Chapter 17
Using Soil and Groundwater Data to Understand Resistivity Surveys over a Simulated Clandestine Grave

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Abstract Geophysical electrical resistivity surveys have been used in a number of attempts to locate clandestine 'shallow' graves, based on the valid assumption that a grave may represent a contrast in the electrical properties of the ground compared to 'background' values. However, the exact causes of measurable geophysical signals associated with graves are not well understood, particularly for electrical methods. In this study, soil and groundwater samples have been obtained from a simulated grave containing a domestic pig (*Sus domestica*) carcass, in order to better understand how the presence of a grave may influence the bulk electrical properties of the soil. This information is used to explain observations based on repeat resistivity surveys over a period of 6 months over a second simulated grave at the same site. An area of low resistivity values was observed at the grave location in the survey data obtained from 4 to 20 weeks post-burial, with the grave being difficult to identify in survey data collected outside of this interval. The low resistivity grave anomaly appeared to be caused by highly conductive fluids released by the actively decomposing carcass and this is consistent with the relatively short timescale during which the grave was detectable. It is then suggested that the most appropriate time to use resistivity surveys in the search for a grave is during the period in which the cadaver is most likely to be undergoing active decomposition. However, other authors have observed low resistivity anomalies over much older graves and it is possible that, for graves in different environments, other factors may contribute to a detectable change in the bulk electrical properties of the soil.

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Introduction

Forensic geophysical surveys have been used in a number of attempts to search for clandestine graves (e.g. Nobes 2000; Buck 2003; Scott and Hunter 2004; Cheetham 2005; Ruffell 2005). Ground penetrating radar (GPR) is perhaps the most commonly used geophysical method in the search for clandestine graves (Cheetham 2005) and its capability for this purpose has been well studied in a number of surveys over controlled animal (Schultz et al. 2002, 2006; Schultz 2008) and human burials (Freeland et al. 2002; Miller et al. 2002). Of the other geophysical techniques that have been used, electrical resistivity surveys have demonstrated success in locating simulated graves (Cheetham 2005; Pringle et al. 2008) and a number of published reports detail the use of such surveys in searches for murder victims (Buck 2003; Scott and Hunter 2004; Cheetham 2005). Graves commonly appear as areas of reduced resistivity compared to background values in resistivity survey data (Cheetham 2005) or, equivalently, areas of increased conductivity in data from electromagnetic surveys (France et al. 1992; Nobes 2000). The possible cause of the reduced resistivity and increased conductivity observed in survey data over both real and simulated shallow graves has been suggested to be the increased porosity of the backfilled soil (France et al. 1992; Scott and Hunter 2004) or moisture trapped within the grave (Nobes 2000). Additionally, decomposing bodies are known to release fluids with a greater ion concentration than normal groundwater (Vass et al. 1992), and this could also, theoretically, cause a low-resistivity anomaly in geophysical data. However, no previous study involving electrical resistivity or conductivity surveys over graves has been supported by direct measurement of porosity, moisture levels or fluid conductivity. Hence, the exact contributions of any of these factors to the anomalies associated with graves in resistivity and conductivity data remains largely unknown. A greater understanding of what causes graves to be identifiable in data from resistivity and conductivity surveys may give more insight into the relative strengths and weaknesses of these techniques for locating graves, giving potential future forensic search coordinators a better appreciation of when and where the use of these methods would be most appropriate.

Measurements made using resistivity survey equipment are equal to the apparent resistivity (which is an idealised version of the true resistivity) of the sub-surface multiplied by a geometrical factor that depends on the relative orientation and separation of the electrodes (Reynolds 1997). Hence, in order to gain an understanding of what may cause a grave to be detectable using electrical resistivity surveying, it is necessary to be aware of which soil physical properties influence the bulk resistivity of the ground. Archie (1942) developed an empirical law that relates the bulk resistivity (ρ_b) of both unconsolidated partially saturated sands and consolidated sandstones to their porosity (θ), degree of saturation (S) and the resistivity of the pore water (ρ_w) that can be written:

$$\rho_b = \theta^{-m} S^{-n} \sigma_w^{-1} \quad (1)$$

where σ_w is the conductivity of the pore water (i.e. ρ_w^{-1}), m appears to depend on the level of consolidation of the medium in question and is generally found to lie in the range 1.3 to 2 and n has a value of approximately 2 (Archie 1942). Although only originally tested on sands and sandstones, Archie's law may be used to describe the electrical properties of soils, although in clayey soils it may be necessary to add an extra 'surface conductivity' term to Equation 1 to account for the fact that clay minerals may exchange ions with the soil solution (Friedman 2005). It can be seen from Equation 1 that an increase in any one, or a combination, of soil porosity, saturation and water conductivity may explain the low resistivity and high conductivity anomalies associated with shallow graves observed in previous studies. Hence, by independently monitoring each of these three variables in a controlled experiment involving a simulated grave, it may be possible to determine the relative importance of each variable to any changes in the measurable bulk resistivity.

Aims

This study had three mains aims: (1) to conduct repeat electrical resistivity surveys over a simulated clandestine grave at regular intervals in order to monitor the time-varying bulk electrical response of the grave; (2) to collect soil and groundwater samples from a second simulated grave and 'undisturbed' ground in order to determine any variations in porosity, saturation or water conductivity and map these variations to the recorded resistivity data; (3) to draw from the analysis of the results any general conclusions regarding the use of electrical resistivity survey techniques in searching for shallow graves.

Methods

Study Site

The site chosen for the study was the back garden of Staffordshire University's 'Crime Scene House' in Stoke-on-Trent, Staffordshire, UK. The garden is grassed, surrounded by hedges and trees and approximately 40 m long by 10 m wide. British Geological Survey borehole data (borehole record SJ84NE2579) from a borehole located on a raised bank approximately 10 m from the study site show a 3 m thick 'made ground' layer above a 1 m thick layer of sandy gravel, beneath which is sandy, silty clay. The 'made ground' is described as a mix of clayey ash, sand and gravel. Digging of the graves revealed a significant amount of debris, including tree roots, whole bricks, concrete and coal fragments in the made ground layer, which extended to a depth of approximately 0.5 m in the Crime Scene House garden. The heterogeneous nature of the shallow subsurface at this site suggests that geophysical data might be expected to exhibit considerable variation across the study site. These localised variations have the potential to mask any subtle geophysical signal from the grave, meaning that the site offers a realistic test environment for geophysical search methods. A previous study at the same site found some difficulty in identifying buried matter using a number of geophysical techniques, including ground penetrating radar and magnetic gradiometry (Pringle et al. 2008).

Simulated Graves

In this study, buried domestic pig (*Sus domestica*) cadavers weighing approximately 31 kg each were used as a proxy for clandestine human graves, due to the ethical and legal issues surrounding the use of human cadavers in experiments in the UK. Two simulated shallow graves were created; one to be surveyed with the geophysical equipment and a second for the collection of soil and water samples, so that the removal of soil and water from the grave did not affect the geophysical data. The graves were approximately 1.1 m long, 0.6 m wide and 0.6 m deep. Carcasses were between 1.0 and 1.1 m in length and had had all internal organs, with the exception of brain, kidneys and bladder, removed via a long (approximately 0.4 m) incision in the abdomen. After placing each of the carcasses in a grave most of the excavated soil was backfilled, tamped down and the turf replaced. This left a mound, raised by a few centimetres relative to the surrounding grass at each grave. Excess soil was then disposed of at the edge of the garden.

Geophysical Data Collection

A survey grid measuring 8 × 4.5 m with one of the pig graves at the centre was marked out for geophysical survey (Figure 17.1). Plastic pegs were used to permanently mark both ends of each survey line in order to ensure that the surveyed area was consistent throughout the study. Electrical resistivity measurements were made using an RM4 resistance meter (Geoscan Research) mounted on a custom-built twin-probe array, which features two mobile probes 0.5 m apart on a mobile frame. The two reference probes were situated 0.75 m apart at a fixed location approximately 17 m from the survey area. Resistivity measurements were obtained every 0.25 m along survey lines 0.25 m apart, a measurement spacing that is recommended for surveys over relatively small graves (Cheetham 2005). Surveys were conducted every 2 weeks between March and October 2007, commencing 2 weeks after burial of the pig carcasses.

Geophysical Data Processing

Raw resistivity data in 'x, y, z' format were median filtered to remove small-scale data 'spikes'. This was achieved by using a rolling filter to take the median of

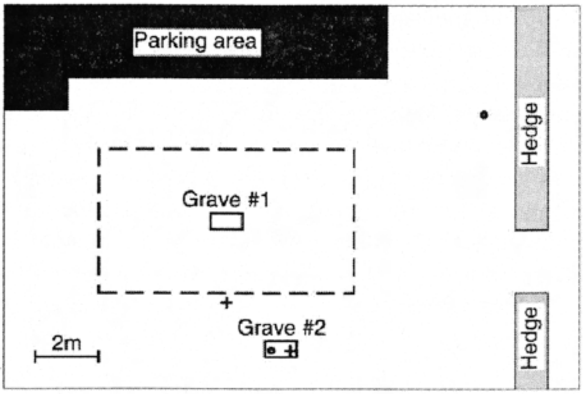

Fig. 17.1 Plan of study site showing: location of simulated graves, geophysically surveyed area (dashed line), lysimeters (circles) and soil sampling positions (crosses)

each triplet of adjacent points in the direction parallel to the 8 m long side of the survey grid. The data were subsequently interpolated to give data points every 2.5 cm using a continuous curvature surface gridding algorithm (Smith and Wessel 1990). Long wavelength trends were then removed by fitting a cubic surface to the gridded data and subsequently subtracting this surface from the data. The principal purpose of the median filtering and trend removal is to eliminate variations at length scales that are much shorter and much longer than that of any signal associated with the grave. Each dataset was then normalised by division by its standard deviation. As the trend removal process involved removal of the mean of each dataset, normalisation results in a set of values that represent the variance of each value in the original (post-interpolation) dataset from the mean in standard deviations, which allows datasets obtained at different times to be more easily compared. The processed resistivity datasets were then plotted using a common grey-scale palette, ranging from black at minus two standard deviations to white at plus two standard deviations.

Groundwater Sampling

Site groundwater and grave water samples were obtained using model 1900 soil water samplers (Soilmoisture Equipment Corp.), also known as lysimeters, which were installed in both the second simulated grave and at a control location at a point approximately 4 m outside the survey area (Figure 17.1). After the pig carcass had been placed in the second grave, a small amount of the excavated soil was mixed with water from the nearby River Trent to create a 'slurry', a small amount of which was then deposited onto the base of the grave between the hind quarters of the pig and the grave wall. The porous end cap of the lysimeter was then inserted vertically into the slurry and the grave was then back-filled. The presence of slurry was necessary to ensure good hydraulic conductivity between the soil and the lysimeter. The control lysimeter was installed by digging a narrow hole (approximately 0.3 × 0.3 m wide) to 0.6 m depth, depositing some slurry at the base of the hole, into which the tip of the lysimeter was inserted, and then back-filling the hole. Once installed, the open ends of the lysimeters at the surface were sealed with a rubber stopper and a vacuum pump was used to generate a suction of 65 kPa within the lysimeters, in order for the instruments to draw moisture from the soil. On each day that a resistivity survey was performed, the rubber stopper was removed from each lysimeter and any water present was extracted using a plastic syringe with a narrow tube attachment. The rubber cap was then replaced and the suction pressure restored. The conductivity of each sample was measured immediately after collection using a multiline P4 multi-parameter meter (WTW Inc.). Conductivity was not measured for the first two water samples obtained from each lysimeter (i.e. the samples obtained 2 and 4 weeks after burial), as these were likely to contain a significant amount of the water used to make the slurry. As such, these samples were considered not to be representative of the site groundwater or the grave water.

Soil Sampling

Narrow (1.5 cm diameter) steel augers were used to collect soil samples to a depth of 0.7 m below ground level. Control samples were obtained from a location near the edge of the surveyed area and grave samples from just inside the edge of the second grave at the opposite end to the grave lysimeter, so that the water removed by the grave lysimeter did not affect saturation levels of the soil samples. Samples were visually inspected upon extraction from the ground and those with sections of soil missing were discarded and a repeat sample was obtained. The augers containing the soil were then immediately returned to the laboratory. Sections from the part of the auger that were 0.1 to 0.3 m below ground level (henceforth referred to as 'shallow soil samples') and 0.4 to 0.6 m below ground level ('deep soil samples') were removed and placed into pre-weighed sample trays and oven dried at 105 °C for 24 h. Each sample along with its container was weighed before oven drying ('wet weight') and after drying ('dry weight'). The weight of water in each sample was calculated by subtracting the dry weight from the wet weight, and the soil weight was calculated as the dry sample weight minus the container weight. Soil volume was calculated using the soil weight and an assumed soil particle density of 2.65 g/cm^3, which is deemed appropriate for most soil types (Hillel 1980). The density of the water lost on drying was assumed to be 1.0 g/cm^3. The cross-sectional area of the auger samples was 0.72 cm^2, meaning that the volume sampled for each 20 cm segment removed from the auger (V_T) was 14.4 cm^3. Porosity and saturation were then calculated for all samples using standard formulae (e.g. Barnes 2000):

$$\theta = \frac{V_a + V_w}{V_T} \qquad (2)$$

$$\mathbf{S} = \frac{V_w}{V_a + V_w} \tag{3}$$

where V_w is the volume of water in each sample, calculated from the water weight and the assumed water density and V_a is the volume of air in each sample, which was calculated by subtracting the soil volume and the water volume for each sample from the total sample volume.

Statistical Analysis of Soil Data

Statistical analysis was conducted using NCSS (Hintze 2001). Statistical hypothesis testing was used to determine whether differences in four measured parameters between the grave soil and the control soil were significant (i.e. due to an actual difference between the two soil types) or non-significant (i.e. due to random variation in measurements). The four tested parameters were shallow porosity, deep porosity, shallow saturation and deep saturation. A paired samples hypothesis test was used as this is most appropriate for experiments involving repeat measurements (Warner 2008): for a given parameter, each pair consisted of the values measured for the grave soil and the control soil each fortnight. Consequently, the test statistic was the mean difference between each pair (grave measurement – control measurement) and the null hypothesis that the mean difference (μ_d) was equal to zero was used. Tests were two -tailed with the level of significance set at 0.05.

Results

Resistivity Data

The processed geophysical data (Figures 17.2 and 17.3) showed a low resistivity anomaly associated with the grave that varied considerably in shape, extent and magnitude between individual datasets. The week 2 resistivity data did not show any obvious features associated with the grave. However, in the data from weeks 4 to 20, distinct areas of low-resistivity were visible at both the head and foot ends of the grave. In the data from weeks 22 and 24, only the low-resistivity feature at the head end of the grave was easily identifiable.

Soil Porosity and Saturation Data

Measured values of porosity and saturation data are shown in Figure 17.4a and b and results of the statistical analysis of these data are given in Table 17.1. For all

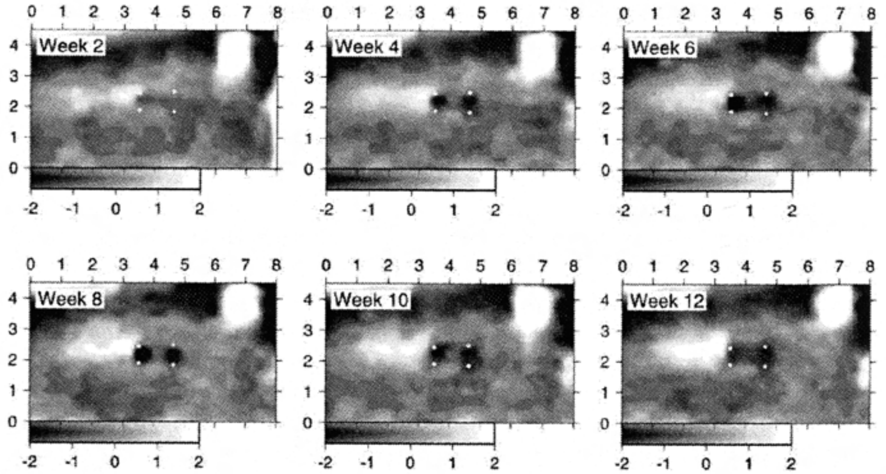

Fig. 17.2 Normalised resistivity survey data acquired over the simulated grave between 2 and 12 weeks post-burial. The grey scale shows the variation from the mean of each dataset in standard deviations. The corners of the grave are indicated by the white circles, with the head end of the grave at the left side of the marked area. Labels at the top left of each plot indicate the time of each survey relative to the time of burial.

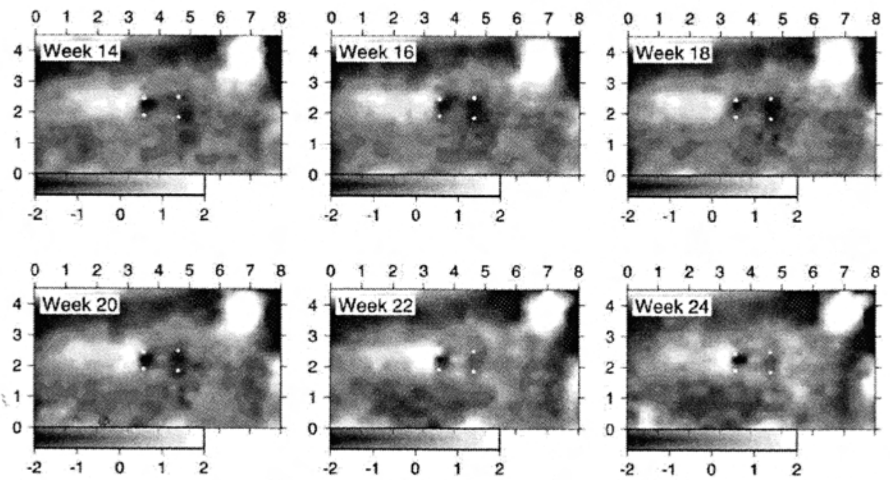

Fig. 17.3 Normalised resistivity survey data acquired over the simulated grave between 14 and 24 weeks post-burial

tests, the p-value is well above the significance level of 0.05, suggesting that differences in saturation or porosity between the grave soil and the control soil are simply due to random variation. When H_0 is accepted, it is necessary to consider the statistical power of the test, which defines the test's ability to reject H_0 when it is false and, ideally, should be greater than 0.8 (Warner 2008). In the tests used here, the

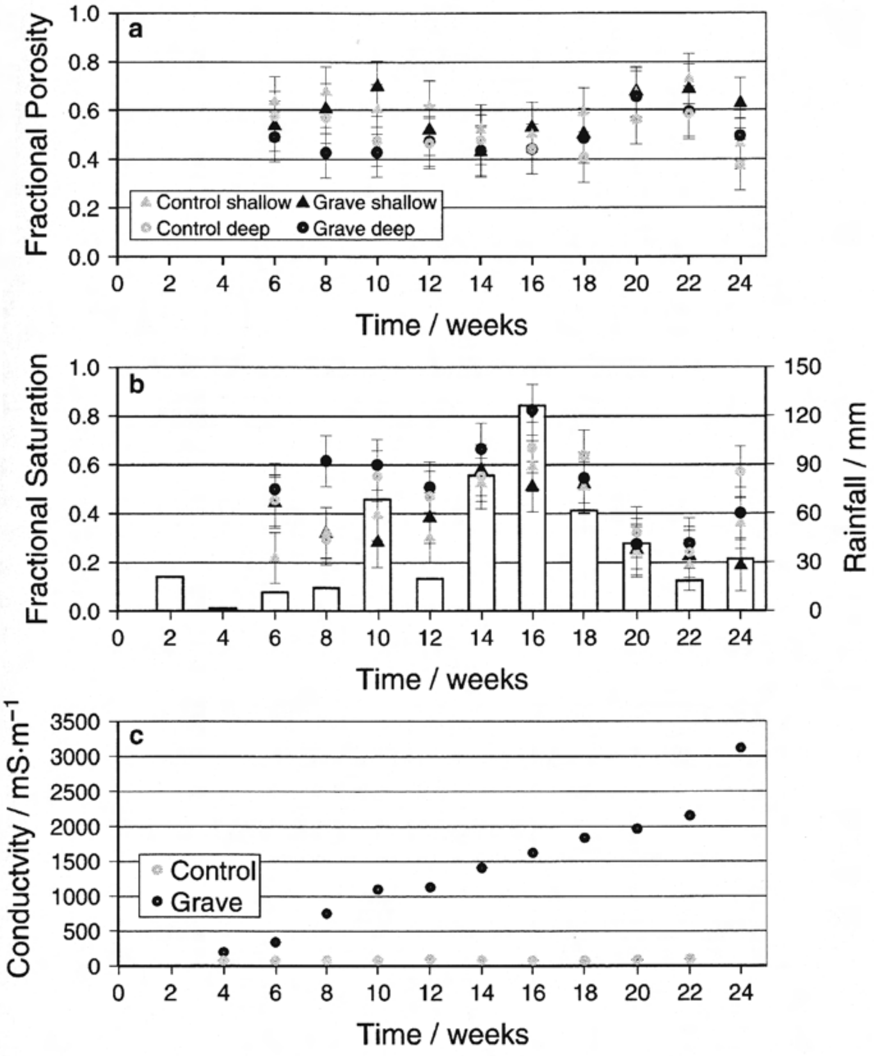

Fig. 17.4 Soil and water data collected during the project. (**a**) Soil porosity data for deep and shallow samples collected from the grave and control locations. (**b**) Soil saturation data plotted with the same symbol key as the porosity data. Bars show rainfall for each fortnight plotted against the right-hand scale. (**c**) Water conductivity for samples collected from the grave and control lysimeters. Error bars in (**a**) and (**b**) represent combined measurement errors from all values used in the calculation of porosity and saturation, respectively

statistical power is at best approximately 0.15, which suggests that the experiment is not well suited to detecting differences in porosity or saturation between the grave and control samples. Low statistical power often indicates a poor signal to noise ratio. Here, this may be a result of too few measurements being made, high measurement error or too much natural variability within the soil samples.

Table 17.1 Outcomes of statistical analysis of soil data

Test parameter	Null hypothesis	Mean difference	Standard error	p-Value	Decision	Power of the test
Shallow porosity	$H_0: \mu_d = 0$	–0.019	0.029	0.531	Accept H_0	0.090
Deep porosity	$H_0: \mu_d = 0$	0.000	0.026	0.998	Accept H_0	0.050
Shallow saturation	$H_0: \mu_d = 0$	0.005	0.035	0.883	Accept H_0	0.052
Deep saturation	$H_0: \mu_d = 0$	0.044	0.043	0.330	Accept H_0	0.152

Groundwater Data

The conductivity of the water samples (Figure 17.4c) obtained from the grave rose in near-linear fashion from 196.6 mS/m in weeks 4 to 2,150 mS/m in week 22, before rising suddenly to 3,110 mS/m in week 24. In contrast to this, the conductivity of the control groundwater was approximately constant, with a minimum of 71.5 mS/m (week 18) and a maximum of 94.5 mS/m week 22). No water was present in the control lysimeter in week 24.

Discussion

Despite the challenging nature of the study site, the simulated grave is clearly delineated in the geophysical survey data, albeit only from 4 to 20 weeks after burial. This is similar to the results of Bray (1996, as cited in Cheetham 2005), in which monthly resistivity surveys did not reveal a low resistivity anomaly over a pig grave until 2 months after burial. Furthermore, a reduction in the contrast between another pig grave and background readings was reported after one year of burial (Bray 1996, as cited in Cheetham 2005).

Analysis of the soil porosity and saturation data is inconclusive and because of the low statistical power of the hypothesis tests it must be concluded that the contribution of changes in soil porosity and saturation to the low resistivity anomaly of the grave cannot be determined in this study. However, a definite increase in fluid conductivity within the grave was observed and is likely to be at least partly responsible for the observed low resistivity anomaly. The increase in fluid conductivity in the grave may be a result of the decomposition of the pig cadaver. The 'active decay' stage of decomposition has been observed to be associated with a release of cadaveric fluids into the ground, causing soil beneath bodies deposited on the surface to take on a darker, stained appearance (Carter et al. 2007) and a similar staining of the soil has been noted in the case of buried pig cadavers (Wilson et al. 2007). Experimental work involving human cadavers deposited on the surface has shown the release of fluid during decomposition to be associated with elevated concentrations of a number of different ions in water extracted from soil samples taken from directly beneath the body (Vass et al. 1992). Fluid conductivity increases with the concentration of dissolved solids (e.g. Drever 1982). Therefore, the elevated ion concentrations in the soil water close to decomposing human remains described by Vass et al. (1992) would have resulted in a localised increase in water conductivity. It is then suggested that a similar phenomenon is responsible for the increase in grave water conductivity observed here. From week 8 onward, the water samples obtained from the pig grave had a brown discoloured appearance and a distinctive 'cheesy' odour which gave way to a more noxious fetid odour after approximately 16 weeks of burial. Similar odours have been associated with excavated pig cadavers (Turner and Wiltshire 1999), adding further support to the notion that alteration of the soil solution in the graves is a result of the decomposition of the pig carcasses.

The possibility that the fluid released by the decomposing pig cadaver is responsible for the low resistivity of the grave appears to be consistent with a number of features in the geophysical data. For example, the two-part nature of the low resistivity grave anomaly (e.g. the data from week 8) mirrors the distribution of organic matter within the grave; as organic matter is the likely source of decompositional fluid, this would be expected. The organic matter with the grave was concentrated at the two ends of the grave because the pig carcasses had been eviscerated; this left only ribs and a thin layer of skin present in the middle of the carcass, whilst the head (complete with brain) and forelegs (with all associated muscle) were situated at one end of the grave and the kidneys, bladder and hind legs (with all associated muscle) were situated at the other end of the grave. The timescale over which the low resistivity anomaly is visible may also be explained in terms of the decomposition of the pig carcasses. That no significant anomaly is visible in the survey data obtained in week 2 could be due to the fact that, after 2 weeks in the ground, the cadaver had either not reached the stage of active decay, or the active decay process had not produced a large enough volume of fluid for the grave to be detectable. The diminished area of low resistivity values at the grave location in the survey data from weeks 22 and 24 may be attributed to a reduction in the volume of highly conductive fluid once the main phase of active decay is over. Such a decrease in the volume of highly conductive fluid within the grave would be consistent with the decrease in saturation observed in the deep grave soil samples compared to the control samples from week 18 onward. A decrease in the volume of conductive fluid within the grave could also explain the fact that the low resistivity anomaly in the survey data reduces in size after week 20 despite the continued rise of the conductivity of the water samples extracted from the grave during this period.

Hence, it seems likely that the low resistivity of the simulated grave is at least partly due to the conductive fluids released by the decomposing cadaver, whilst the contribution of any changes in the soil porosity and saturation to the geophysical anomaly are undetermined in this case. This suggests that if a cadaver is undergoing active decomposition, it should be detectable using the electrical resistivity technique, even if the ground conditions are complex and challenging, such as those at the study site discussed here. However, it should be noted that if the low resistivity anomaly is solely due to the cadaveric fluids, it is possible that the results of an electrical resistivity survey over a cadaver that is wrapped (e.g. in a blanket or tarpaulin), or even one that is clothed, may differ significantly from those that are presented here.

Finally, the relatively short-lived nature of the low-resistivity anomaly presented here conflicts somewhat with other published reports of electrical resistivity and conductivity surveys used in murder enquiries. For example: a low resistivity anomaly associated with a murder victim buried 16 years before a resistivity survey was undertaken (Cheetham 2005) and a high conductivity anomaly in data collected over a murder victim buried approximately 12 years previously (Nobes 2000) demonstrate that detectable areas of altered soil resistivity associated with a grave can be present several years after burial. Comparison of the GPR response of several buried pig cadavers ranging from approximately 30 kg (Schultz 2008) to approximately 64 kg (Schultz et al. 2006) suggests that heavier bodies can be detected for longer post-burial intervals than lighter ones. If the same is true for resistivity surveys, this may explain the relatively short period over which the small (approximately 31 kg) pig cadavers used in this study were detectable using resistivity surveys. However, only one location is considered in this study and it is possible that burials in other environments, where the soil type or climate is different to that discussed here, may also produce a longer-lasting resistivity anomaly.

Conclusions

The electrical resistivity survey method used here over a buried pig cadaver shows considerable promise for the location of shallow graves in the first few months after burial, despite the difficult survey conditions provided by the study site and the relatively small size of the buried pig cadaver. The low-resistivity anomaly, which allows the grave to be easily identified, appears to be at least partly caused by an increase in fluid conductivity within the grave. This increase in fluid conductivity is suggested to be a result of an increased concentration of dissolved ions in the water within the grave as a result of fluids released by the buried cadaver. The short-lived nature of the anomaly associated with the grave in the geophysical data raises concerns over the suitability of resistivity surveys for the location of small cadavers that have been buried for longer than approximately 6 months. However, further work is necessary to understand how a grave may be detectable using resistivity surveys in other environments, soil types, burial conditions and over longer timescales.

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