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A study of the effect of seasonal climatic factors on the electrical resistivity response of three experimental graves

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ABSTRACT

Electrical resistivity surveys have proven useful for locating clandestine graves in a number of forensic searches. However, some aspects of grave detection with resistivity surveys remain imperfectly understood. One such aspect is the effect of seasonal changes in climate on the resistivity response of graves. In this study, resistivity survey data collected over three years over three simulated graves were analysed in order to assess how the graves' resistivity anomalies varied seasonally and when they could most easily be detected. Thresholds were used to identify anomalies, and the 'residual volume' of grave-related anomalies was calculated as the area bounded by the relevant thresholds multiplied by the anomaly's average value above the threshold. The residual volume of a resistivity anomaly associated with a buried pig cadaver showed evidence of repeating annual patterns and was moderately correlated with the soil moisture budget. This anomaly was easiest to detect between January and April each year, after prolonged periods of high net gain in soil moisture. The resistivity response of a wrapped cadaver was more complex, although it also showed evidence of seasonal variation during the third year after burial. We suggest that the observed variation in the graves' resistivity anomalies was caused by seasonal change in survey data noise levels, which was in turn influenced by the soil moisture budget. It is possible that similar variations occur elsewhere for sites with seasonal climate variations and this could affect successful detection of other subsurface features. Further research to investigate how different climates and soil types affect seasonal variation in grave-related resistivity anomalies would be useful.

1. Introduction

Along with several other near-surface geophysical techniques (see e.g. Cheetham, 2005; Pringle et al., 2012a; Ruffel and McKinley, 2005), electrical resistivity surveys have proven useful for detecting several different types of grave. To date, resistivity surveys have been used in searches for graves of archaeological interest (e.g. Ellwood et al., 1994), unmarked cemetery graves (Ellwood, 1990) and clandestine graves containing the remains of murder victims (Cheetham, 2005). From around 2000 onwards, there has been particular interest in the use of resistivity surveys for locating clandestine graves (e.g. Buck, 2003; Pringle and Jervis, 2010; Scott and Hunter, 2004). During the same period, several controlled experiments have been conducted in order to improve our understanding of how resistivity surveys can be used to detect this type of grave (e.g. Jervis et al., 2009a,b; Juerges et al., 2010; Powell, 2010; Pringle et al., 2008, 2012b,c). However, some aspects of grave detection with resistivity surveys remain incompletely understood. For example, the effects of soil type and seasonal changes in soil resistivity on the resistivity response of graves are not fully understood.

This study was conducted to investigate the effect of seasonal climatic changes on the ability of resistivity surveys to detect clandestine graves. There is evidence that changes in soil moisture content caused by seasonal weather patterns can affect the detection of clandestine graves with ground penetrating radar (Hammon et al., 2000; Schultz and Martin, 2012). Since soil resistivity is known to vary seasonally, it is possible that grave detection with resistivity surveys may be similarly affected.

1.1. Seasonal variation in resistivity data

Moisture content is one of the two main factors that affect the electrical conductivity of soil (the other being the conductivity of the water in the soil; Friedman, 2005). As such, seasonal changes in soil moisture content or the level of the water table will cause seasonal variation in soil resistivity. Seasonal changes of approximately ±15% in soil resistivity relative to the annual average for a 500 m long profile have been reported (Aaltonen and Olofsson, 2002). Furthermore, seasonal patterns in soil conductivity have been shown to closely resemble the soil moisture budget (i.e. the net loss or gain in soil moisture content due to the combined effects of rainfall and evapotranspiration; Binley et al., 2002). In addition to affecting the bulk resistivity of the soil, seasonal climatic factors can influence the appearance and even

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detection of individual features in resistivity survey datasets. The resistivity anomalies associated with some infilled archaeological defence ditches, for example, are easier to detect around the time of either the annual minimum or maximum (depending on the individual ditch) of the soil moisture budget (Clark, 1996). Al Chalabi and Rees (1962) found that the 'average anomaly' (which they computed as the standard deviation of a resistivity profile) of one such ditch was inversely proportional to the soil moisture budget. Similarly, the resistivity anomalies of archaeological graves at a cemetery in Garchy in France have been shown to be easiest to detect when the soil is relatively dry (Scollar et al., 1990). Seasonal variation in the appearance of resistivity anomalies can be caused by differences between the moisture retention characteristics of the feature that causes the anomaly and those of the surrounding soil (Clark, 1996; Scollar et al., 1990). As such, different soil types and local geological conditions can influence the seasonal variation in a resistivity anomaly. For example, Clark (1996) found the seasonal variation in ditches at locations with chalk bedrock to be unusual compared to that observed at locations with different geologies. Another possible cause of seasonal variation in resistivity anomalies is change in the effective depth of resistivity measurements, which is caused by seasonal change in the resistivity of near-surface soils.

1.2. Background to this study

In this study, we used existing resistivity datasets that were collected at a test site where buried pig cadavers were used as a proxy for clandestine graves (Jervis et al., 2009b; Pringle et al., 2012c). We focussed on three of these test graves: one contained a pig cadaver, the second did not contain a cadaver, and the third contained a pig cadaver wrapped in a porous tarpaulin made of woven polyethelene strands — we refer to these respectively as the 'pig grave', the 'empty grave' and the 'wrapped pig grave'. The pig grave was typically detected as a low resistivity anomaly, which was predominantly caused by electrically conductive fluid within the grave (Jervis et al., 2009b). This 'grave fluid' was most likely decomposition fluid mixed with soil water. The wrapped pig grave was primarily detected as a high resistivity anomaly, although low resistivity anomalies were occasionally present around the edges of the grave (Pringle et al., 2012c). The high resistivity anomaly was probably caused by the tarpaulin-wrapped cadaver acting as a barrier to the flow of electrical current in the ground. The low resistivity anomalies may have been caused by grave fluid that had leaked through the weave of the tarpaulin. Alternatively, these anomalies may have been caused by a pool of percolating soil-water that had become trapped on the uppermost side of the tarpaulin. No obvious anomaly was observed for the empty grave (Jervis et al., 2009b; Pringle et al., 2012c).

The resistivity datasets of Pringle et al. (2012c) are particularly useful for studying seasonal variation because they cover three years. As such, seasonal variation should be evident as annually repeating patterns in the data. Pringle et al. did observe that the graves were easiest to detect around the time of "winter to mid-spring" (Fig. 1) and suggested that this was because the noise levels in the resistivity data were lowest at this time. Jervis (2010) studied variation in the resistivity responses of these graves during the first year after burial and found that characteristic properties of the pig grave anomaly were moderately correlated with the soil moisture budget. In this study, Jervis's methods are developed and applied to the three years' datasets collected by Pringle et al. The primary aim was to gain a better understanding of the nature and causes of the seasonal variation in the graves' resistivity anomalies.

2. Methods

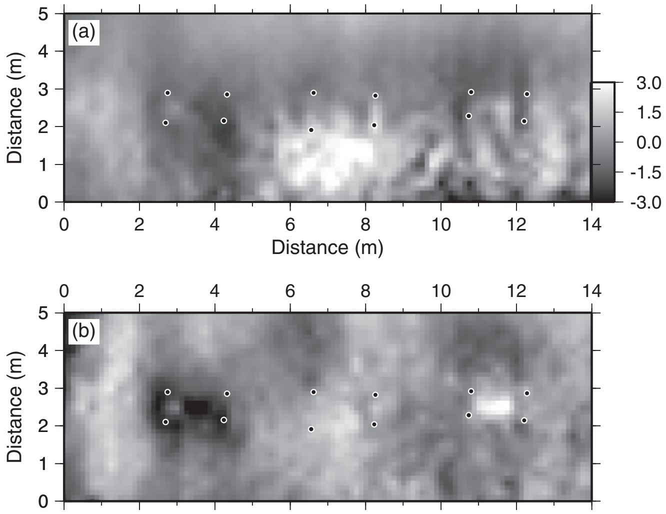

Fig. 1. Example processed resistivity survey datasets, showing the resistivity responses of the three graves (a) in late summer (August 2009), and (b) in early spring (March 2010), and demonstrating the seasonal variation in the data. Common scale is standard deviation. The grave corners are indicated by white circles with black centres; the pig grave is on the left side of the figure, the empty grave is in the centre, and the wrapped pig grave is on the right. After Jervis et al. (2009b) and Pringle et al. (2012c).

Because the study site and methods of data collection and processing have already been described elsewhere (Jervis, 2010; Jervis et al., 2009b; Pringle et al., 2012c), only a brief summary is provided here. Instead the focus in this section is on the methods used to identify and study seasonal patterns in the resistivity responses of the graves.

2.1. Study site and simulated graves

The site of the experimental work was an area of former garden land in the campus of Keele University in Staffordshire in the UK. The soil at the site was predominantly sandy loam, with fragments of the shallow sandstone bedrock present at about 0.5 m below ground level. It was judged to be a semi-rural environment. The empty grave was created on the 6th of December, 2007, and the pig grave and the wrapped pig grave were created on the 7th of December, 2007. All three graves were 0.5 m deep. The empty grave contained only backfilled soil, and the pig grave and the wrapped pig grave both contained a pig cadaver that weighed approximately 80 kg. The cadaver in the wrapped pig grave was wrapped in a tarpaulin made of woven polyethelene strands (see Jervis et al., 2009b).

2.2. Resistivity survey data collection and processing

Each resistivity survey dataset consisted of measurements made 0.25 m by 0.25 m apart using a twin probe array with a mobile electrode separation of 0.5 m. The array's reference electrodes were placed 1 m apart at a position that was 17 m from the survey area. The datasets used here were collected between the 4th of January, 2008 and the 3rd of December, 2010, which was 28 to 1092 days after burial. These datasets were collected every 28 days up to 728 days after burial and approximately every 30 days from 794 to 1092 days after burial.

During data processing, the values in each dataset were converted from resistance to resistivity by multiplication by an appropriate geometric factor (see e.g. Reynolds, 2011). For the electrode arrangement described above, the geometric factor was $34\pi/49$. The resistivity datasets were then de-spiked by visually identifying and removing isolated outliers, and interpolated to a cell size of 0.125 m by 0.125 m to aid visual interpretation. Each dataset was subsequently de-trended by the fitting and removal of a third order polynomial surface. Each processed dataset was then normalised by dividing its values by the dataset's standard deviation. As a result of trend removal and normalisation, respectively, each dataset had a mean of zero and a standard