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Locating Grave Sites Using Geophysics at Walton Cemetery, Picatinny Arsenal, New Jersey

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Contents

Preface

A geophysical investigation consisting of magnetic, electromagnetic, and ground penetrating radar surveys was conducted at Picatinny Arsenal, New Jersey, by personnel of the Geotechnical Laboratory (GL), U.S. Army Engineer Waterways Experiment Station (WES), 6 to 10 May 1994. The investigation was conducted in conjunction with the Environmental Laboratory (EL), WES, for the U.S. Army Armament Resource Development and Engineering Center, Picatinny Arsenal, New Jersey with funds from the Department of Defense Legacy Resource Management Program.

This report was prepared by Dr. Janet E. Simms, Earthquake Engineering and Geosciences Division (EEGD). The work was performed under the direct supervision of Mr. Joseph R. Curro, Jr., Chief, Engineering Geophysics Branch, EEGD. The work was performed under the general supervision of Drs. A. G. Franklin, Chief, EEGD, and William F. Marcuson III, Director, GL. Field work was performed by Drs. Janet E. Simms and Frederick L. Briuer, Environmental Resources Division (EL), and Mr. Bruce W. Bevin, Geosight, New Jersey. The geophysical investigation was conducted in conjunction with archaeological field survey, detailed topographic mapping, and survey grid preparation at the cemetery by archaeologist team members from Historic Conservation and Interpretation Inc., New Jersey under the direction of Mr. Ed Rutsch. Geographic Information System mapping was provided by Dr. Briuer and Gary Hebler (EL) to archaeologist team members and Dr. Simms. Geophysical data analysis was performed by Dr. Simms.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
feet	0.3048	meters
feet per second	0.3048	meters per second
gamma	1.0	nanoTesla
miles (U.S. statute)	1.609347	kilometers
millimho per foot	3.28	millimho per meter
millimho per meter	3.28	milliSiemen per meter

1 Introduction

Background

Picatinny Arsenal is located in Morris County, New Jersey (Figure 1). It was established on September 6, 1880 as the Dover Powder Depot. Four days later, at the request of the First Commander, it was renamed the Picatinny Powder Depot (Envirosphere Company 1986). It underwent one other name change in June 1893, the United States Powder Depot, before receiving its present designation in October 1907. The Arsenal was originally established for storing powder, projectiles, and explosives. In 1907 construction of a smokeless powder factory was initiated and the manufacture of cannon powder began in 1908. In 1911 a school to provide training in the chemistry of explosives, ballistics, and ammunition for manufacturing processes was established. During World War I the role of the Arsenal was expanded to include research on explosive materials. Research and development of explosive materials are the primary mission of Picatinny Arsenal at the present time.

Picatinny Arsenal covers approximately 36,000 acres. Walton Cemetery is located in the southeast section of the Arsenal within the enclosure near Gate 2 (Figure 2). The cemetery was used by the old families which resided in the area and dates back to the late 1700's (W. W. Munsell & Co. 1882). The headstone which marks the grave of John Walton d. 1787, father of Rev. John Walton, is still in place and in good condition. One other headstone is partially intact and some of the inscription is readable, however, the section of the marker where the name was inscribed is missing. Efforts have been made to preserve these headstones by placing plexiglass covers over them. There are many rocks, large and small, scattered over the cemetery. The orientation of some of the stones suggests that they may mark burial sites. In "The History of Morris County, New Jersey" (W. W. Munsell 1882) it is mentioned that many of the graves were marked by "...the rough mountain stone of the locality."

Objectives

At the request of the Environmental Resources Division, U.S. Army Engineer Waterways Experiment Station (WES), under the direction of the

U.S. Army Armament Resource Development and Engineering Center, Picatinny Arsenal, personnel of the WES conducted a geophysical investigation at Walton Cemetery during the period 6 and 10 May 1994. The geophysical survey was conducted in conjunction with archaeological field survey, mapping, and archival research for the Walton burial ground. The location of the majority of the graves is unknown and, for historical reasons and future cultural resource management, it is desired to determine their location. Three geophysical methods, magnetic, electromagnetic, and ground penetrating radar, were used to identify the location of possible burial sites.

2 Geophysical Test Principles and Field Procedures

Geophysical Test Principles

Electromagnetic surveys

The electromagnetic (EM) method is used to measure terrain conductivity. The conductivity of a material is dependent on the degree of water saturation, the types of ions in solution, porosity, the chemical constituents of the soil, and the physical nature of the soil. Due to these factors, conductivity values can range over several orders of magnitude.

The EM system consists of a transmitter and receiver coil separated by a fixed distance. An alternating current, generally in the kilohertz range, is passed through the transmitter coil, thus generating a primary time varying magnetic field. This primary field induces eddy currents in the subsurface conductive materials. These currents are the source of a secondary magnetic field which is detected by the receiver coil along with the primary field. Under a fairly wide range of conditions, the measured component that is ninety degrees out of phase (quadrature component) with the primary field is linearly related to the terrain conductivity (Keller and Frischnecht 1982, Dobrin 1976, Telford et al. 1973). Conductivity is measured in units of millimho per meter (mmho/m) or, in the SI system, milliSiemen per meter (mS/m).

There are two components of the induced magnetic field measured by the EM equipment. The first is the quadrature phase component, sometimes referred to as the out-of-phase or imaginary component, which gives the ground conductivity measurement. Disturbances in the subsurface due to soil removal and fill activities or buried objects may produce conductivity readings different from that of the background values, thus indicating anomalous areas. The second component is the inphase or real component, which is the ratio of the induced secondary magnetic field to the primary magnetic field. The inphase component is primarily used for calibration purposes, however, it is significantly more sensitive to large metallic objects and therefore very useful when looking for buried metal containers (Geonics Limited 1984). The inphase component is measured relative to an arbitrarily set level and assigned units of parts per thousand (ppt).

Geonics EM-31 and EM-38 terrain conductivity meters were used for this investigation. The EM-31 has a transmitter-receiver coil separation of 12 ft and an effective depth of investigation of approximately 20 ft (Geonics Limited 1984). The EM-31 meter reading is a weighted average of the earth's conductivity as a function of depth. A thorough investigation to a depth of 12 ft is usually possible, but below that depth the effect of conductive anomalies becomes more difficult to distinguish. When the EM-31 is carried at a height of approximately 3 ft, it is most sensitive to features at a depth of about 1 ft. Half of the instrument's readings result from features shallower than about 9 ft, and the remaining half from below that depth (Bevan 1983). Carrying the instrument about 3 ft above the ground surface reduces the meter reading by 12 percent, however, the instrument has been calibrated to read correctly when carried at this height (Geonics Limited 1984). For this survey, the EM-31 was carried at hip level, which is approximately 3 ft. The instrument can be operated in both a horizontal and vertical dipole orientation, each having different depths of investigation. The instrument is normally operated with the dipoles vertically oriented (coils oriented horizontally and co-planar) which gives the maximum depth of penetration.

The EM-38 has a shallower depth of investigation than that of the EM-31. The transmitter and receiver coils are spaced one meter apart which gives a maximum depth of investigation of approximately five feet. Data were collected with the instrument at ground level and in vertical dipole mode, which provides the greatest depth of investigation.

Another electromagnetic instrument, the Geonics EM-61, was also used to survey the site. It is used to detect shallow metallic objects and is relatively insensitive to interference from nearby surface metal. Unlike the EM-31 and EM-38, which operate in the frequency domain, the EM-61 operates in the time domain. The principles of EM induction apply to all three instruments, however the manner in which the EM-61 induces the eddy currents is different from that of the EM-31 and EM-38. Instead of applying an alternating current and measuring the secondary magnetic field while the transmitter is transmitting, the EM-61 transmits a steady current for a specified time span and then turns the transmitter off. The constant current generates a steady magnetic field which does not begin to induce eddy currents into the ground until transmitting ceases and the primary magnetic field begins to vary with time. To eliminate effects due to conductive soils, which have a shorter decay rate than those of metals, the secondary magnetic field response is not measured until a few microseconds after the transmitter is turned off. Since the transmitter is off when the signal is being received, the same coil can be used as both the transmitter and receiver.

The EM-61 consists of two horizontal, parallel coils. The coils are one meter square with one positioned 40 cm above the other. Wheels are attached to the lower coil so the instrument can be pulled along the survey line. The lower coil rests approximately 40 cm above the ground. The received signal is measured using both coils, allowing a measurement at two depths of investigation and a differential reading. The measured signal is in units of millivolts (mV). The EM-61 can detect a single 55 gallon drum at a depth of three meters (Geonics Limited 1993).

Ground penetrating radar survey

Ground penetrating radar (GPR) is also an electromagnetic method, but it differs significantly from the induction EM methods described above to warrant a separate discussion. At the lower frequencies (kiloHertz range) where EM induction instruments operate, conduction currents (currents which flow via electrons in a metallic matrix or ions in solution) dominate and energy diffuses into the ground. At the higher frequencies (megaHertz range) which GPR utilizes, displacement currents (currents associated with charges which are constrained from moving any distance) dominate and energy propagates into the ground as a wave.

Ground penetrating radar is used to image the subsurface. This is achieved by transmitting an electromagnetic pulse, which propagates into the earth where it undergoes refraction, reflection, scattering, and dispersion, and measuring the return signal. The frequencies employed in GPR typically range from 1 to 1000 MHz. Contrast in the dielectric permittivity at layer boundaries causes the EM wave to be reflected and refracted. The dielectric permittivity is the proportionality factor relating the displacement current to the energy. Since electromagnetic fields consist of both electric and magnetic fields, any properties of the geologic material which affect either of these fields will also affect the propagation of the EM wave in the subsurface. Generally, the electrical properties of the soil and rock have a greater influence on the EM wave propagation. Soil conductivity is a major factor in determining if GPR can be used successfully at a site. High conductivity soils, such as those with a high clay content, can significantly attenuate the EM signal and render GPR virtually useless.

A Sensors & Software, Inc. pulseEKKO IV system employing 100 Mhz and 200 Mhz antennas was used to collect the GPR data. The survey was performed in reflection mode where the transmitter and receiver antennas are kept a fixed distance apart and both antennas are simultaneously moved along the survey line. The time required for the EM wave to travel through the subsurface and return to the receiver was recorded at each sample station.

Magnetic survey

A magnetic survey measures changes in the earth's total magnetic field due to variations in the magnetic mineral content of near surface rocks and soils or iron objects. These anomalies are generally local in extent. Magnetic anomalies are due in part to induction by the magnetizing field and to remanent magnetization (Parasnis 1986). Remanent magnetization is permanent magnetization and depends on the thermal and magnetic history of the body; it is independent of the field in which it is measured (Breiner 1973). Induced magnetization is temporary magnetization that disappears if the material is removed from the inducing field. Generally, the induced magnetization is parallel with and proportional to the inducing field (Barrows and Rocchio 1990).

The general operating theory of a magnetometer involves the generation of an external magnetic field by applying a sinusoidal current to a fluid-filled sensor (either liquid or gas). The applied magnetic field excites the atomic particles (protons or electrons) within the fluid causing them to precess about the axis of the resultant field (between that of the external magnetic field and earth magnetic field). The frequency at which the atomic particles precess is proportional to the strength of the local magnetic field. The sensor on the magnetometer used in this study contains a cesium fluid. A sinusoidal current at the Larmor frequency is applied to the fluid which excites the electrons in the cesium atom to a higher energy level. The local magnetic field strength can be determined from the precession frequency of the electrons. For a more detailed explanation of the operating theory of a cesium magnetometer, refer to Telford et al. (1976).

An EG&G Geometrics G-822L cesium magnetometer was used to survey the site. This magnetometer is equipped with one sensor carried at the end of a wand. It can be operated in sweep mode or the survey data can be collected and stored on a peripheral laptop computer. Sweep mode is ideal for reconnaissance operations, allowing the operator to cover a large area in a relatively short period of time. For this survey, data were collected at stations along the survey lines and stored on a field computer for later analysis.

The magnetometer has both a digital display and an audio indicator. The frequency of the audio tone is dependent on the strength of the measured magnetic response; as the magnetic anomaly increases, the frequency increases thus producing a higher pitched tone. The G-822L magnetometer measures the total magnetic field and has a sensitivity of 0.1 nanoTesla. The sensor was carried approximately six inches above the ground so that small, shallow, ferrous objects, such as nails, that may be relevant to the archaeological history of the site would produce a measurable anomaly.

Field Methods

A grid flagged at five foot spacings was prepared by archaeologist members of the research team prior to conducting the geophysical investigations. EM-31 readings were taken at 5 ft intervals along the grid and the EM-38 data were collected at 2.5 ft spacings. The EM-31 and EM-38 data were collected in both the quadrature (conductivity) and inphase mode. EM-61 data were collected on a 2.5 ft station spacing along survey lines spaced 5 ft apart. A data logger connected to each instrument was used to store the data during the surveys and, at the conclusion of each survey, the data were transferred to a field computer for later plotting.

The magnetic data were collected at 2.5 ft intervals along survey lines spaced 5 ft apart.

The GPR data were collected along north-south survey lines between 72.5 east and 262.5 east at five foot intervals using the 100 MHz antennas. Four east-west survey lines were profiled with the 200 MHz antennas. Selected sections of the grid were profiled using both antennas over the location of known burial sites. The 100 MHz transmitter and receiver antennas were separated by two feet and oriented normal to the survey direction. Both antennas were simultaneously moved at one foot increments and a measurement taken. A one foot antenna separation was used with the 200 MHz antennas while they were moved at 0.25 ft and 0.5 ft intervals. The data were recorded on a field computer for later processing.

3 Geophysical Results and Interpretation

The location of the site is shown in Figure 2. The cemetery is enclosed by a three feet high rusted wire and metal post fence. The ground surface is cluttered with both small and large rocks, the largest being about six feet in diameter. There are four main rock types observed: granite, quartzite, gneiss, and conglomerate. The granitic rocks tend to have a strong magnetic component. Some rocks are oriented vertically and may indicate the location of burial sites. Figure 3 shows the location of possible grave sites, rocks, trees, and other significant surface features as mapped by archaeologist members of the research team. Note the high density of rocks. A possible grave site was determined based on the orientation of a rock. If a rock resembled the shape of a headstone and looked as if it had been placed in a vertical position, then it was considered a possible grave site. The cluster of headstones located at (87E, 197N) in Figure 3 are actually broken pieces of the headstone that mark the grave of John Walton. The headstones at (107E, 195N) and (107E, 198N) are also known graves.

The EM-31, EM-38, EM-61, and magnetic data are presented as contour plots. Anomalies are identified as areas that differ significantly in value from the average or background value. On contour plots, anomalies are indicated by a concentration of contour lines and, on color plots, by the 'hot' (violet) and 'cold' (blues) colors. The violet colors indicate high anomalous values whereas the blues indicate low anomalous values. Anomaly detection is dependent not only on the type and size of material buried and the depth of burial, but also on the contrast between the soil and buried material.

The GPR data are presented as travel time versus distance along survey line.

A plot of the EM-31 conductivity data is given in Figure 4. The anomaly high along the perimeter of the cemetery is due to the wire fence. The conductivity data show very little variation, with a slight increase from west to east.

The EM-31 inphase data (Figure 5), which identifies metallic objects, does not indicate anomalous areas within the cemetery boundaries. The only anomalous response is that due to the surrounding metal fence.

The conductivity data obtained using the EM-38 (shallow investigation) are presented in Figure 6. Several small anomaly highs are present. The largest is located between (82E-90E, 192N-208N). The known grave of John Walton is located within this area and is covered with plexiglass with metal hardware. The other small anomalies are located at (122E, 178N), (184E, 136N), (206E, 184N), and (208E, 138N). The anomaly at (184E, 136N) is within a depression.

The EM-38 inphase data show many small anomaly highs scattered across the site (Figure 7). One set of anomalies forms a linear trend from (170E, 128N) to (164E, 212N).

Figure 8 is a contour plot of the EM-61 data. Three small anomaly highs are seen, two of which are associated with the location of two know graves that are covered with plexiglass ((86E, 196N) and (106E, 198N)). The third anomaly is at (186E, 140N).

Several small anomaly highs are present in the magnetometer data (Figure 9). It is possible that some of the anomalies may be due to rocks that are located on the surface or in the shallow subsurface which have a strong magnetic component. A cluster of anomalies is located in the northeast corner of the grid between (210E-245E, 175N-205N). Only a few rocks are observed on the surface at this location (see Figure 3). Other small anomalies are located at (80E, 145N), (80E, 163N), (115E, 145N), (122E, 155N), (122E, 173N), (127E, 190N), (148E, 148N), (148E, 163N), (164E, 148N), and (164E, 163N). Figure 10 is a combined plot of the magnetic anomalies, possible headstones, and rocks. There does not appear to be any correlation between the magnetic anomalies and possible headstones. There are rocks present where several of the magnetic anomalies exist, however it cannot be positively determined if the anomaly is due to the rock without knowing the type of rock.

The ground penetrating radar data reveal three subsurface reflectors (Figure 11). The first (A) is a strong, continuous reflector at an average depth of 2 ft. The other two reflectors range in depth from 5-6 ft (B) and 7-9 ft (C); they are discontinuous with an irregular surface. The rocky nature of the shallow subsurface makes identification of a grave difficult. Figure 12 shows a GPR anomaly that may identify a grave site. Each radar record was studied to distinguish reflections due to possible graves from those which appear to be reflections from rocks. The distinction was made based on the width of the hyperbolic reflection and anomaly depth. A grave would cause a wider hyperbolic reflection than smaller rocks and, because of the rocky soil, it is suspected that the graves may be shallower than normal, ranging from 3 to 7 ft. Figure 13 is a plot of possible burial site locations determined from the GPR data. A few GPR anomalies correspond to suspected grave sites but the majority do not.

4 Conclusions

A geophysical investigation to determine the location of unmarked graves was conducted at Walton Cemetery located on Picatinny Arsenal, New Jersey. The rocky nature of the soil made the identification of possible burial sites difficult. Archaeologists identified some possible graves based on the vertical orientation of local rocks, suggesting the rocks were purposely placed. The results of the geophysical surveys performed cannot confirm the location of these possible graves. Figure 14 shows the location of possible burials and the anomalies detected using the various geophysical methods. There is not a strong correlation between the anomalies and possible graves; only a few of the possible graves are associated with a geophysical anomaly. Some of the magnetic anomalies may be due to the presence of granitic rock, which has a relatively high magnetic response. The abundance of rocks in the subsurface made it difficult to determine if a GPR anomaly was due to the presence of a grave.

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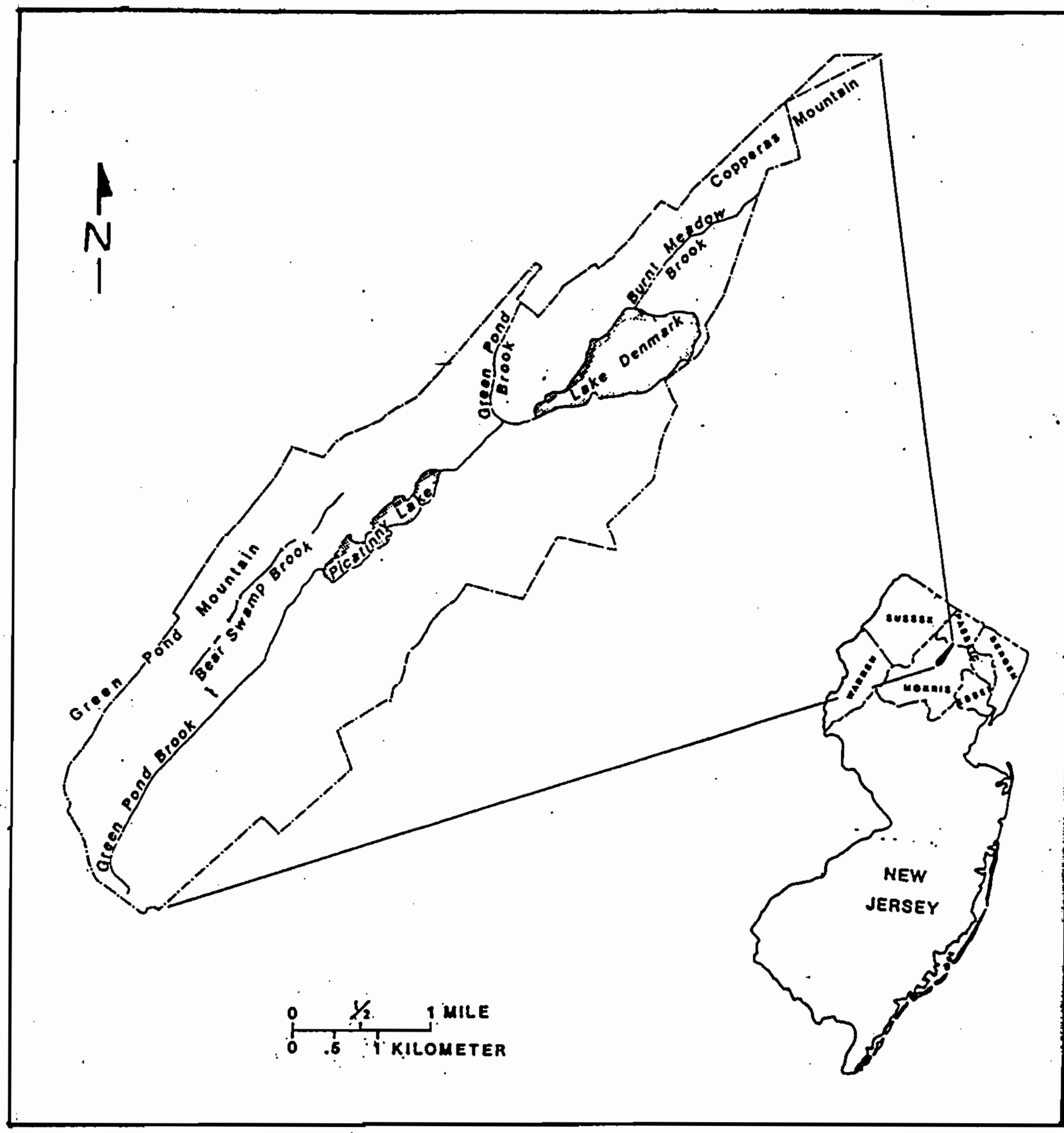

Figure 1. General location of Picatinny Arsenal

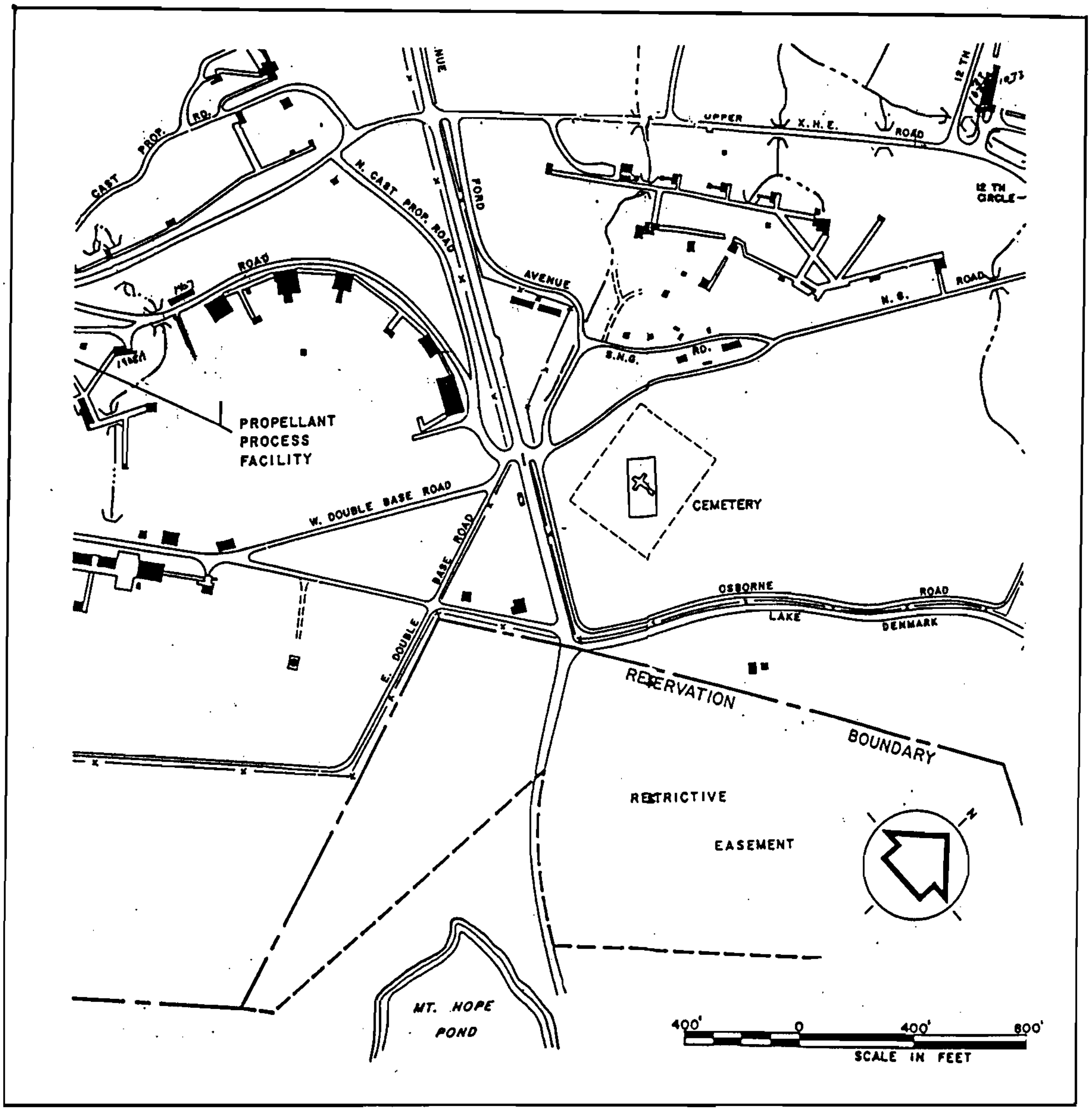

Figure 2. Location of Walton Cemetery

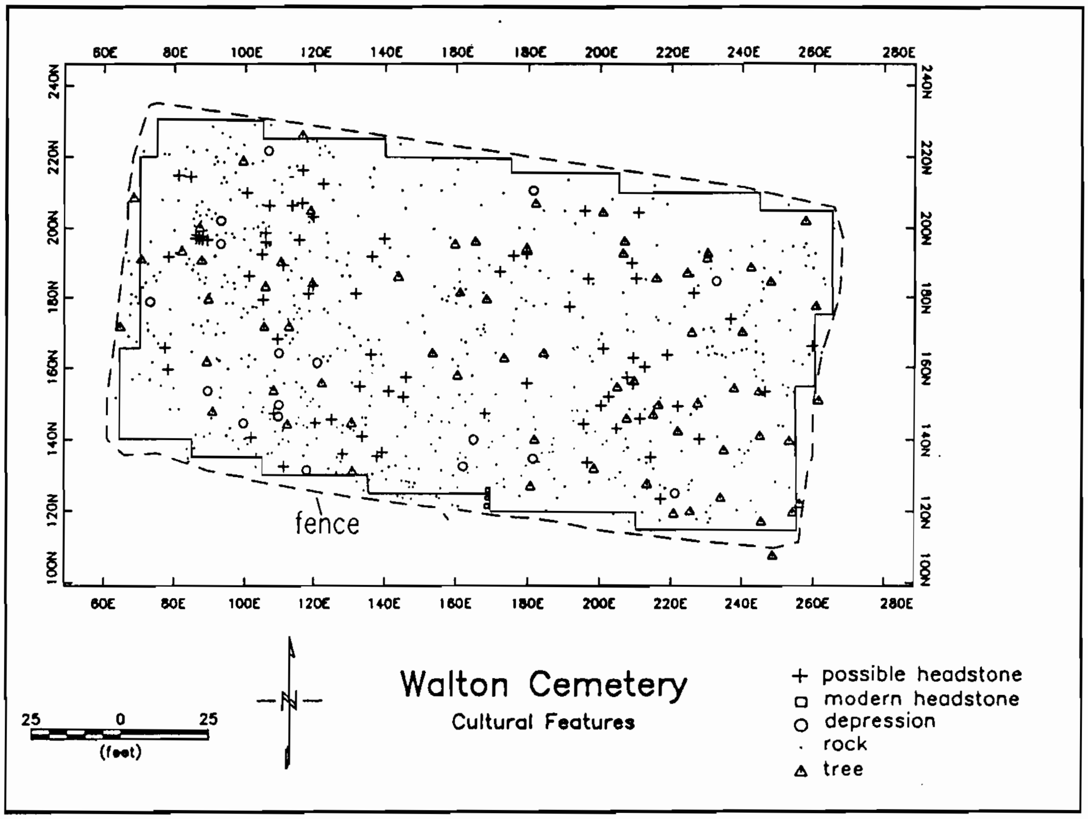

Figure 3. Location of significant surface features at Walton Cemetery

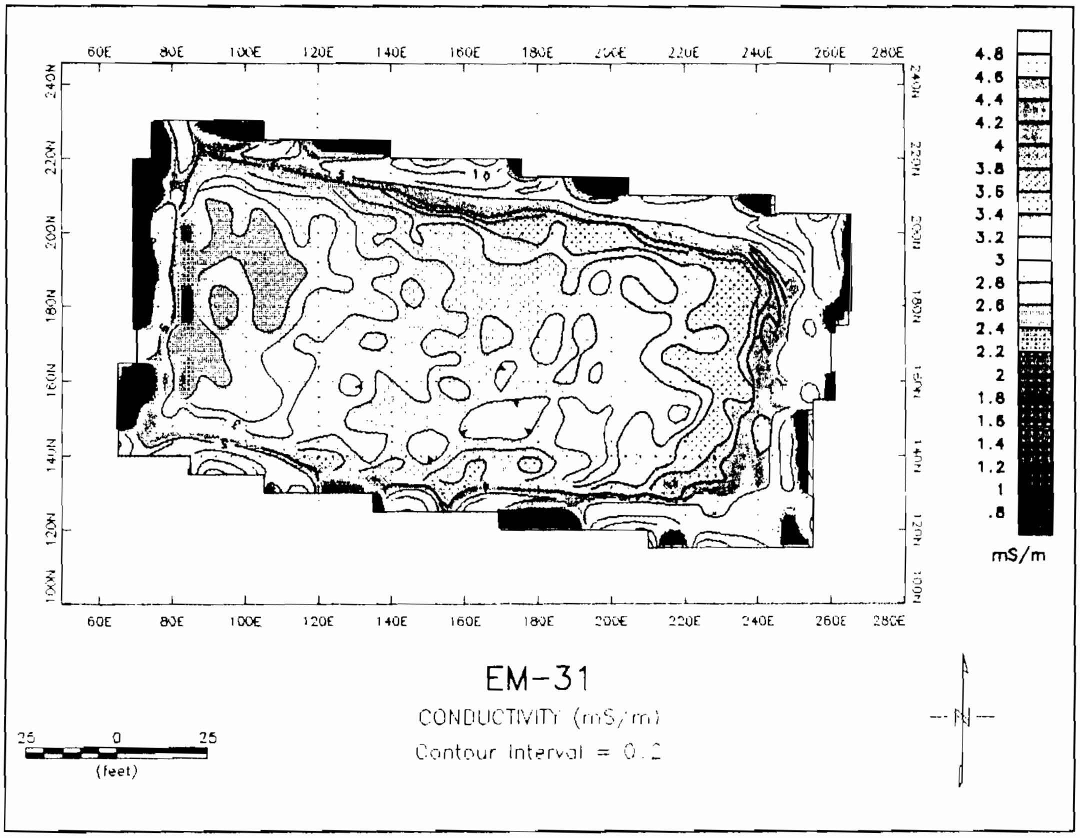

Figure 4. Results of EM-31 conductivity survey

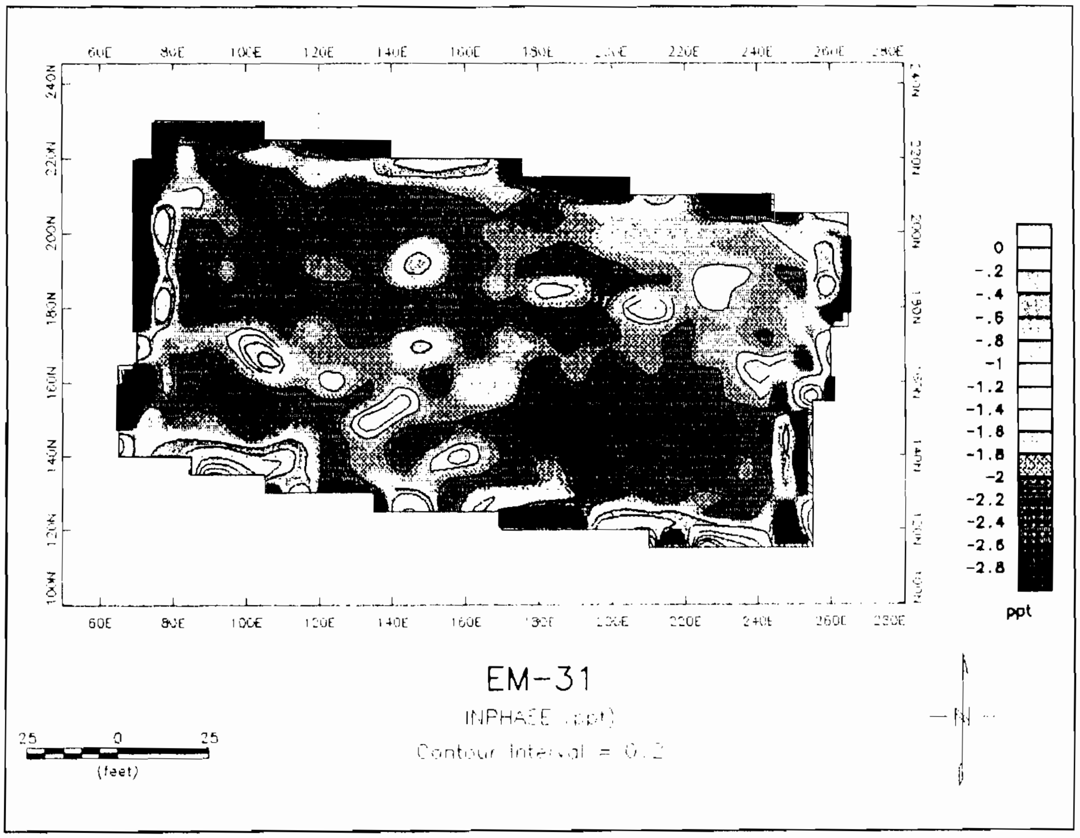

Figure 5. Results of EM-31 inphase survey

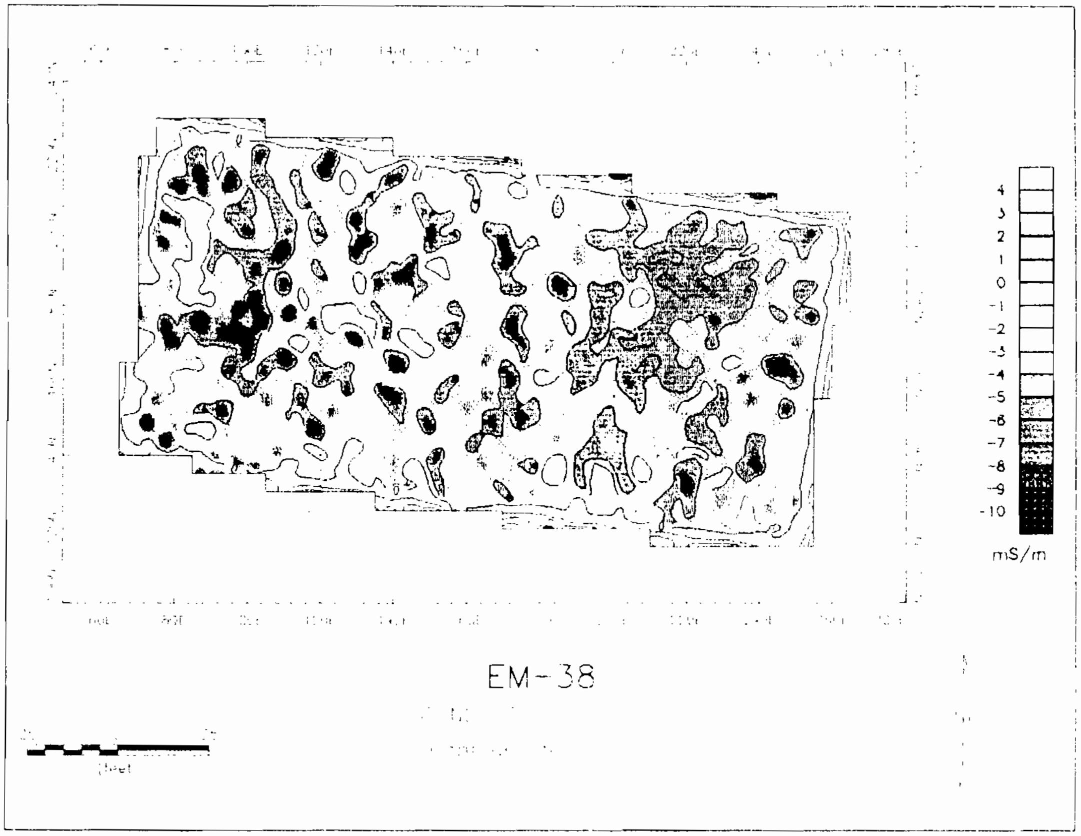

Figure 6. Results of EM-38 conductivity survey

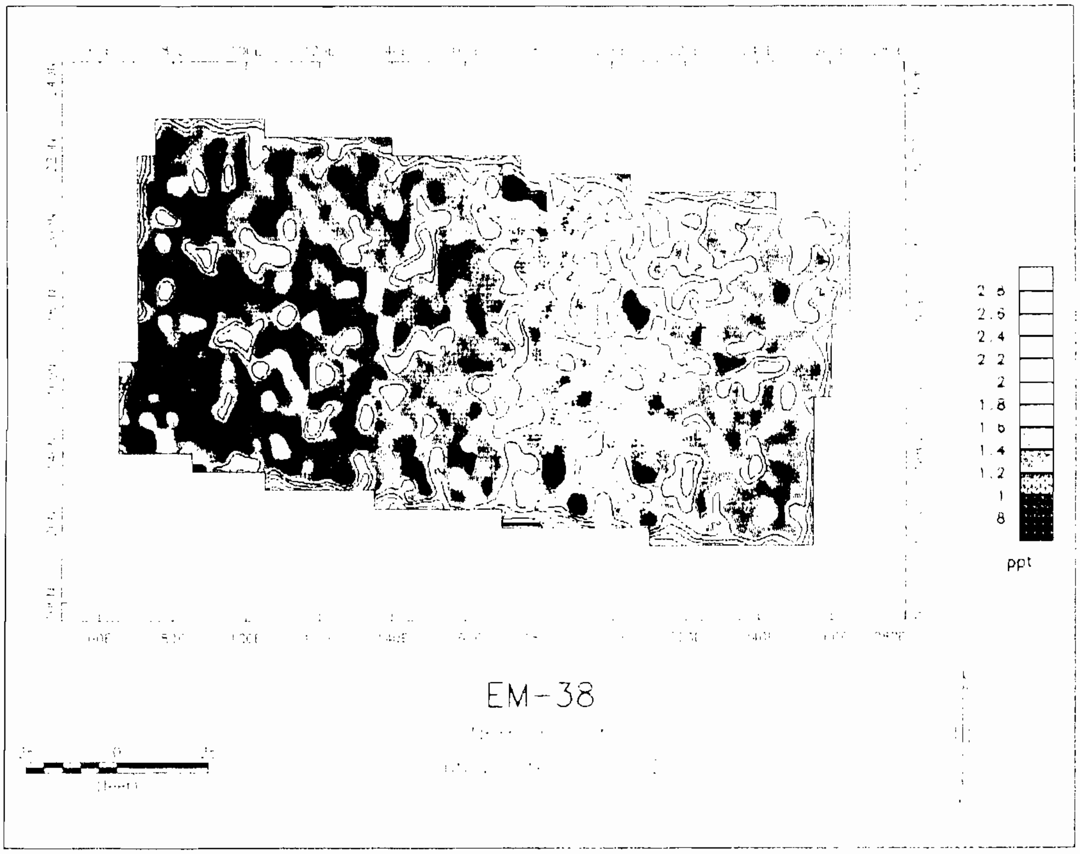

Figure 7. Results of EM-38 inphase survey

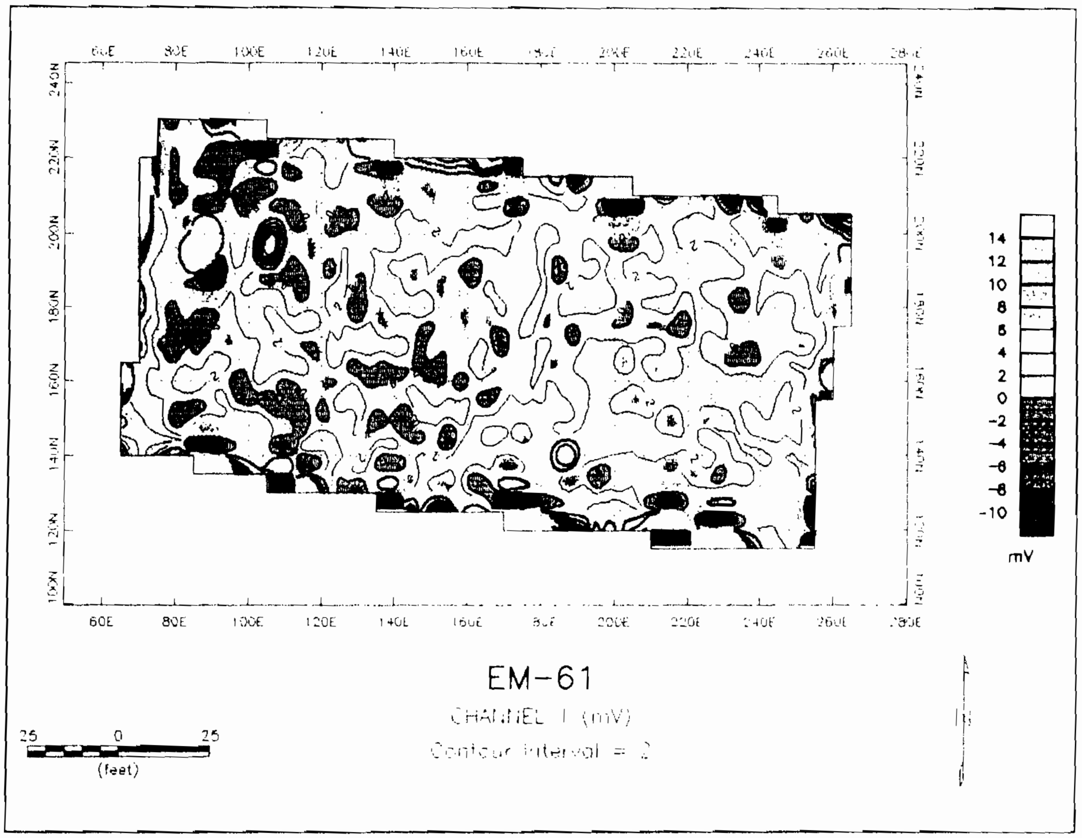

Figure 8. Results of EM-61 survey

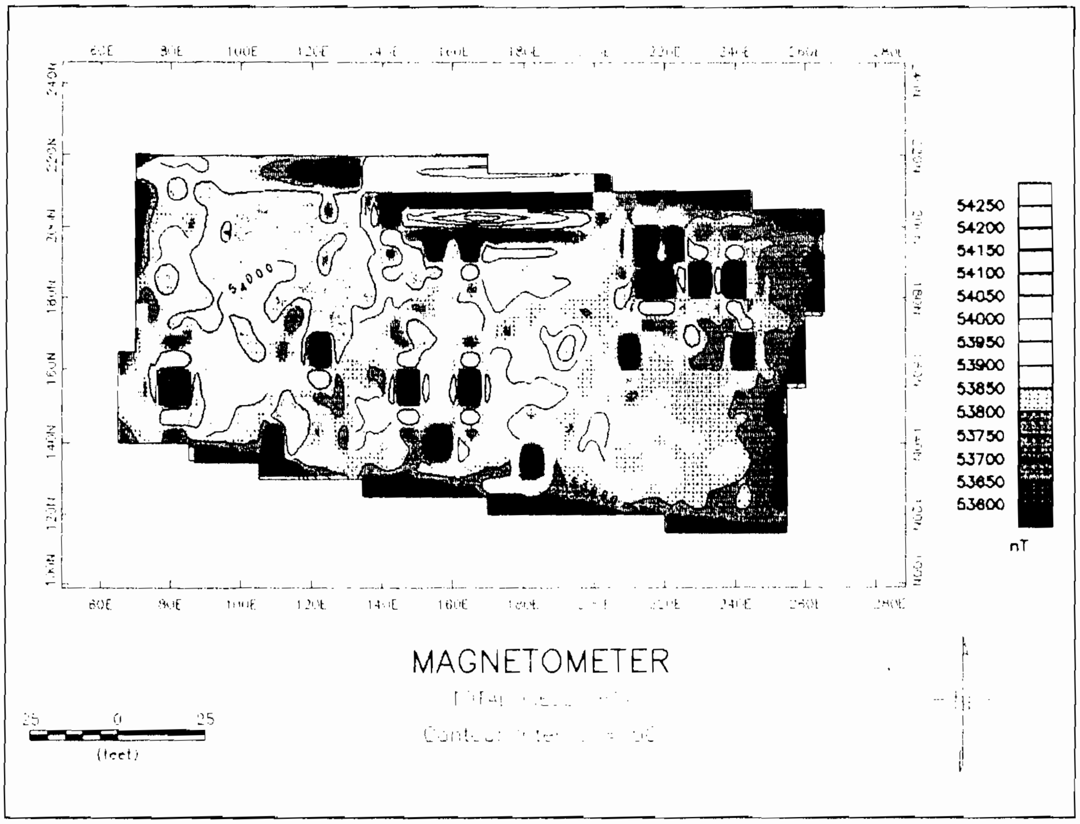

Figure 9. Results of magnetic total field survey

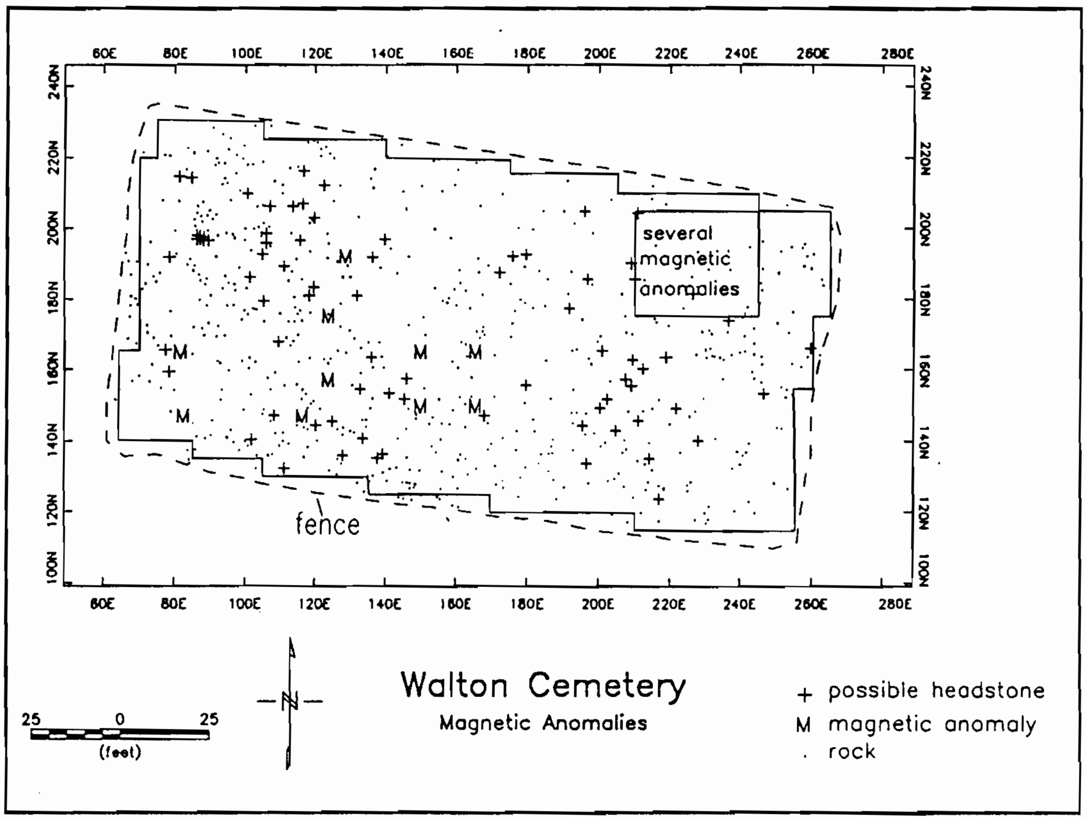

Figure 10. Location of significant magnetic anomalies

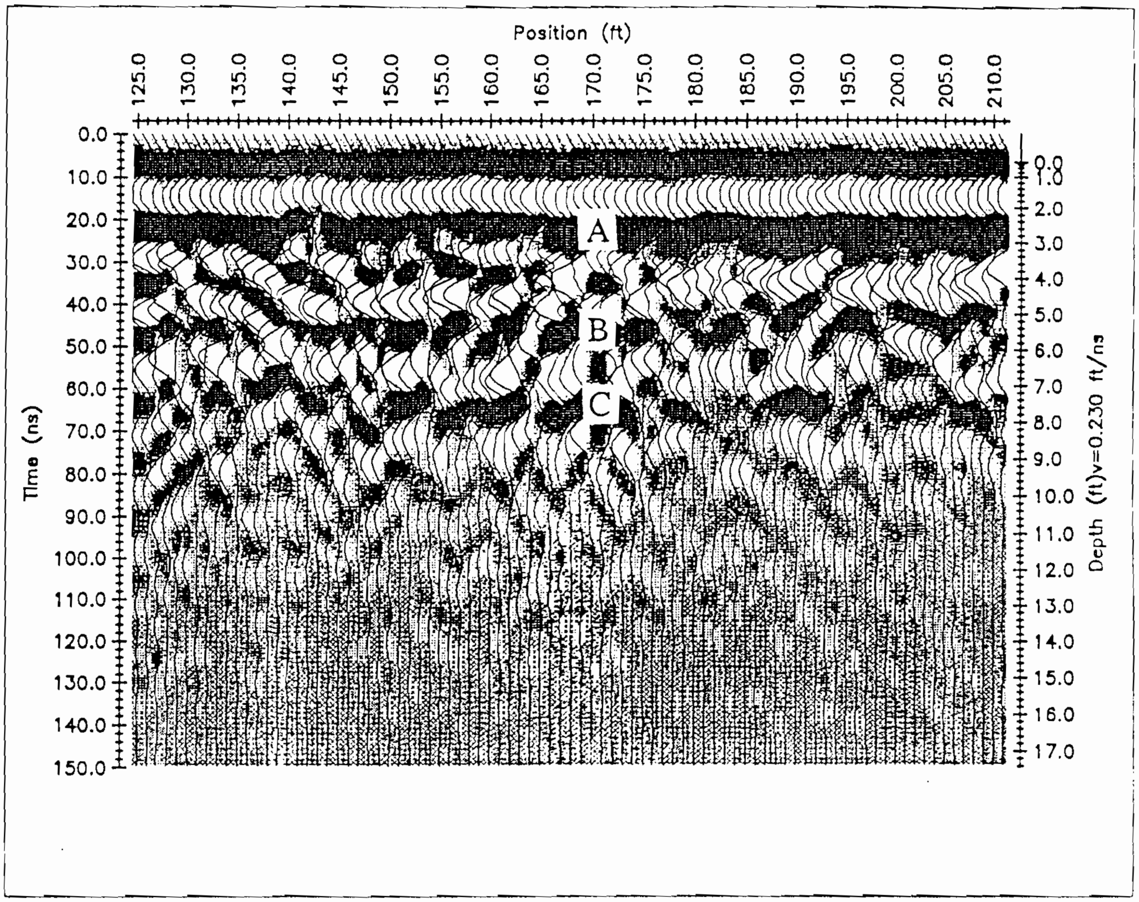

Figure 11. GPR profile showing three subsurface reflectors

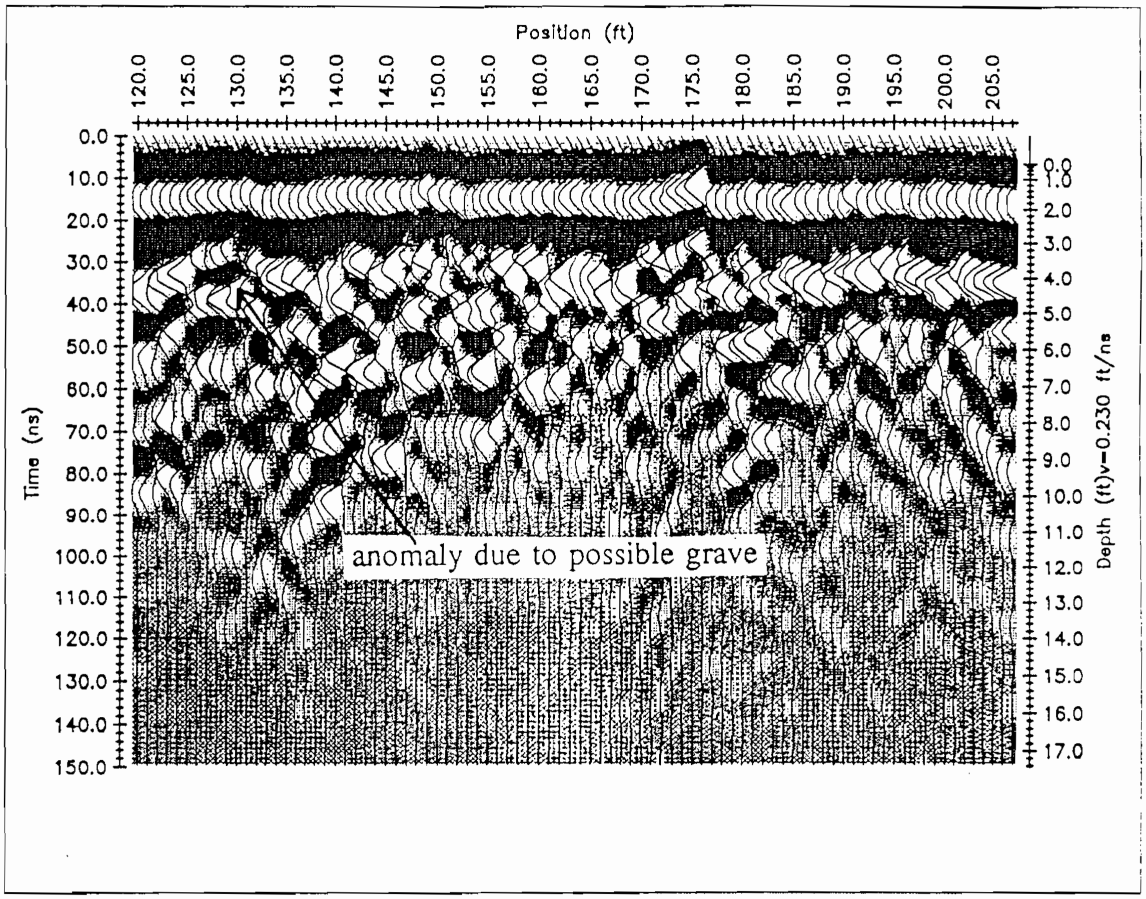

Figure 12. GPR profile showing reflection from possible grave

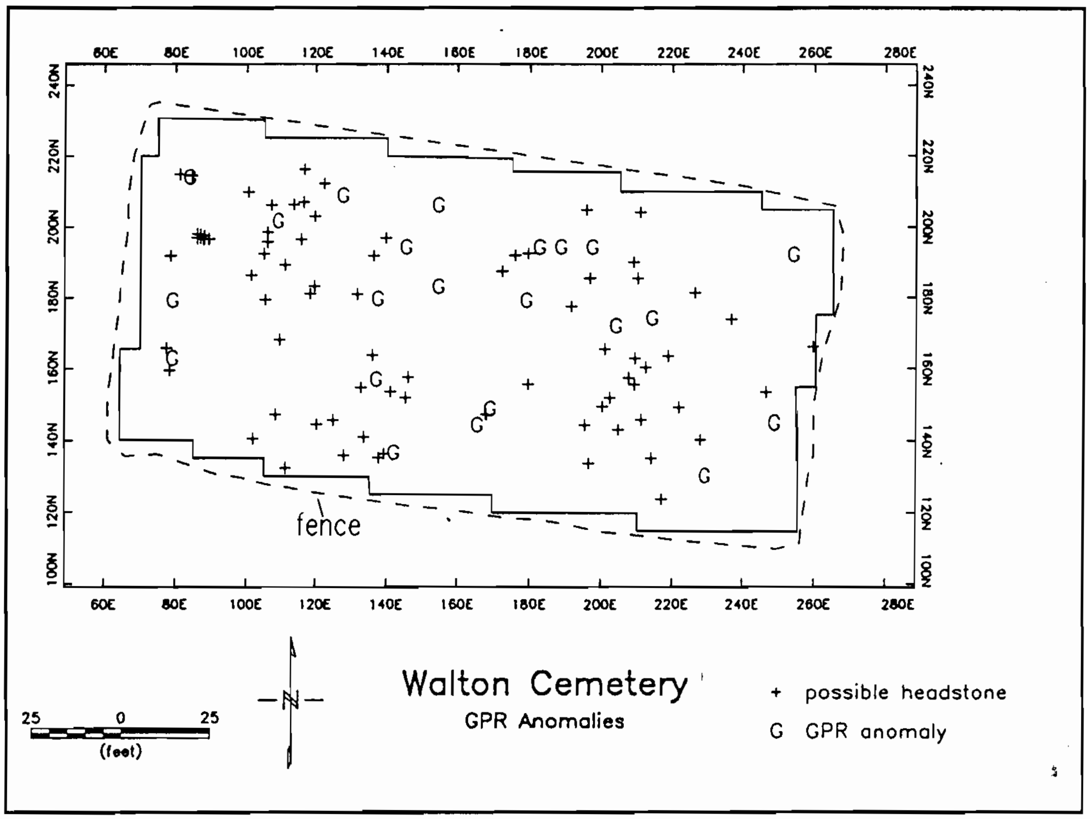

Figure 13. Location of significant GPR anomalies

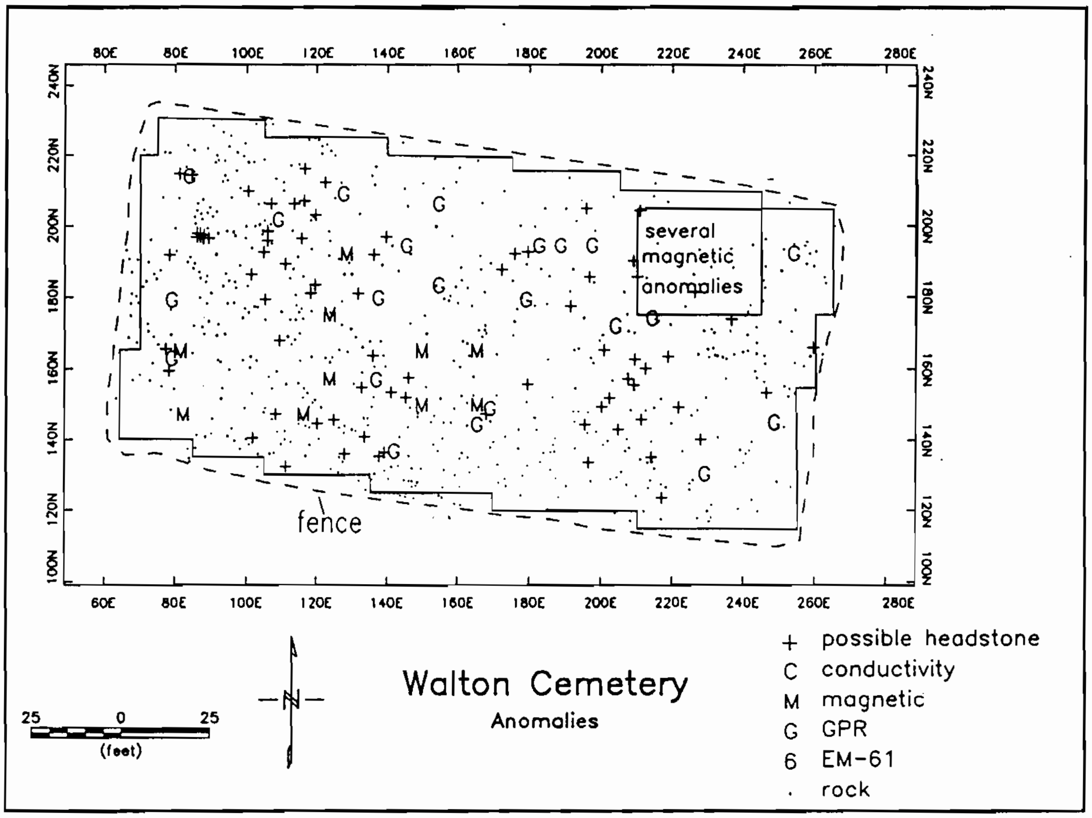

Figure 14. Location of all significant anomalies using the various geophysical methods