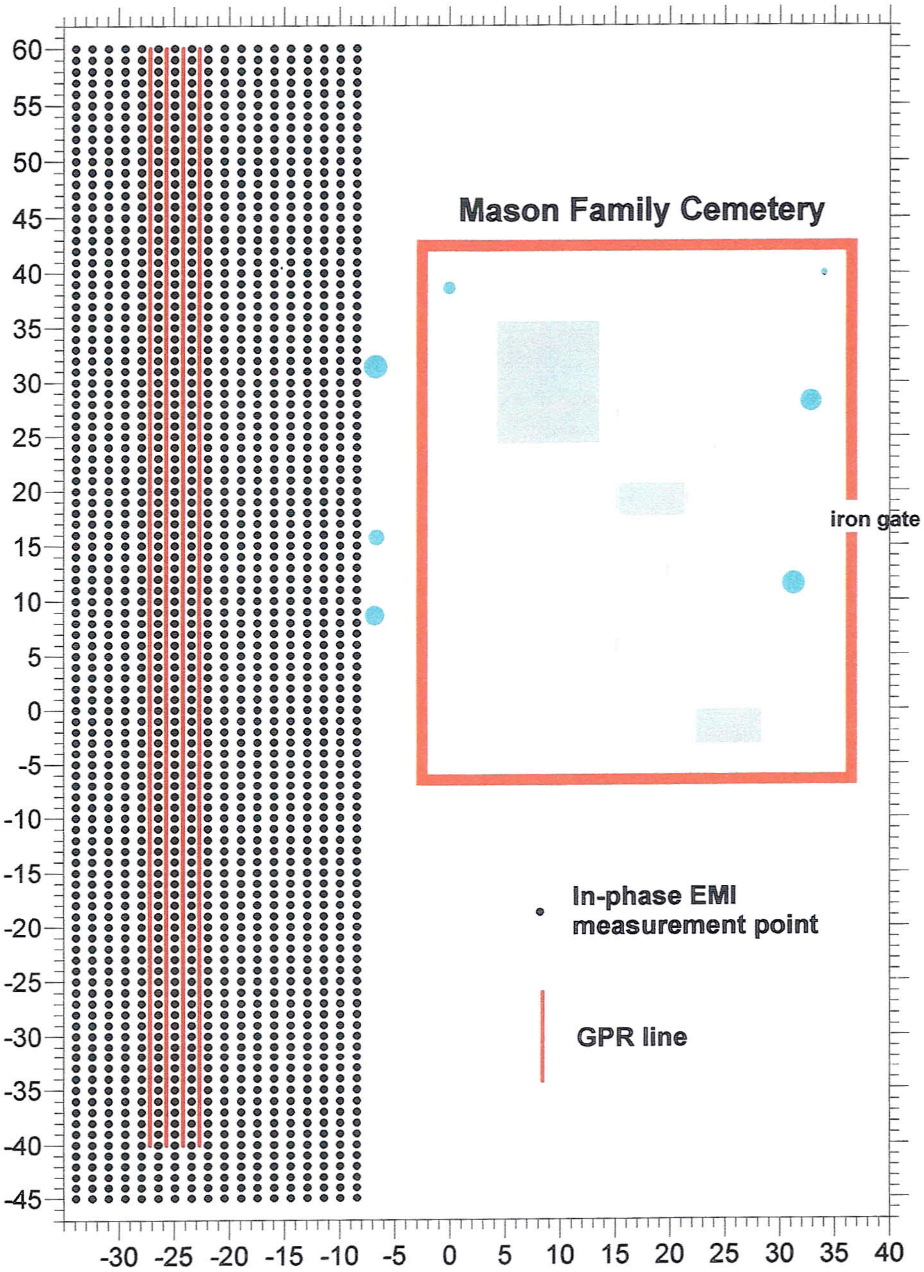


Figure 22. In-phase EMI measurement points and GPR lines immediately west of the wall of the Mason Family Cemetery.

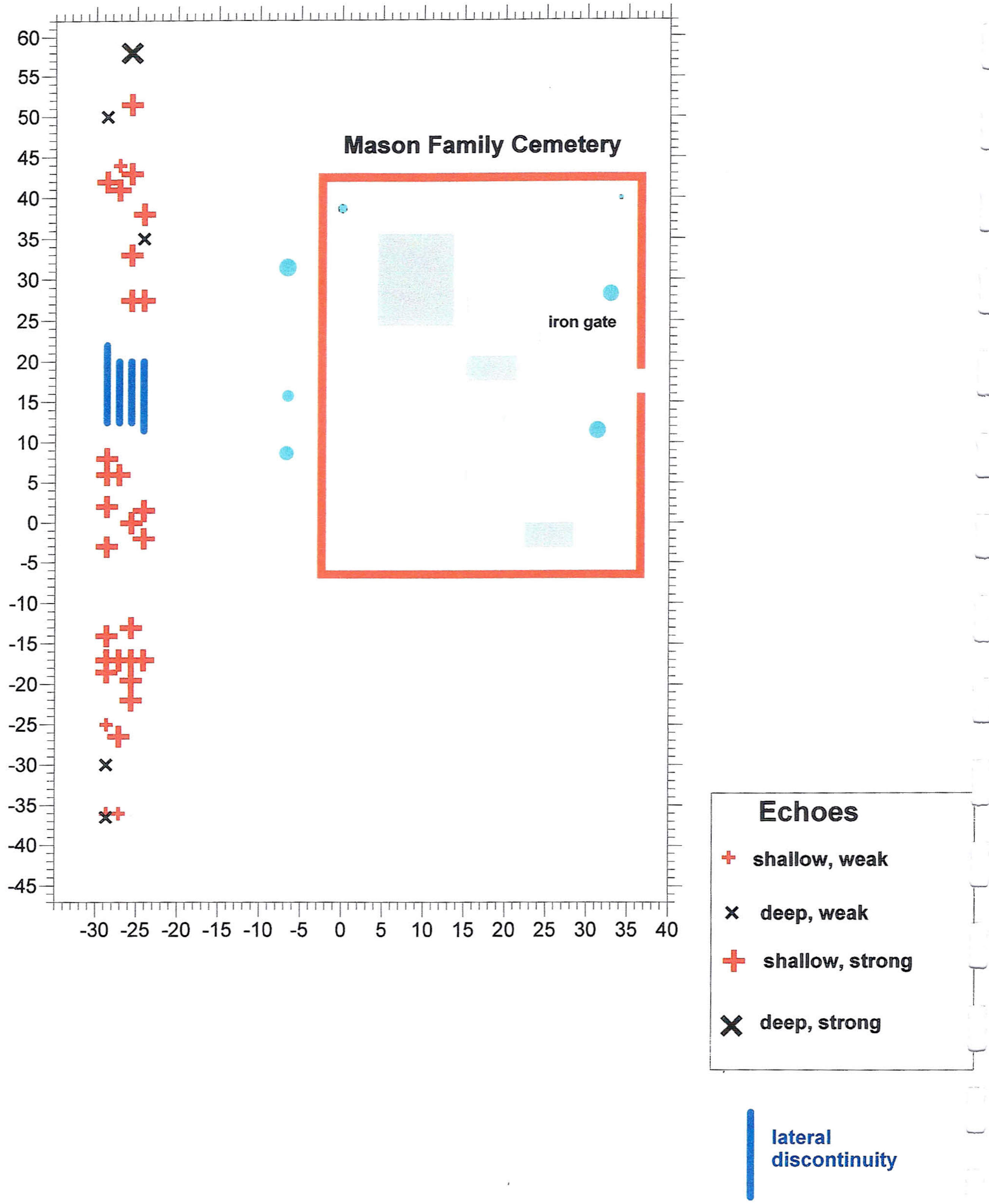


Figure 23. GPR echoes and lateral discontinuities of a small region immediately west of the wall of the Mason Family Cemetery.

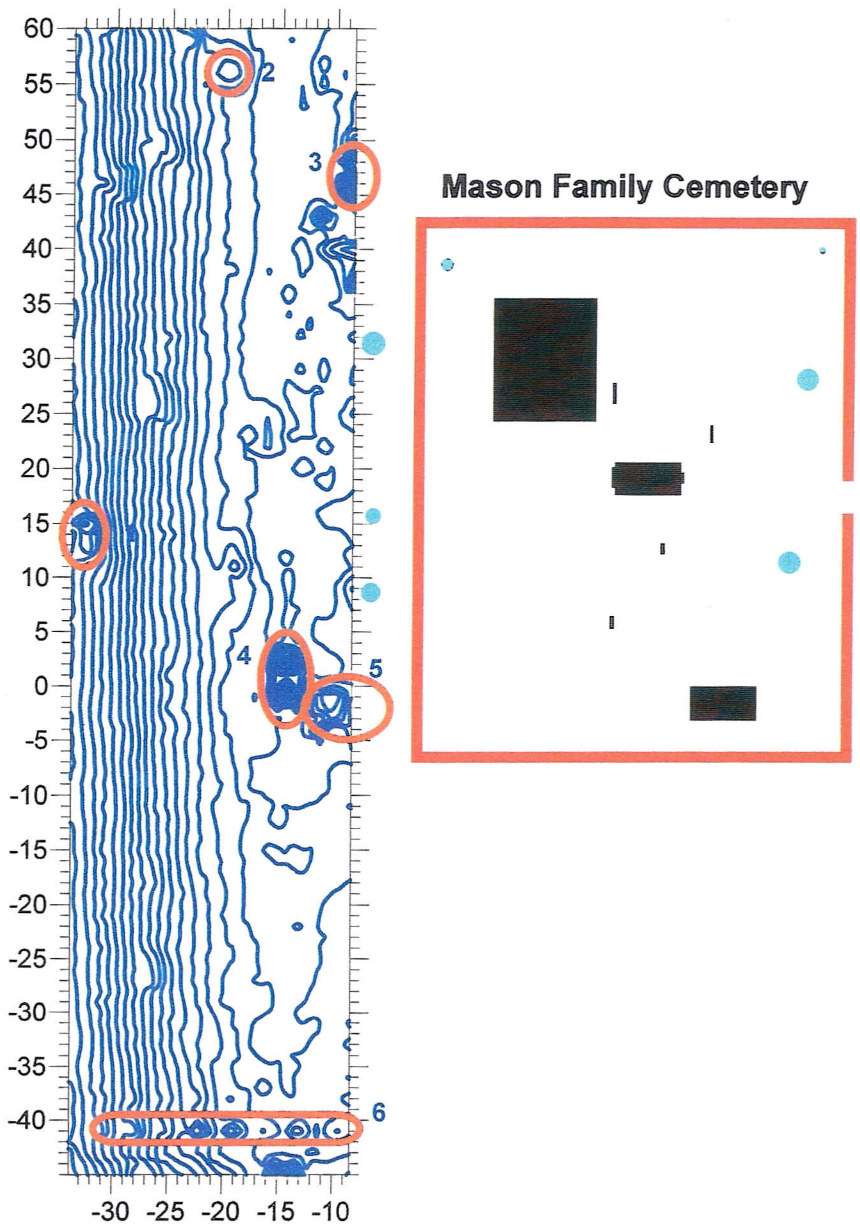


Figure 24. In-phase EMI anomalies west of the Mason Family Cemetery. The rectangular grid was established as close as possible to the west wall of the cemetery, blocked only by clusters of trees.

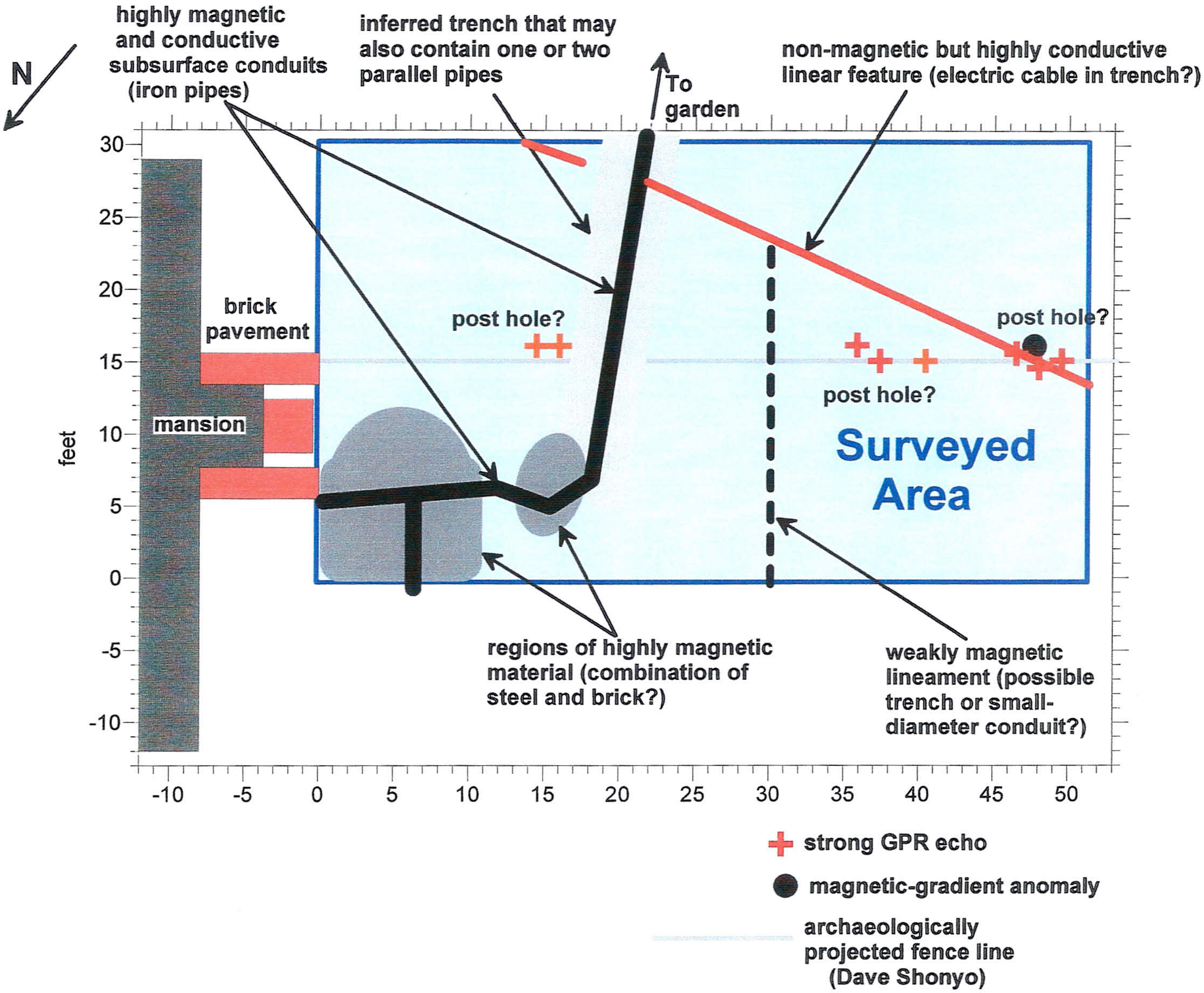


Figure 25. Inferred subsurface features in surveyed part of southwest side yard of Gunston Hall mansion.

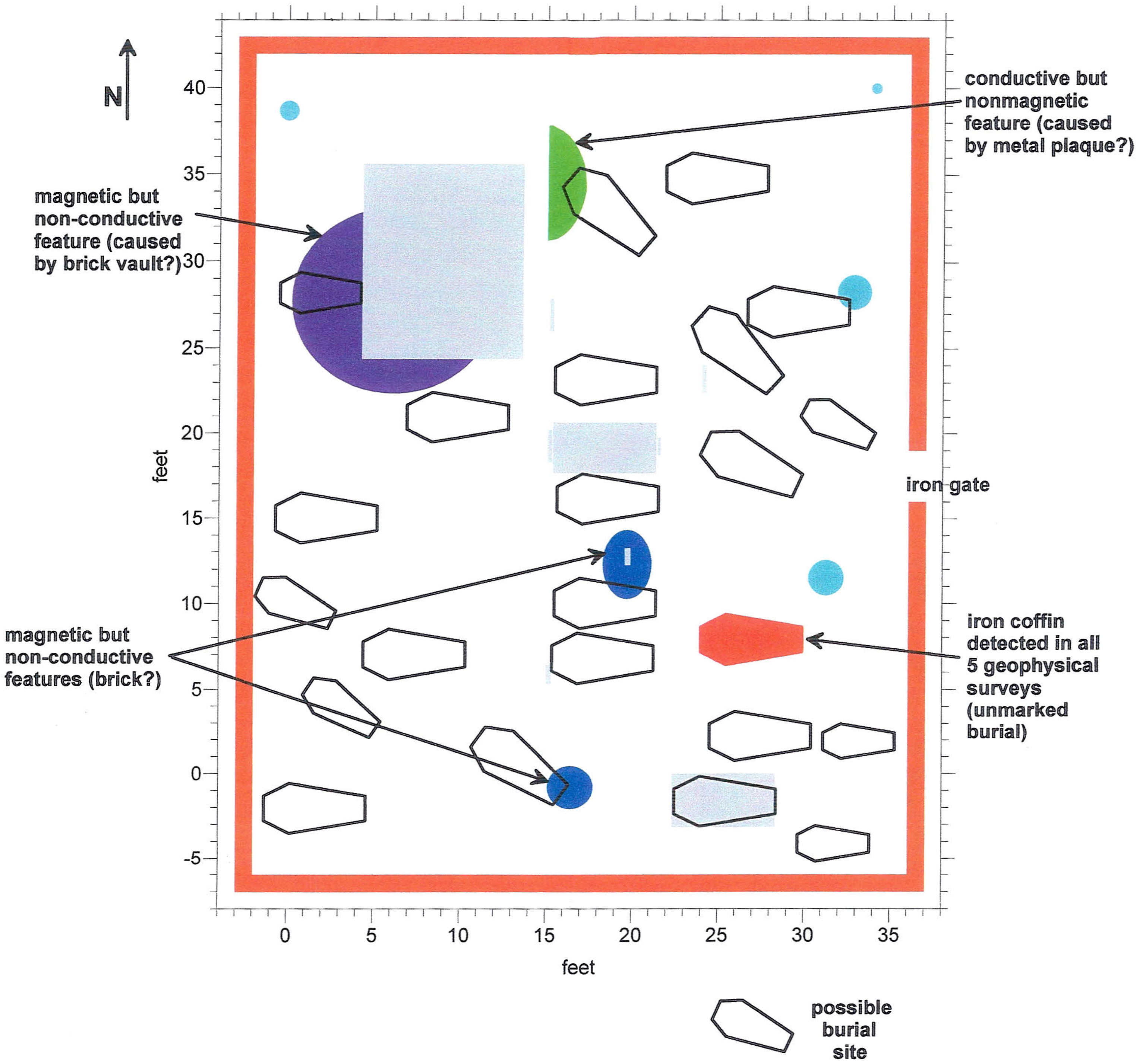


Figure 26. Inferred burial sites or significant ground disturbances, in relation to inscribed markers, Gunston Family Cemetery. The inferred iron coffin, which has no associated marker, is unique. Note that several coffin icons are skewed relative to the usual east-west orientation. Other conductive or magnetic features are shown.

APPENDIX A: GPR Echoes, Southwest Side Yard, Gunston Hall

X-coord (ft)	Y-coord (ft)	2W_TT (ns)	Signal Strength	Comment	Line#
0.75	13.5	8.0	5		1
2.25	5.5	13.0	5		2
2.25	6.5	6.0	5	rvrb	2
2.25	23.0	9.0	5	nrrw	2
3.75	5.5	14.0	5		3
3.75	6.0	6.5	5	rvrb	3
3.75	8.5	6.5	5		3
5.25	5.0	6.0	5	rvrb_LHf	4
6.75	6.0	11.0	5		5
8.25	7.0	13.0	5		6
9.75	7.0	13.0	5	rvrb	7
11.25	6.5	12.5	5	rvrb	8
11.25	8.0	32.0	3		8
12.75	6.5	13.0	5	rvrb	9
12.75	8.5	5.5	5	nrrw_rvrb	9
12.75	12.0	9.0	5		9
14.25	4.0	6.5	5	nrrw_rvrb	10
14.25	6.0	13.0	5	rvrb	10
14.25	8.0	6.0	5	nrrw_rvrb	10
14.25	12.0	6.0	5	nrrw_rvrb	10
14.25	16.0	4.5	5	nrrw_rvrb	10
14.25	29.0	8.0	5	rvrb	10
15.75	2.5	3.5	5	nrrw_rvrb	11
15.75	3.5	6.0	5	rvrb	11
15.75	5.5	11.0	5	rvrb	11
15.75	12.0	6.5	5	rvrb	11
15.75	13.0	6.5	5	rvrb	11
15.75	16.0	6.0	5	rvrb	11
15.75	19.0	6.0	5	nrrw_rvrb	11
15.75	26.5	9.0	5	LHf_brkn	11
15.75	28.0	8.0	5	rvrb	11
17.25	26.5	15.0	5		12
18.75	2.0	7.0	5	rvrb	13
18.75	3.5	6.5	5	nrrw_rvrb	13
18.75	27.0	13.0	5	spot	13
20.25	1.0	5.5	5	nrrw_rvrb	14
20.25	18.0	8.5	2	nrrw_clr	14
20.25	26.0	10.0	5		14
21.75	26.0	9.5	5		15
23.25	2.5	8.0	5	nrrw_chevr	16
23.25	4.0	8.0	5	nrrw_chevr	16
23.25	13.0	11.0	5	chevr	16
23.25	26.0	9.5	5		16
24.75	2.5	9.0	5		17
24.75	8.0	6.0	5		17
24.75	13.5	8.0	5		17
24.75	18.0	8.0	5		17
24.75	22.0	11.0	5		17
24.75	24.5	11.0	5		17
24.75	28.0	7.0	5		17

APPENDIX A: GPR Echoes, Southwest Side Yard, Gunston Hall

26.25	2.0	10.5	5		18
26.25	23.0	13.0	5		18
27.75	22.5	14.0	2		19
29.25	22.0	14.0	5		20
30.75	7.5	3.0	5	spot	21
30.75	14.0	6.0	5	nrrw	21
30.75	17.0	10.0	5		21
30.75	21.5	9.0	5	nrrw_rvrb	21
32.25	4.0	5.0	5		22
32.25	8.0	6.0	5	nrrw_rvrb	22
32.25	21.5	15.5	2		22
32.25	23.0	5.5	5	rvrb	22
33.75	4.0	6.0	5	rvrb	23
33.75	7.5	6.0	5	rvrb	23
33.75	21.0	13.0	5	RHf	23
35.25	5.5	9.5	5		24
35.25	7.0	5.0	5	RHf_rvrb	24
35.25	16.0	6.5	5		24
35.25	27.0	11.5	5	nrrw_brkn	24
36.75	15.0	6.0	5		25
36.75	18.0	15.5	2		25
39.75	15.0	10.0	5	nrrw_rvrb	26
39.75	17.5	16.0	2		26
39.75	17.5	10.5	5	rvrb	27
41.25	6.0	5.5	5	rvrb	28
41.25	17.5	17.0	2		28
42.75	10.0	6.0	5	nrrw_rvrb	29
42.75	17.0	16.0	2	brd	29
44.25	3.0	27.0	2	brd	30
44.25	15.5	16.0	2		30
44.25	27.0	9.0	5	asymm	30
45.75	4.0	26.0	2	brd	31
45.75	15.5	16.0	3		31
45.75	28.5	9.0	5	rvrb	31
47.25	14.5	15.5	5	spot	32
47.25	23.0	5.5	5	rvrb	32
47.25	26.5	7.5	5	RHf_rvrb	32
48.75	6.0	25.0	2		33
48.75	15.0	16.0	3		33
50.25	6.0	26.0	2		34
50.25	8.0	5.0	5	rvrb	34
50.25	11.5	6.0	5	rvrb	34
50.25	13.0	6.0	5	rvrb	34
50.25	24.0	7.5	5	rvrb	34
50.25	29.0	6.0	5		34
51.75	8.0	4.0	5	rvrb	35
51.75	12.5	15.0	2		35
51.75	16.0	6.5	5		35
51.75	17.0	6.0	5		35
51.75	19.0	7.0	5		35
51.75	23.0	7.5	3		35
51.75	27.5	9.5	5		35

APPENDIX B: GPR Echoes, Gunston Family Cemetery

X-coord (ft)	Y-coord (ft)	2W_TT (ns)	Signal Strength	Comment	Line#
-0.75	-2.0	20.0	2		1
-0.75	-2.5	26.0	1	brd_vague	1
-0.75	10.5	15.0	2		1
-0.75	15.0	19.0	1	brd	1
-0.75	30.0	16.0	3	brd_clr	1
0.75	-3.0	26.0	2	brd_vague	2
0.75	-1.0	24.0	2		2
0.75	1.5	25.0	1	brd	2
0.75	10.0	12.0	1		2
0.75	15.0	12.0	1		2
0.75	17.5	16.0	1	flnks_vague	2
0.75	22.5	14.0	2	vague	2
0.75	27.5	20.0	3	metal	2
0.75	29.0	17.5	3		2
0.75	33.0	16.5	1	vague	2
2.25	-2.0	21.0	2	brd	3
2.25	4.5	30.5	2	brd_rvrb	3
2.25	15.5	9.0	2		3
2.25	22.0	12.0	2		3
2.25	27.5	21.0	2		3
2.25	38.5	17.5	2	brkn	3
3.75	-2.0	25.0	1	brd	4
3.75	3.5	32.5	1		4
3.75	12.5	16.5	1		4
3.75	25.0	16.0	1		4
5.25	6.5	20.0	2	rvrb	5
5.25	8.0	25.0	2	distort	5
5.25	15.0	12.0	2		5
6.75	7.0	26.0	2	LHf_distort	6
6.75	13.0	23.0	1	brd_vague	6
8.25	7.0	28.0	4	metal?	7
8.25	21.0	22.0	1	rvrb	7
9.75	2.5	32.0	1	spot	8
9.75	7.0	24.0	1	brd_rvrb	8
9.75	18.0	11.0	3		8
9.75	21.0	24.0	2	rvrb	8
11.25	-2.0	17.0	2		9
11.25	1.5	27.0	2	brd	9
11.25	15.0	21.0	1		9
11.25	21.0	11.0	3		9
12.75	-4.0	14.5	3		10
12.75	-1.5	15.0	1	nrrw_rvrb	10
12.75	0.5	31.0	2	brd_brkn	10
14.25	-1.0	8.0	3	rvrb	11
14.25	0.5	33.0	3		11
14.25	2.5	13.5	1	RHf	11
14.25	13.0	15.5	3		11
14.25	17.5	14.5	3		11
14.25	22.5	5.0	5	vert_clr	11
14.25	30.0	32.5	1	brd	11

14.25	36.0	19.0	1	RHf	11
15.75	-1.0	11.5	3		12
15.75	2.5	15.5	2	brkn	12
15.75	9.0	10.0	3		12
15.75	13.0	10.5	3		12
15.75	16.0	21.0	3		12
15.75	24.0	9.0	3	clr_strat	12
15.75	26.5	9.0	3	metal	12
15.75	34.0	15.0	1	RHf_vague	12
17.25	-2.5	15.0	1	brd	13
17.25	7.0	28.0	3		13
17.25	10.0	12.5	3		13
17.25	15.0	14.0	3	metal	13
17.25	17.0	14.0	3	LHf	13
17.25	22.5	30.0	3	clr_strat	13
17.25	30.5	17.0	2		13
17.25	33.0	29.0	1	brd_brkn	13
18.75	7.0	29.5	1	brd	14
18.75	15.5	19.5	2	LHf	14
18.75	23.0	25.5	3	clr_strat	14
18.75	26.0	28.5	1	rvrb	14
18.75	32.0	25.0	3		14
18.75	34.0	15.5	3	brd	14
20.25	5.0	8.0	3	metal?	15
20.25	10.0	9.0	3	metal	15
20.25	15.5	27.0	3	metal	15
20.25	23.0	31.0	1		15
20.25	28.0	33.0	1		15
20.25	36.0	24.0	3	RHfs	15
21.75	5.0	16.0	2	br4d	16
21.75	7.5	11.0	3	nrrw_rvrb	16
21.75	17.0	16.0	2		16
21.75	21.0	28.0	1	brd_RHf	16
21.75	28.0	28.0	2		16
23.25	-2.0	7.0	3	nrrw_brkn	16
23.25	9.0	14.0	3		17
23.25	18.0	11.0	1		17
23.25	22.5	8.0	1		17
23.25	34.5	13.0	3	RHf_brkn	17
23.25	40.0	25.0	3		17
24.75	-1.0	8.0	1	LHf	18
24.75	2.0	21.0	1	rvrb	18
24.75	8.0	14.0	5	brd_rvrb	18
24.75	12.0	19.0	1	chevrons	18
24.75	19.0	9.0	3		18
24.75	22.0	12.0	2		18
24.75	25.0	9.0	3	nrrw_rvrb	18
24.75	26.5	12.0	3	clr_strat	18
24.75	35.0	12.5	2	LHf	18
26.25	-2.0	33.0	1		19
26.25	8.0	9.0	5	brd_rvrb	19
26.25	19.0	8.0	3		19

26.25	24.0	30.0	5		19
26.25	26.0	16.5	3	spots	19
26.25	35.0	12.0	3		19
27.75	2.5	11.0	3	metal	20
27.75	8.0	7.0	5		20
27.75	13.0	7.0	4		20
27.75	18.0	10.0	3		20
27.75	23.0	28.0	2	brkn	20
27.75	27.5	15.0	2	brd_rvrb	20
27.75	33.0	26.0	1	brd_LHf	20
29.25	8.0	14.0	5	brd_rvrb	21
29.25	17.0	14.0	3		21
29.25	27.0	21.5	3		21
30.75	-4.5	17.0	3	RHf_metal	22
30.75	5.0	7.5	3	rvrb	22
30.75	18.5	13.5	2	brkn_vague	22
30.75	21.0	27.0	2		22
30.75	27.0	20.5	3		22
30.75	38.0	29.5	2		22
32.25	-4.0	25.0	1		22
32.25	2.0	18.0	2	brd_brkn	22
32.25	20.5	31.0	2	clr_strat	22
32.25	32.0	17.0	1	RHf_vague	23
33.75	2.0	26.0	2	clr_strat	23
33.75	11.0	4.5	5	nrrw_rvrb	23
33.75	11.5	16.5	5	brd_rvrb	24
33.75	22.0	14.0	2		24
33.75	23.5	13.0	3	clr_strat	24
33.75	28.0	16.5	2	brd_rvrb	24

APPENDIX C: GP Echoes, West of the Mason Family Cemetery

X-coord (ft)	Y-coord (ft)	2W_TT (ns)	Signal Strength	Comment	Line#
-28.67	-36.5	32.0	1	brd	1
-28.67	-36.0	10.5	1	nrrw_rvrb	1
-28.67	-30.0	21.0	1	rvrb	1
-28.67	-25.0	14.5	1	rvrb	1
-28.67	-18.5	10.0	2		1
-28.67	-17.0	10.0	3	metal?	1
-28.67	-14.0	8.0	3	RHf_met?	1
-28.67	-3.0	13.5	3	metal	1
-28.67	2.0	13.5	3	metal	1
-28.67	6.0	9.5	2		1
-28.67	8.0	10.5	3	spots	1
-28.67	42.0	12.5	3	metal	1
-28.67	50.0	23.0	1	brd_rvrb	1
-27.17	-36.0	10.0	1		2
-27.17	-26.5	7.5	3		2
-27.17	-17.0	9.0	3	flanks	2
-27.17	6.0	11.0	2		2
-27.17	41.0	10.0	3	metal	2
-27.17	44.0	11.0	1		2
-25.67	-22.0	7.0	3		3
-25.67	-19.5	8.0	3		3
-25.67	-17.0	6.0	3		3
-25.67	-13.0	9.0	3		3
-25.67	0.0	3.5	3	chevrons	3
-25.67	27.5	9.5	3	metal	3
-25.67	33.0	9.0	3		3
-25.67	43.0	8.0	3		3
-25.67	51.5	5.0	3	chevrons	3
-25.67	58.0	26.0	3	metal?	3
-24.17	-17.0	7.0	3		4
-24.17	-2.0	10.0	3		4
-24.17	1.5	7.5	3		4
-24.17	27.5	8.0	3		4
-24.17	35.0	22.5	1	brd_rvrb	4
-24.17	38.0	10.0	2		4