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Ground Penetrating Radar Use in Three Contrasting Soil Textures in Southern Ontario

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Ground penetrating radar use in three contrasting soil textures in southern Ontario

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Abstract

Ground penetrating radar (GPR) is a non-invasive, geophysical tool which can be used for the identification of clandestine graves. GPR operates by detecting density differences in soil by the transmission of high frequency electromagnetic (EM) waves from an antenna. Domestic pig (*Sus domesticus*) carcasses were clothed in 100% cotton t-shirts and 50% cotton/50% polyester briefs, and buried at a consistent depth at three field sites of contrasting soil texture (silty clay loam, fine sand and fine sandy loam) in southern Ontario. GPR was used to detect and monitor the graves for a period of 14 months post burial. Analysis of collected data revealed that GPR had applicability in the identification of clandestine graves in silty clay loam and fine sandy loam soils, but was not suitable for detection in the fine sandy soil studied. The results of this research have applicability within forensic investigations involving decomposing remains by aiding in the location of clandestine graves in loam soils in southern Ontario through the use of GPR.

Key Words: geoforensics, ground penetrating radar, soil texture, buried remains

The ability to identify the location of a clandestine grave is of importance to forensic investigators in order to identify the victim and further advance the criminal investigation. Traditional methods of locating a clandestine grave site include observations of foliage, soil changes, and determination of soil conductivity, temperature and pH (Rodriguez & Bass, 1985; Ruffell et al., 2009). Immediate changes in the foliage over a freshly dug grave may be evident, as the disturbance of the soil reduces plant growth (Rodriguez & Bass, 1985). However, an older grave of approximately one year or more may have an increased amount of foliage on the grave and in the surrounding area due to the organic nutrients that are released from a decomposing body into the soil (Rodriguez & Bass, 1985). Soil sinking or compaction as decomposition proceeds, such as when the chest cavity collapses, can also be apparent. Traditional methods used to locate a grave are presumptive and cannot determine with certainty if a body is located at that site.

One method of locating buried anomalies is through the use of ground penetrating radar (GPR). GPR is a non-invasive, geophysical tool that can be used for the location of unexploded ordnance, buried utility lines, landfill debris, mineral resources and artefacts at prehistoric sites (Miller, 1996; Neubauer, 2001; Rodriguez & Bass, 1985). Law enforcement search teams and military organizations have used GPR to search for buried organic remains (Miller, 1996; Ruffell, 2005; Ruffell & McKinley, 2008; Ruffell et al., 2009). GPR is increasingly used in the search for forensic evidence because of its non-destructive nature and because it can be used in combination with other non-invasive methods to locate areas for further testing (Schultz et al., 2006). Other methods used for locating clandestine graves and human remains include; magnetometry, electrical resistivity, probing, cadaver dogs and geochemical sampling (Buck, 2003; Nobes, 2000; Owsley, 1995; Ruffell et al., 2009; Schultz et al., 2006).

The underlying physics of GPR involves the transmission and reflection of high-frequency electromagnetic (EM) waves into the ground from an antenna, and reflection back to the surface and detection by the receiving antenna (Ruffell, 2005; Ruffell & McKinley, 2008; Ruffell et al., 2009). The antenna transmits the EM waves, which are reflected when changes in the electrical properties of the ground are detected, such as the difference between buried human remains and the surrounding soil texture (Davis et al., 2000). The electrical properties of soils will vary depending on the amount of moisture held by soil particles. For example, sands typically have a low electrical conductivity, while silts and clays have medium and high electrical conductivities, respectively. The electrical conductivity of a soil correlates strongly to its particle size and texture (Grisso et al., 2009).

Common GPR models use antennae of 300, 500 or 900 Megahertz (MHz) centre frequency (Davis et al., 2000; Miller, 1996; Schultz et al., 2006). A short pulse antenna (900 MHz) is effective with near-surface targets ($\leq$ 0.5 m), such as buried ordnance (Miller, 1996). A 500 MHz antenna is useful for depth investigations of 0.5 m to 3.5 m, which includes most of the items of interest in a forensic investigation (Miller, 1996). A long pulse antenna (300 MHz) is effective for sub-surface imaging of depths greater than 3.5 m and up to 9.0 m, such as water-tables (Davis et al., 2000; Miller, 1996). Overall, a decrease in antenna frequency will increase the depth of investigation, while decreasing the vertical resolution of the subsurface (Schultz et al., 2006). Alternatively, an increase in antenna frequency will decrease the depth of investigation, while increasing the resolution of subsurface objects (Schultz et al., 2006). An antenna in the frequency range of 500 MHz is ideally suited to forensic investigations, as it provides a suitable compromise between depth of penetration and resolution of subsurface features.

Controlled forensic studies using GPR provide training for operators and determination of soil properties and environmental conditions that are applicable to the use of the radar and detection of burial location. Operator experience can be a limiting factor of GPR use in a forensic setting, and therefore, research conducted in a known setting is necessary to interpret the data collected during a criminal investigation (Schultz et al., 2006). Experienced GPR operators may overlook a body when conducting a survey if transects are not collected over a grid or line pattern that utilizes appropriate spacing (Schultz et al., 2006). Davis et al. (2000) and Neubauer (2001) suggest applying archaeological GPR parameters to forensic cases by using transects separated by 0.5 m or less. The use of control graves, which consist of only disturbed backfill, are also important to demonstrate that hyperbolic anomalies are primarily the result of a decomposing cadaver.

Ground penetrating radar has proven useful in the search for historic burial grounds. Ruffell et al. (2009) used GPR for the location and assessment of an unmarked, historic burial ground in north-west Ireland believed to contain decedents of the Great Famine of 1845-1851. Soils in the area comprised post-glacial sands, glacial till and Carboniferous sandstones (Ruffell et al., 2009). Prior to GPR use, 84 possible burials were located based upon historical records, aerial photographs and landscape interpretation (Ruffell et al., 2009). The target area (area of suspected burials) was analyzed using GPR with three different antenna frequencies; 100, 200 and 400 MHz (Ruffell et al., 2009). After data interpretation, it was determined that the 400 MHz antenna centre frequency was the most appropriate antenna to use, as the location of over 300 possible burials were obtained using this antenna. In contrast, the 100 MHz antenna gave only an indication of some possible burials, whereas the 200 MHz antenna detected 210 possible burials (Ruffell et al., 2009).

Soil properties and environmental conditions can enhance, limit, or impair GPR performance. Research has shown that GPR yields reliable results in sandy soils (typically low moisture and conductivity) (Schultz et al., 2006), permafrost (Davis et al., 2000), glaciers and concrete/pavement (Ruffell et al., 2009). The use of GPR is often difficult in clay soils (high moisture and conductivity) (Schultz, 2008; Schultz et al., 2006) and after periods of heavy rain (Ruffell et al., 2009). Clays demonstrate a high adsorptive capacity for water and exchangeable cations causing high attenuation losses. As a result, the penetration depth of GPR in clay soils is restricted, often penetrating less than 1 metre in wet clays (Doolittle et al., 2007).

Schultz et al. (2006) found that pig carcasses buried in sandy soils could be detected using GPR for 21.5 months, while exhibiting variable decomposition stages, including complete skeletonization. However there was a weak contrast between the skeleton and the surrounding soil (Schultz et al., 2006). Difficulties imaging the carcasses during the later stages of decomposition were experienced in clay soils. During the first six months of burial, the graves and carcasses were generally detectable (Schultz et al., 2006). However, as the disturbed ground became more compact over the duration of the study, the response became increasingly difficult to interpret, even though the carcasses had undergone little decomposition (Schultz et al., 2006). Despite the fact that carcasses buried in clay were difficult to detect, Schultz et al. (2006) found that it was possible to image disruptions or breaks in the clay horizon that were the result of soil disturbance from the presence of the grave and carcass. However, detecting clandestine graves based solely on soil features may not be possible, as the response from the disturbed soil of the grave will be reduced over time (Schultz et al., 2006).

A more recent study in sandy loam soil (Pringle et al., 2012) demonstrated that a wrapped or clothed victim in a shallow burial can be located using medium dominant frequency (110-450 MHz) GPR antennae because the wrapping produces a good reflective contrast. An unclothed "naked" victim could also be located initially but after 18 months burial, the remains attenuated a large proportion of the signal making it difficult to locate the clandestine graves using GPR. Resistivity surveys were recommended for clay-rich soils due to the possibility of a highly-conductive leachate being retained in the soil from the decomposing body and the poor penetration depths typically experienced by GPR in these soil types. However, GPR was recommended over resistivity surveys in the sandy loam soil due to its ease of data processing.

The applicability of GPR to forensic investigations involving homicide victims buried in clandestine graves has been demonstrated by controlled research in the USA and UK (Schultz, 2008; Schultz et al., 2006; Pringle et al., 2012). The research consisted of burying pig carcasses as human body analogues, and subsequently detecting and monitoring the carcasses for a period of time post burial. The current study involved the burial of clothed, domestic pig carcasses (*Sus domesticus*) in a range of contrasting soil textures (silty clay loam, fine sand and fine sandy loam) at three field sites in southern Ontario, Canada. GPR was used to detect the graves over a range of post burial intervals (PBI) representing the first large-scale study to investigate the applicability of GPR to forensic investigations in Canada.

Materials and methods

Site locations

Field experiments, which consisted of burying and subsequently exhuming domestic pig (*Sus domesticus*) carcasses in contrasting soil textures, were conducted over a 14 month period. The domestic pig is commonly used as a model for human decomposition in forensic research (Notter et al., 2009; Schoenly et al., 2006). This is due to the ethical restrictions of using human bodies for research (Notter et al., 2009), their similar internal anatomy, fat distribution, size of chest cavity, lack of heavy fur, and omnivorous diet, suggesting a similar gut fauna (Schoenly et al., 2006).

Three field site locations within southern Ontario, Canada were selected for GPR data collection based upon soil texture; 'Nashville', a grazing field located in Nobleton, Ontario; 'Springwater', a commercial gravel pit located in Springwater, Ontario; and 'Dummer', a grazing field located in Douro-Dummer Township, Ontario. Analysis of control soil samples collected from each site to determine soil texture and electrical conductivity was performed by the University of Guelph Laboratory Services – Agriculture and Food Laboratory.

The Nashville field site (43° 54’ 08” N, 79° 41’ 10” W) soil texture was silty clay loam, with the following components; gravel 0.0%, sand 19.1%, silt 53.4% and clay 27.5%. The electrical conductivity was 7.5 mS/m and the soil moisture content varied between 20 - 30% throughout the study. Annual temperatures in the region range from -32.8°C to 40.6°C, with a daily mean temperature of 9.2°C. Average annual rainfall in the region is 709.8 mm with 834 mm of precipitation and 133.1 cm of snowfall (www.climate.weatheroffice.ec.gc.ca).

The Springwater field site (44° 22’ 48” N, 79° 45’ 80” W) soil texture was fine sand, with the following components; gravel 0.0%, sand 97.6%, silt 1.2% and clay 1.2%. The electrical conductivity was 5.9 mS/m and the soil moisture content varied between 2 - 6% throughout the study. Annual temperatures in the region range from -35°C to 36°C, with a daily mean temperature of 6.7°C. Average annual rainfall in the region is 700.2 mm, with 938.5 mm of precipitation and 238.4 cm of snowfall (www.climate.weatheroffice.ec.gc.ca).

The Dummer field site (44° 18’ 00” N, 78° 19’ 00” W) soil texture was fine sandy loam, with the following components; gravel 0.0%, sand 59.9%, silt 35.2% and clay 4.9%. The electrical conductivity was 39.5 mS/m and the soil moisture content varied between 15 - 18% throughout the study. Annual temperatures in the region range from -35.5°C to 36.5°C, with a daily mean temperature of 6.6°C. Average annual rainfall in the region is 715.3 mm, with 869.6 mm of precipitation and 165 cm of snowfall (www.climate.weatheroffice.ec.gc.ca).

Burial parameters

A total of 45 pig carcasses were buried across the three field sites. Burial formations at the Nashville and Dummer sites were in the shape of a cross (Figure 1). This grave arrangement was used for ease of data collection for GPR and other geophysical surveys (data not included in this study). At the Springwater site, burials were arranged in two parallel lines due to a space constraint and potential safety hazards to researchers. Burial occurred on August 11, 2008. Pig carcasses were purchased from a dead stock company and were euthanized according to industry standards (head bolt) (Olfert et al., 1993). Carcasses were buried within several hours of death (approximately 1-5 hours depending upon site location). Each site consisted of 15 graves containing a carcass and 5 control graves containing no carcass, to establish a baseline for comparison to the decomposition process of pig carcasses (a total of 20 graves per site).

To more closely represent forensic scenarios, the carcasses were buried at a depth of approximately 0.76 m (2.5 ft) in 100% cotton t-shirts and 50% cotton/50% polyester briefs, which are representative of common textiles. The control graves also contained the t-shirts and briefs, in order to determine the natural rate of decomposition of the fibres based upon the soil texture and microbial environment.

GPR data collection

The study was conducted over a 14 month period from August 11, 2008 until October 23, 2009. GPR data were collected during the following months; August, September and October of 2008, and July, August, September and October of 2009. Data collection correlated with the climate of south-central Ontario. This climate experiences temperatures ranging from -35°C in the winter to 41°C in the summer and several months of snowfall in fall, winter, and spring. Due to heavy rain in the area, GPR data was not collected from the Nashville site for the month of July, 2009.

A Sensors & Software Inc. Noggin Plus 500 (Mississauga, Canada) ground penetrating radar antenna was used for surveying the graves. A SmartCart configuration was used to allow for quick and efficient coverage of the sites. A Digital Video Logger (DVL) was used in the field as a guide for line tracking, to provide real-time display and record data. All data were stored onto a SanDisk Extreme III 1.0 GB CompactFlash, and downloaded to a computer.

A line survey pattern was used at the Nashville site due to the rough terrain. The use of the line pattern adhered to procedures used by forensic identification officers (Ruffell & Mckinley, 2008). A grid pattern was used at the Springwater and Dummer sites for greater detail. The use of the grid pattern adhered to procedures used by researchers and archaeologists (Davis et al., 2000; Neubauer, 2001). A total of 8 lines were collected at Nashville. Springwater consisted of four grids; three 10 m x 10 m and one 2 m x 10 m. Dummer consisted of three grids; one 40 m x 5 m and two 5 m x 15 m. A transect spacing of 0.5 m was used (Davis et al., 2000; Neubauer, 2001). The grid, line and spacing parameters used ensured coverage of all sites, and overlap of undisturbed soil.

The software used to view, analyze and qualitatively interpret the GPR data was produced by Sensors & Software Inc.; GFP Edit, EKKO View, and EKKO View Deluxe (Mississauga, Canada). The programs are designed to create, view and edit GFP (GPR Files and Parameters) files.

Results

Pringle et al. (2012) found that target hyperbola(e) for buried pig carcasses were evident in raw 2D data profiles and that "time slices" need only be produced when the time since burial exceeds 18 months. The burial period for the current study was 14 months. The GPR results are presented as raw data to demonstrate the anomalies observed in real time at the grave sites. Further processing of the data assisted in enhancing the hyperbola and confirming the GPR reflection response for grave sites. A representative line from each site including 10 graves (both experimental and control) is shown to demonstrate the degree of reflection evident at the completion of the study period. Given the large number of grave sites studied, it was not possible to include single, enhanced images for each of the grave sites surveyed at all three locations.

Nashville

Line data were collected in two sections (cross formation) containing ten graves each; seven experimental and three controls. A strong hyperbola was identified for the ten graves located in each line. Throughout the period of study, the GPR data remained similar in that a hyperbolic shaped reflection response from all 20 graves was detected on all of the data collection dates. A representative line collected in October, 2009 is shown in Figure 2 demonstrating the seven experimental graves and three control graves for one line. A discernible difference in the hyperbolic shaped reflection response between the control and experimental graves was not observed.

Springwater

Grid data were collected across the two parallel lines containing ten graves each. Figure 3 shows a representative line from a grid pattern collected in September, 2008 (32 days PBI). Reflection responses were identified as hyperbola with severely reduced reflection amplitudes. Within the parameters of the collected line, four graves should have been detected (three experimental and one control) however, only three experimental graves were identified. The control grave did not produce any hyperbolic shaped reflection responses. The September 2008 data set represented the first and only collection date where graves were evident. Reflection responses were not detected for any of the other collection dates at the Springwater grave sites.

Dummer

Grid data were collected over the two lines in the cross formation. The graves could be consistently and clearly identified by strong hyperbola. By the completion of the GPR data collection in October 2009, the grave locations at the Dummer site were still discernible (Figure 4) although demonstrating reduced reflection amplitudes. Within this figure, 11 hyperbolic shapes representing graves are present. This response was accurate as 11 graves were dug within the section, despite the fact that only 10 were required. A distinct difference in hyperbolic shaped reflection responses between the control and experimental graves was not identified.

The soil composition, EC, moisture content and GPR results are summarized in Table 1. Figure 5 is also included (from Grisso *et al.*, 2009) as reference for the expected ranges in conductivity for different soils.

Discussion

It has been extensively reported that soil properties (including soil texture, moisture, and electrical conductivity) will affect the capability of GPR to detect clandestine graves. Results from the current study indicate that GPR provided the most valuable data when used in a silty clay loam soil with medium-low electrical conductivity and moderate-high moisture content (Nashville site). All 20 graves at the Nashville site were detectable by GPR for the entire 14 month duration of the study. The hyperbolae were discernible with consistently strong reflection amplitudes. These findings contradict results presented by Buck (2003), who found that GPR use was not successful in locating an excavated and backfilled trench in silty clay loam soil that was only days old. GPR testing in areas of known soil conditions with clearly defined features of known dimensions are important to determine radar applicability based upon soil texture, moisture and conductivity. Long pulse antennae (300 MHz) are effective for imaging depths of greater than 3.5 m (Davis et al., 2000; Miller, 1996) whereas 500 MHz antennae are useful for depth investigations greater than 0.5 m (Miller, 1996). The study by Buck (2003) involved a trench that was 2.5 m deep. It is possible that the antenna frequency selected did not provide sufficient depth penetration to clearly detect the trench outline in that particular soil environment.

Schultz et al. (2006) found that carcasses buried in clayey soils were only generally detectable by GPR for the first six months post burial, and more difficult to discern after that time period. Soils which contain high clay content and have a high electrical conductivity can attenuate EM wave propagation resulting in a reduction of depth of penetration into the ground and prevention of the detection of burial sites and features contained within them (Schultz et al., 2006). Clay can mask the remains by limiting the dielectric permittivity of the body with that of the soil horizon (Schultz et al., 2006). The clay content in the silty clay loam soil at the Nashville site was 27.5%. The fact that the Nashville soil was a loam mixture with medium-low conductivity may explain why graves and carcasses were detectable using GPR in the present study, but not by Schultz et al. (2006).

In contrast to previous research (Schultz, 2008; Schultz et al., 2006), the present study found that clandestine graves could not be detected with accuracy by GPR in a fine sandy soil with low electrical conductivity and moisture content (Springwater site). Schultz (2008) found that the degree of skeletonization of buried carcasses appeared to have the greatest effect on whether or not a distinctive hyperbolic shaped response was discernable over the duration of a 21.5 month period. Over time, as a carcass progresses through the stages of decomposition, the dielectric permittivity surrounding the body will equilibrate to the surrounding soil due to the movement of the soil solution or ground water (Schultz, 2008), making detection by GPR more difficult. It is unclear why, in the present study, graves were not detectable even during the early stage of decomposition (autolysis). The dry, sandy conditions combined with a low electrical conductivity are considered ideal for GPR responses. It is thought that the contrasting textures of sandy soil in the current study compared to those studies conducted by Schultz et al. (2006) and

Schultz (2008) played a role. The specific properties of the sand within those studies were not stated, and it is possible that those soil environments consisted of more uniform sand particles.

The Springwater site was located at a commercial gravel pit which represents an extensively disturbed site. The soil environment consisted of fine and very fine sand as well as some gravel identified below the depth of the graves. Nobes (2000) highlights the difficulty in detecting a body or bones in sites which are substantially disturbed because the target response can be readily masked by the background site variation. Within sand, depth of GPR penetration is dependent upon the pore water conductivity, more so than the sand material, and bedding within wet sand deposits can also mask grave detection (www.sensoft.ca). However this was not the case in the current study as the moisture content of the soil only varied between 2-6% throughout the entire study period. It is therefore likely that the nature of the disturbed soil caused the greatest attenuation of the EM waves and may explain our contradictory findings.

Grave detection in fine sandy loam soil (Dummer site) was successful for the duration of the present study. The hyperbolic shaped reflection responses from the graves became less defined as the study progressed but were still visible in both experimental and control graves after 14 months burial. These findings correlate with results by Pringle et al. (2012) who found that GPR could successfully locate buried pig carcasses in a sandy loam soil up to 18 months post burial. It should be noted that the soil moisture content varied between the two studies although the background soil conductivity measurements were comparable.

The results of the current study suggest that GPR is most applicable in loam soils even with varying degrees of sand, silt and clay in southern Ontario, Canada. Our findings contradict some of the previously established ideas about the usefulness of GPR in sand versus clay soils. However, it must be highlighted that soil texture alone does not dictate the value of using GPR in a forensic investigation. Soil properties and environmental conditions need also be considered when determining the likelihood of success in locating a clandestine grave or buried anomaly.

Conclusion

Ground penetrating radar is a useful tool in the location of clandestine graves in areas of known soil conditions, specifically due to its non-invasive nature. Although the use of GPR in forensic scenarios has seen increased interest in recent years, the use of other more traditional non-invasive techniques, such as changes in foliage and soil depression above a grave, should also be considered. We believe that the most effective means of searching for a clandestine grave is a combination of techniques including GPR. Further controlled research into the applicability of GPR for the detection of clandestine graves based upon soil properties (i.e. texture, moisture, and electrical conductivity), rate of carcass decomposition, and length of burial is necessary for GPR to remain an effective tool within law enforcement.

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Figure captions

Fig. 1. Nashville field site burial arrangement schematic.

Fig. 2. Representative GPR line data from Nashville – October 16, 2009 (14 months post burial). Lines bisecting graves represent: ----- control and ----- experimental.

Fig. 3. Representative GPR line data collected from a grid pattern from Springwater – September 11, 2008 (1 month post burial). Lines bisecting graves represent: ----- experimental graves.

Fig. **4**. Representative GPR line collected from a grid pattern from Dummer – October 15, 2009 (14 months post burial). Lines bisecting graves represent: ----- control, ----- experimental and ----- extra grave.

Fig. 5. Expected ranges of soil conductivities for sand, silt and clay (from Grisso *et al.*, 2009: http://pubs.ext.vt.edu/442/442-508/442-508_pdf.pdf)

Table 1. Summary of results

	Conductivity (mS/m)	Soil Moisture (%)	Soil Composition (%)	Comments on data and GPR response
Nashville	7.5	20-30	Sand: 19.1 Silt: 53.4 Clay:27.5	Medium low conductivity (not consistent with Fig. 5), moderate high moisture, good GPR response over study period*
Springwater	5.9	2-6	Sand: 97.6 Silt: 1.2 Clay: 1.2	Low conductivity (consistent with Fig. 5), low moisture, poor GPR response initially and then no GPR response*
Dummer	39.5	15-18	Sand: 59.9 Silt: 35.2 Clay: 4.9	Medium conductivity (~1 order of magnitude higher than in other sites), medium moisture, good GPR response but decreasing with time*

*GPR response refers to the quality and amplitude of hyperbolic shaped reflection responses