Report of Geophysical Field Investigations

13 October 2017 and 18 January 2018

Old Charlestown Cemetery

Charlestown, PA

Charlestown Twp.

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1. Executive Summary

The objectives of the geophysical surveys at the Old Charlestown Cemetery in Charlestown, PA are to locate and analyze any geophysical anomalies indicative of 1) a mass burial of dimensions appropriate to hold 50 soldiers, 2) the foundations of the church associated with the cemetery and built in 1743, and 3) a midden pit associated with the church. To achieve these objectives, detailed reconnaissance geophysical mapping using a magnetometer in dual sensor mode and a ground penetrating radar (GPR) in continuous survey mode was performed throughout the site. The magnetometer survey was performed using a Geometrics G-858 Cesium Vapor Magnetometer. The GPR survey was performed using a GSSI SIR 4000 system with 400MHz antenna, set to 50 nanosecond scan length. As a result, geophysical maps (from both instruments) and profiles (from the GPR) were produced. The magnetometer map shows the vertical magnetic gradient for the survey area. The magnetometer reveals anomalous responses due to ferrous metallic objects, burn features, and other magnetic disturbances. The GPR map and profiles give an indication of subsurface structures based on electrical property contrasts. The field work was completed in two days, 13 October 2017 and 18 January 2018. Results are compiled into maps including labels of known surface features and black dashed lines highlighting anomalous responses. The corroborative evidence from the magnetometer and GPR reveals three anomalous response zones. Overall, these three anomalous areas may correlate to the three objectives of this project and may require further investigation.

This report is organized according to the following table of contents.

2. Objectives

The objectives of the geophysical surveys at the Old Charlestown Cemetery in Charlestown, PA are to locate and analyze any geophysical anomalies indicative of 1) a mass burial of dimensions appropriate to hold 50 soldiers, 2) the foundations of the church

associated with the cemetery and built in 1743, and 3) a midden pit associated with the church. These objectives are all related to the hand-drawn map of the site that is held by the Charlestown Historical Society (Figure 1).

3. *Methodology*

To achieve the above objectives, detailed reconnaissance geophysical mapping using a magnetometer in dual sensor mode and a ground penetrating radar (GPR) in continuous survey mode was performed throughout the site. A geophysical survey grid of 100 ft east-west and 85 ft north-south was established at the site during the initial reconnaissance mapping performed on 13 October 2017. The area was surveyed by Dr. Sherrod's Fall 2017 GEL 358 students using a line spacing of 1.5 ft. This preliminary surveying produced results which were inconclusive but encouraged further investigation. Heather Willever led additional surveying as a research project during the subsequent winter months to produce the geophysical images contained in this report. Following a site visit to map the surface features with GPS (Figure 2), Heather scheduled a day of field work (18 January 2018) to run a larger geophysical survey grid of 30 m (98 ft) east-west by 45 m (148 ft) north-south. A line spacing of 0.5 m (1.6 ft) was used, with fiducial marks every 15 m (49 ft) for the magnetometer survey.

The magnetometer survey was accomplished using a Geometrics G-858 cesium vapor magnetometer in dual sensor mode. This geophysical method resulted in the production of a vertical magnetic gradient map of the site (Figure 3). Known surface features are designated and anomalous response zones are highlighted with black dashed lines. The GSSI SIR 4000 GPR system with 400 MHz antenna set to 50 nanosecond scan length was also used for this survey. A selection of profiles and a time slice section are included in this report (Figures 4 through 6) with anomalous zones highlighted with black dashed lines.

Theory

Geometrics G-858 Cesium Vapor Magnetometer

The G-858 Cesium Vapor Magnetometer is a highly sensitive magnetic surveying instrument. This device has been used to locate and investigate: buried drums, other underground storage containers, pipelines, well-heads, other utilities, unexploded ordnance, discarded weapons, geologic structures, mineral deposits, graves, archaeological interests such as foundations, ferrous artifacts, and burn pits, and other objects. The operation of the instrument is based on magnetic theory. Simply stated, the earth acts as a dynamo generating a natural magnetic field. Magnetic fields are dipolar in nature. That is, they contain a positive pole and a negative pole. Magnetic ferrous objects within the earth, buried deep, or shallow, enhance the earth's magnetic field and therefore create an

anomalous magnetic dipole. The "anomaly map" generated for this investigation shows local highs and lows which are representative of buried or surface ferrous objects that enhance the earth's natural magnetic field. Some objects exhibit a positive (red/orange) and negative (blue/purple) trend. This represents the dipolar nature of the object and indicates that the object is probably oriented horizontally with respect to its magnetic dipole. If the anomaly shows one pole, the magnetic dipole of the object is probably oriented vertically. Burn pits have been observed as monopolar anomalies in previous surveys.

The displacement of rocks from their original orientation to serve as foundation stones of a building can cause an anomalous magnetic signature due to the shift in orientation. As buildings are typically constructed in a rectangular shape, anomalous magnetic responses that are observed in a rectangular pattern may relate to the foundations of buildings. In a similar manner, the disturbance of soil that occurs when digging a burial may disrupt the detrital magnetic signature of the soil and leave a very small magnetic anomaly in the shape of the burial. This magnetic response is expected to be very small and difficult to observe, particularly if there are other magnetic anomalies in the area which may mask the small anomaly caused by the burial. The response of a midden pit will be dependent upon both the shifting of the soil that may have occurred in digging the pit as well as the characteristics of objects within the pit. Ferrous objects can be expected to have a strong magnetic signature and midden pits which have experienced burn episodes may be easier to identify in a magnetic response map than those which have not been burned as the process of burning can create a magnetic anomaly in the soil.

GSSI SIR 4000, Ground Penetrating Radar Survey Instrument

The GPR method is analogous to the seismic reflection method, except that a single receiver is used at a fixed, very short distance from the source. The system measures total time from the transmitter to reflectors, then back up to the receiver. The transmitter emits a very short radio pulse that travels at 1/3 to 1/5 of the speed of light into the earth. Radio wave velocities are about a million times faster than seismic wave velocities, and thus the 2-way travel times are measured in nanoseconds (billionths of a second) instead of milliseconds, as is the case in seismology. Because the entire transmit-receive cycle is finished in several hundred nanoseconds, the system can easily transmit 50,000 pulses per second, using stacking and averaging tactics over hundreds of pulses to improve the signal quality of each composite scan or trace.

As in seismology, depth can only be determined if velocity is known as a function of depth. For GPR, the velocity is inversely proportional to the square root of the relative permittivity of the earth. The relative permittivity of earth materials is almost completely a function of their water content, as water has a far higher dielectric constant than the silicate minerals. Thus, contrary to the seismic case, wave velocity decreases as wetter formations are encountered. On the other hand, increasing electrical conductivity decreases the intensity or amplitude of the radio pulse. Salt water is effectively

impenetrable, and temperate-zone clay minerals also attenuate the signal very rapidly because of their adsorbed ions and enhanced surface conductivity. Thus, clayey tills, lakebed clays, or concrete with reinforcing rod or mesh near the surface might prohibit the use of GPR.

The transmitter and receiver antennae are physically equal, and have the form of flattened dipoles. The frequency being transmitted is an inverse function of the length of the dipole. Lower frequencies (which penetrate deeper) require larger antennae. The antennae are contained in insulating plastic boxes, but must be placed near the surface of the earth. Lifting an antenna or one side of an antenna by as little as a quarter wavelength will cause de-coupling from the earth, and consequently a low frequency ringing which obliterates reflections.

In general, solid metallic objects in the subsurface may be identified as strong, ringing reflections. The edges of a discrete object (including tree roots and stones) will produce hyperbolic reflections in the survey profile while the center will be represented as a flat vertical sequence of positive and negative reflected peaks. The disturbance of the ground by digging or trenching sections of the subsurface can be imaged with GPR as a truncation of the continuous bedding layers. A mass burial site, for example, could be expected to produce a GPR image that shows truncation of horizontal layers at the edges of the burial pit. A recent burial may also be expected to contain hyperbolic reflections from discrete objects within the pit. However, a mass burial site of significant age may not contain hyperbolic reflections but could show signs of degradation in the form of sagging of the surface layers. The foundation of a building may be imaged through correlation of hyperbolic reflections across multiple profiles or as a rectangular pattern in the reflections in a time slice view of the GPR data. A midden pit can be expected to combine the above mentioned features, with truncation of the layers at the edges of the pit and hyperbolic reflections from discrete objects buried within the pit.

Field Acquisition

A single geophysical survey grid was established at the site in January 2018. The GPS coordinates of the four corners of the survey area are:

40.1037507°, -075.5570606°
40.1036358°, -075.5573824°
40.1032687°, -075.5571680°
40.1033802°, -075.5568491°

This survey area contains the suspected location of the mass burial site as well as the foundation of the church in the northeastern corner of the hand-drawn map (Figure 1). The surveyed area is approximately 30 m (98 ft) east-west by 45 m (148 ft) north-south. Field data were collected in a single field day, 18 January 2018, under very cold weather conditions with snow on the ground.

The Geometrics G-858 Cesium Vapor Magnetometer was used to obtain magnetic field data. This instrument was used with two sensors (in gradiometer mode). Both sensors were oriented vertically to ensure that no null readings were obtained. Line spacing was 0.5 m

(1.6 ft) and data were collected with a 10-mark per second time in bi-directional survey mode in a north-south direction. Fiducial marks were inserted every 15 m (49 ft). The results of this data are displayed in Figure 3.

The GSSI SIR 4000 was used with 400MHz antenna to collect the GPR data. The scan length was set at 50 nanoseconds and the subsurface velocity was assumed to be 0.1 m/ns. Each profile was stored as an individual file. The operator pushed the antenna along the survey line in continuous collection mode. Lines were surveyed in a similar grid pattern to that used in the magnetometer survey from 0 m (0 ft) East to 23 m (75 ft) North. Line spacing for the GPR survey was identical to that used for the magnetometer survey. Samples of the results of this data are displayed in Figures 4, 5, and 6.

4. Results and Interpretation

The G-858 vertical magnetic gradient is obtained by subtracting the top sensor response from the bottom sensor response and dividing by the sensor separation as measured in the field (0.7 m for this survey). As such, many large-scale anomalies are removed from the map and only the smaller, individual anomalies remain. This is particularly useful when searching for small discrete objects in the subsurface. The geophysical results from the magnetometer were compiled into a map using minimum curvature to display the vertical magnetic gradient at the site (Figure 3). The locations of known surface features are labeled on this plot. Three zones of interest are highlighted with black dashed lines.

The profiles produced from the GPR survey show the structure of the subsurface and the location of discrete objects within the subsurface may be accurately determined by the presence of hyperbolic reflections in the record. The GPR geophysical results were plotted as profiles (Figures 5 and 6) and used to create a time slice map of the survey area (Figure 4). The three anomalous response zones are highlighted with black dashed lines in the profiles and map.

Overall Interpretations

The corroborative evidence from the G-858 and GSSI SIR 4000 reveals three anomalous response zones relating to the objectives of this project.

The first zone, at the location of the mass burial site on the hand drawn map, likely correlates to this feature. The GPR response at this location shows both truncation of the layers in the subsurface as well as sagging of the surface layers which may have been caused by degradation over the course of the last 250 years since the burial. The GPR profile (Figure 5) and time slice image (Figure 4) both clearly indicate an anomalous response. The size of this geophysical anomaly is approximately 7 m (23 ft) east-west by 10 m (33 ft) north-south with a depth of approximately 1.5 – 2 m (5 – 7 ft), an appropriate size for a mass burial site containing 50 soldiers. The magnetic map does not show anomalous responses related to the mass burial site. The GPS coordinates of the center of the GPR geophysical anomaly for this feature are 40.1034337°, -075.5570854°.

The second zone, at the location of the church on the hand drawn map, likely correlates to this feature. Although the GPR profiles were not collected over the entire survey area, the GPR response at this location shows a rectangular pattern of reflections. Likewise, the magnetic response at this location has a similar rectangular pattern of magnetic anomalies. The size of this feature is approximately 9 m (30 ft) east-west by 5 m (18 ft) north-south. There is a smaller rectangular anomaly within the first larger feature. This smaller anomaly is 3 m (10 ft) east-west by 2 m (7 ft) north-south. This smaller feature is of unknown source, but may be of archaeological interest. The orientation of the suspected foundation in the geophysical survey maps appears slightly off-line when compared to the hand drawn map. However, it is oriented nearly perpendicular to the rows of known graves. The GPS coordinates of the center of this geophysical anomaly are 40.1036425°, -075.5570711°.

The final zone of anomalous response is located along the northwestern boundary of the survey area. This feature is not visible as an anomaly in the magnetic map, but is shown as a large anomalous zone in the GPR profile (Figure 6). The truncation of the layers at the edges of the feature as well as the numerous hyperbolic reflections within the feature seem to indicate a pit filled with many discrete objects. The size of this feature is larger than that of the geophysical anomaly at the site of the mass burial, with dimensions of 3.5 m (11 ft) east-west by 20 m (66 ft) north-south. The final objective for this project was to locate a midden pit associated with the church. While this final anomalous response zone may be the midden pit for the church, its size is expansive and it may be related to some other unknown source, such as remnants of the wall illustrated in the northwestern side of the hand drawn map (Figure 1). The GPS coordinates of the center of this geophysical anomaly are 40.1035504°, -075.5572628°

Figure 7 shows the site map in relation to the GPR profiles of Figures 5 and 6 (gray lines) as well as the boundaries of the geophysical anomalies identified in this report (black rectangles).

5. Recommendations

The results from these non-intrusive geophysical investigations at the site provide indications of three areas of anomalous responses. These anomalous responses may relate to the objectives of this project. Overall, these three locations are recommended for further investigation, particularly the suspected location of the church foundation and the possible midden pit. Excavation at these locations could clarify the source of the anomalies and confirm or disprove the conclusions drawn from the geophysical data.

6. Figures

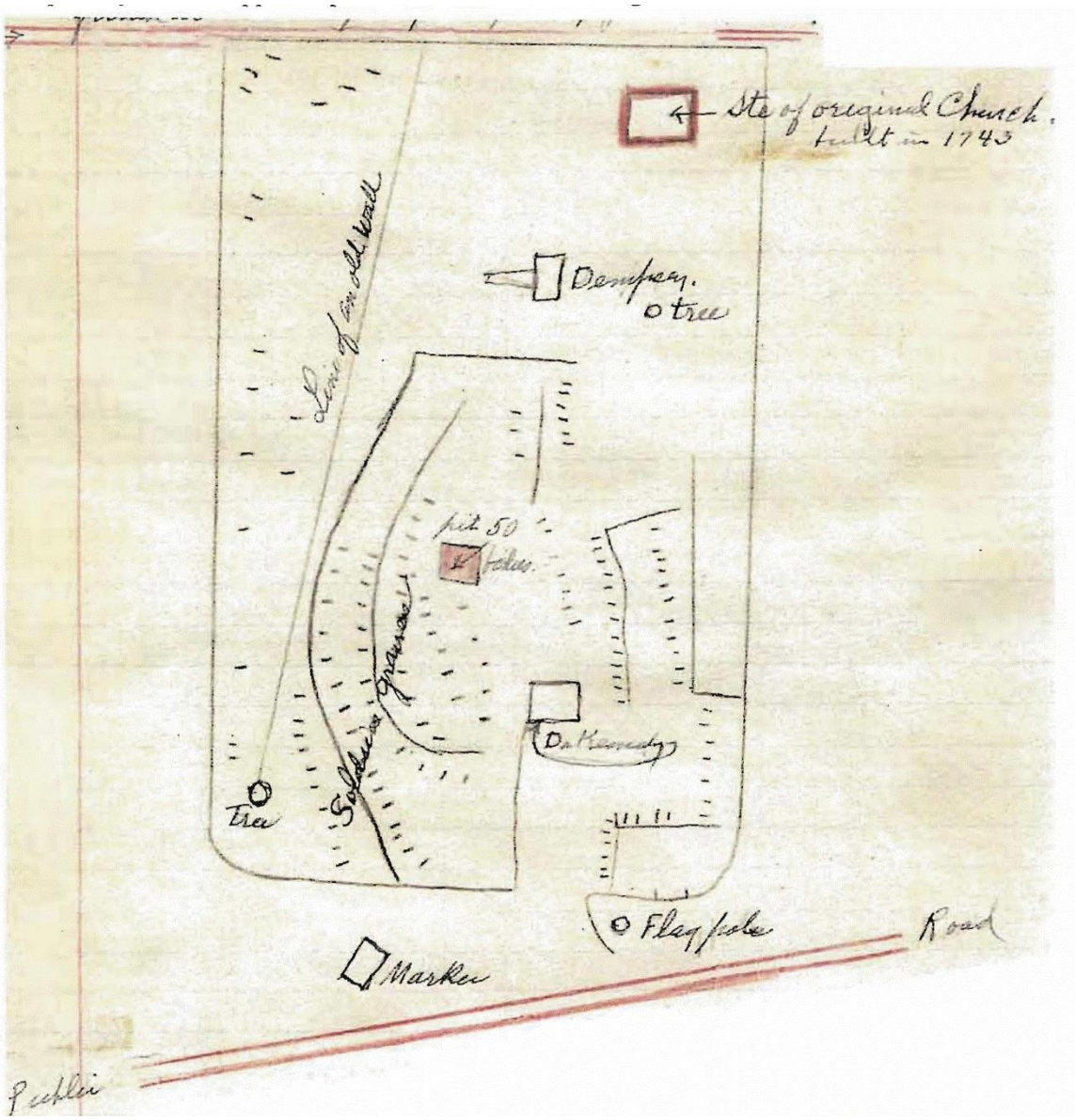

Figure 1: Hand-drawn map recovered from the wall of the Chester Springs Hospital in the 1800s. This map was discovered by the carpenter, Jacob Rapp (b. 1761- d. 1838). Note the location of the pit with 50 bodies in the center of the map and the location of the original church built in 1743.

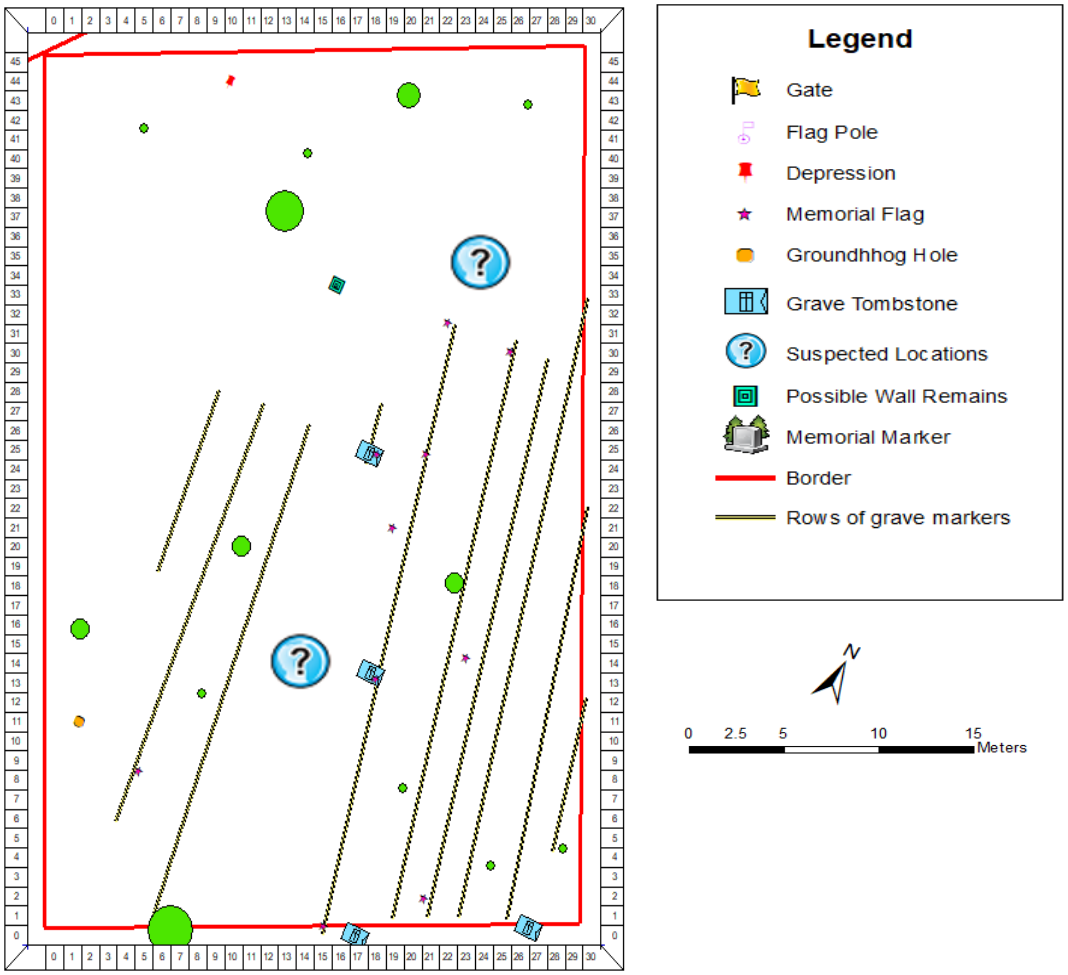

Figure 2: Digitized site map created using GPS coordinates of surface objects at the site. The question marks relate to the objectives of the survey, indicating the expected location of the mass burial (south) and the church foundation (north). The presence and location of the midden pit associated with the church is not marked on the original map (Figure 1) and is therefore uncertain and not indicated on this map.

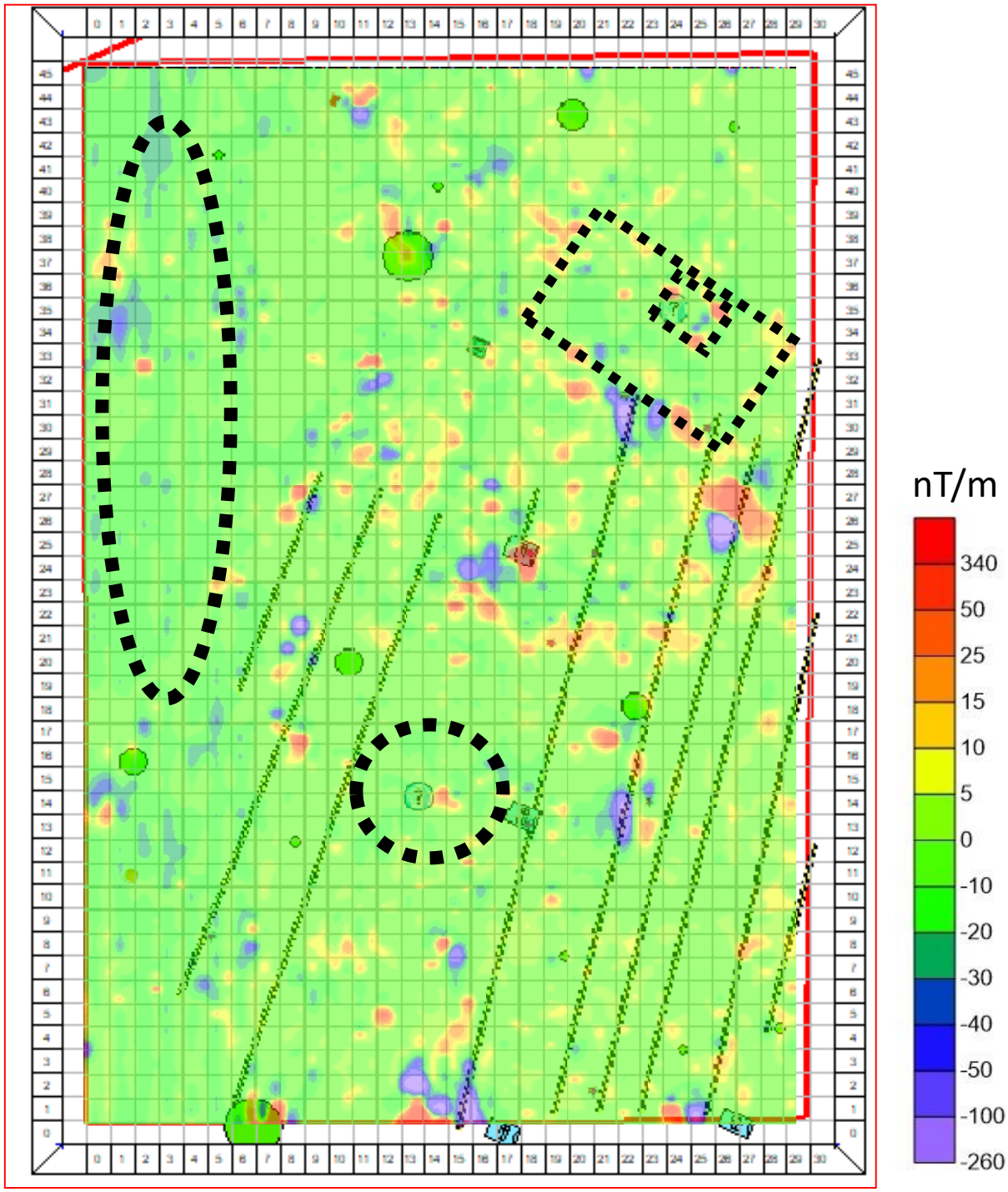

Figure 3: Vertical magnetic gradient of the site overlain on the digitized site map. Areas of interest are highlighted with black dashed lines.

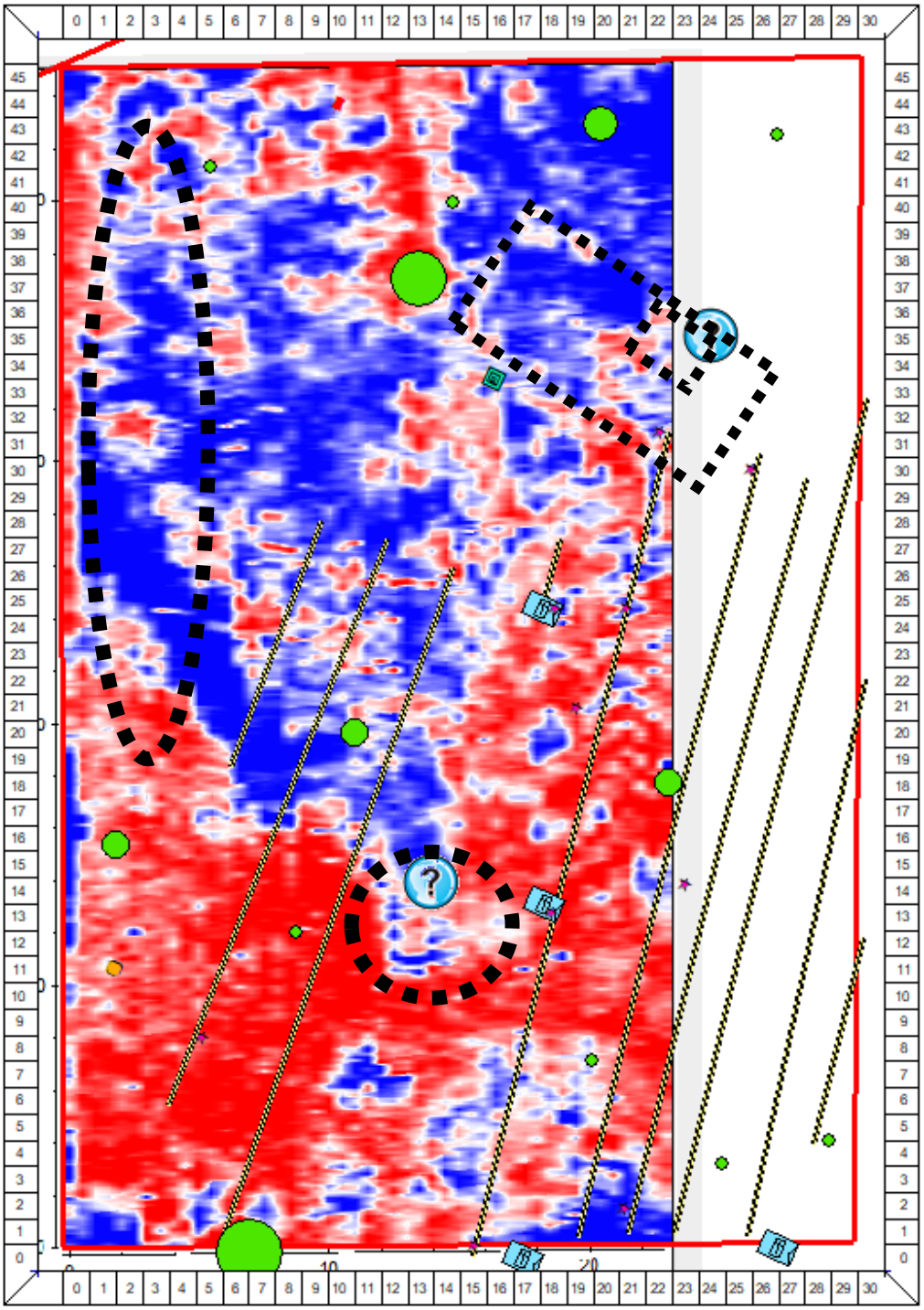

Figure 4: GPR time slice of the site at 2 ns overlain on the digitized site map. Areas of interest are highlighted with black dashed lines.

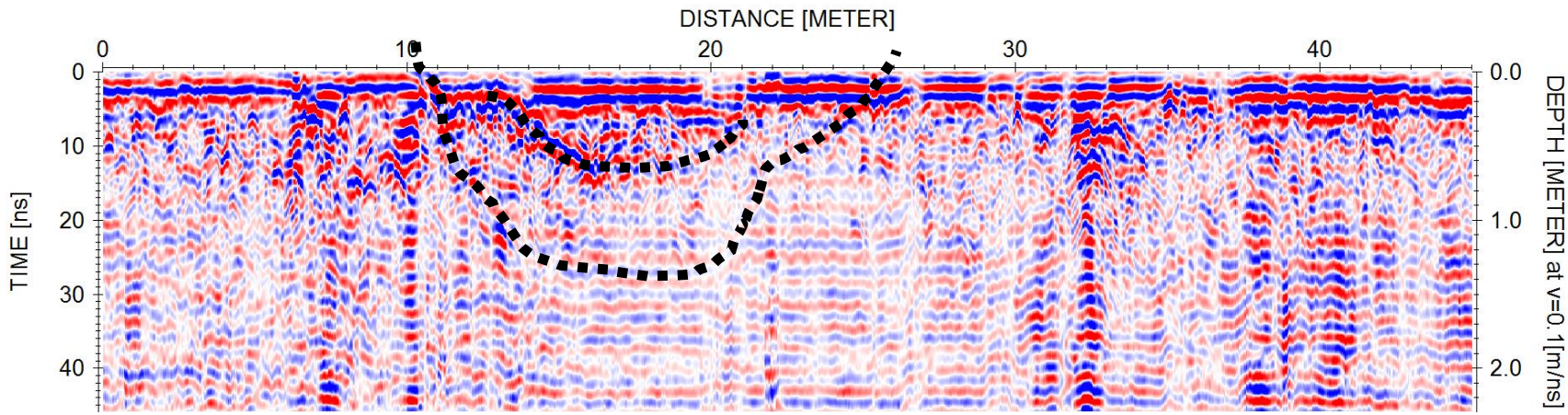

Figure 5: GPR profile of the site at 14 m East depicting the suspected location of the mass burial site with the black dashed lines highlighting a possible boundary of the pit (lower line) and sagging of the surface layers (upper line).

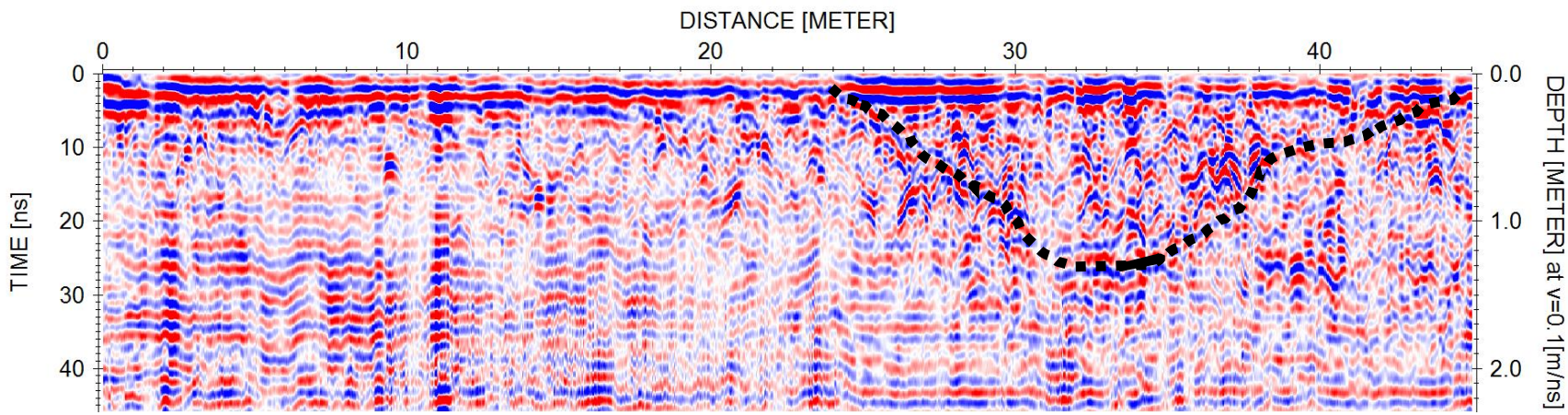

Figure 6: GPR profile of the site at 5 m East depicting the GPR anomaly of unknown source with the black dashed line highlighting a possible boundary of the feature.

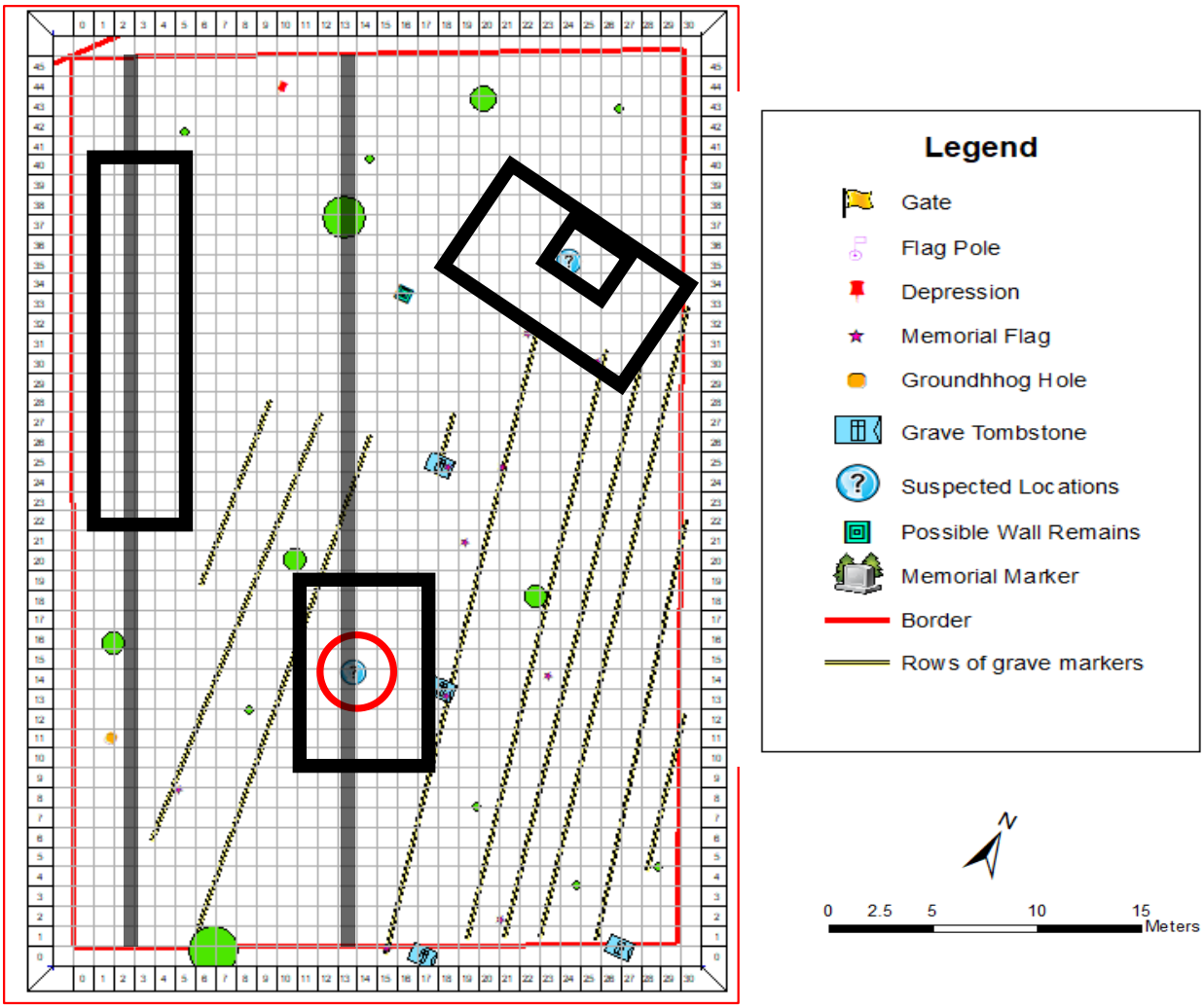

Figure 7: Site map showing the location of the GPR profiles in Figures 5 (eastern gray line) and 6 (western gray line) as well as the boundaries of the suspected mass burial location (central black rectangle), church foundation (northeastern black rectangle), and the anomalous zone of unknown source (northwestern black rectangle).