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GPR and bulk ground resistivity surveys in graveyards: Locating unmarked burials in contrasting soil types

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ABSTRACT

With graveyards and cemeteries globally being increasingly designated as full, there is a growing need to identify unmarked burial positions to find burial space or exhume and re-inter if necessary. In some countries, for example the U.S. and U.K., burial sites are not usually re-used; however, most graveyard and cemetery records do not have maps of positions. One non-invasive detection method is near-surface geophysics, but there has been a lack of research to-date on optimal methods and/or equipment configuration. This paper presents three case studies in contrasting burial environments, soil types, burial styles and ages in the U.K. Geophysical survey results reveal unmarked burials could be effectively identified from these case studies that were not uniform or predicted using 225 MHz frequency antennae GPR 2D 0.5 m spaced profiles. Bulk ground electrical surveys, rarely used for unmarked burials, revealed 1 m probe spacings were optimal compared to 0.5 m, with datasets needing 3D detrending to reveal burial positions. Results were variable depending upon soil type; in very coarse soils GPR was optimal; whereas resistivity was optimal in clay-rich soils and both were optimal in sandy and black earth soils. Archaeological excavations revealed unmarked burials, extra/missing individuals from parish records and a variety of burial styles from isolated, brick-lined, to vertically stacked individuals. Study results, evidence unmarked burial targets were significantly different from clandestine burials of murder victims which are used as analogues.

1. Introduction

Globally graveyards and cemeteries are suffering from a chronic lack of burial space, for example in the UK there is a need to accommodate ~140,000 burials every year [1], but a 2006 U.K. Government report listed less than 1/4 of the current burial grounds have room to accept new burials [2]. In addition, only 20% had designated land as yet unused, with them expected to be filled within 25–30 years [3]. In the same report comparatively shallow graves are even being utilised. There has been the rapid expansion of so-called 'green' burial sites, for example, over 200 created in the UK since 2004 [4]; these taking up some of the demand although having a variety of burial styles [5]. Re-use of existing graveyards and cemeteries is one solution, for example, burial regulation relaxations have been in force in London since 2005 [2]. However, burial records, if present, rarely indicate burial positions, and even gravestones are not always reliable indicators as [6] documents; with [7] suggesting some gravestones may have been rotated for optimal viewing from passing paths, or even moved. Different countries also have different rules on the removal of human remains, for example, the United States generally leave remains *in situ* in perpetuity, the United Kingdom have a common 100 year rule although this is variable [7], whereas in Germany remains can be moved when only 25 years old [6]. In order to determine the positions of unmarked burials, probing methods (see [8]) would not be deemed considerate of religious and social sensitivities, and thus the use of non-invasive detection techniques should be considered.

Other authors have used remote sensing methods including aerial photography and satellite imagery, to identify unmarked burials (e.g. see [9–10]), and thermal imaging equipment either mounted on aircraft [11] or hand-held (e.g. see [12]). [13] identified historic (150–160 years old) unmarked graves using aerial photographs and confirmed positions by subsequent geophysical surveying. Forensic geomorphology methods have also been utilised for burial detection [14]. Localised vegetation growth may also have different characteristics to background areas, for example, different species and with more or stunted growth [15–16] that [17] attributes to localised pH soil changes and differing ground characteristics. [18] give a comprehensive overview of current commonly-used terrestrial search methods and relevant case study examples.

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One potential ground-based, non-invasive detection method is near-surface geophysics. Magnetic surveys are commonly used to detect near-surface geotechnical targets (see [19]). Magnetic surveys for clandestine burials of murder victims have had varied grave detection success (see [20]), although detection using magnetics for ancient archaeological graves have been successful (e.g. see [21]). [22] and [23] encountered difficulties in locating 19th century graves in cemeteries and a mass grave from 1921, respectively, using magnetic methods. Above-ground sources of magnetic interference seem to cause significant issues with this technique as [18] note. [24] showed fluxgate gradiometry equipment was successful to detect 20th century graves in an Australian cemetery.

Electro-magnetic (EM) surveys have shown to have variable detection success; [25] did locate and characterise unmarked burials in Jordan, with resulting target(s) contrasts with background levels dependent on the proportion of silt present within the graves. [26] attempted to locate unmarked graves in a New Zealand cemetery, but was largely unsuccessful due to differentiating anomalies from background effects caused by both fence boundaries and local topography. [27] undertook an EM survey over historic North American Indian burial grounds and identified over 60 anomalies, where previous excavations had found burials >2 m bgl; but here there were no above-ground interfering structures present. Interestingly [26] found that the ‘head’ ends of unmarked graves were easier to identify than the ‘foot’ ends for reasons that were unclear. [28] was also successful in locating a 12 year old unmarked clandestine burial of a murder victim in woodland.

Bulk-ground electrical resistivity surveys should be less affected by above-ground interference by physically inserting probes into the ground (see [29]). Resistivity surveys have been successfully used to locate unmarked burials in cemeteries (e.g. [30–31]), although local variations in soil moisture content, particularly when surveying in dry conditions in heterogeneous ground, affected many surveys by masking target locations (e.g. see [22]). [29] showed obtaining data from areas surrounding graves can be problematic due to inability for probes to penetrate concrete, tarmac or other hard surfaces. Electrical resistivity surveys for clandestine burials of murder victims have also been undertaken with mixed success (see [32–34]). Long-term monitoring studies of simulated clandestine burials of murder victims have shown electrical resistivity methods should resolve burials, although detection success depends on burial style, soil type and time since burial (see [35]). Optimum surveys have also been shown to be undertaken during winter months; in dry conditions numerous non-target anomalies are present due to differential drying of heterogeneous soil (see [36]). Simulated studies also evidence that decompositional fluids may be the dominant factor for detecting murder victim clandestine graves (see [35,36]) which may be retained in grave soil for considerable periods of time post-burial (see [20]) that is detected electrically.

Ground penetrating radar (GPR) has been used to locate unmarked grave burials in graveyards and cemeteries with varying degrees of success (e.g. [6,22,24,32,37–42]), and indeed of a suspected clandestine burial of a murder victim within a graveyard [43]. Suggestions by [13] suggest optimum 200–400 MHz frequency antennae for unmarked burials. Long-term monitoring studies of simulated clandestine burials of murder victims have again proved useful in determining optimum antennae frequency for detection and effect of local soil type and burial environment (see [35,44–47]). That said, there was wide variation on optimum GPR antennae frequencies for clandestine graves of murder victims, with suggested frequencies commonly varying from 110 MHz up to 800 MHz. There have also been studies which document rapidly-dug grave burials for mass fatalities (19th Century Irish Potato famine ([13]), early 20th Century Spanish Flu victims ([48]) and animal disease outbreaks [49] respectively, which evidence depths of burial significantly shallower than 1.8 m below ground level or bgl. GPR has become the geophysical tool of choice for unmarked graves due to detection success, but may not be suitable in all occasions, for example, where clay-rich and saline soils are present in survey areas where radar waves become rapidly attenuated (see [19,50]). This poses problems in certain countries, for example the UK has soil types which are dominantly clay-rich [51]. However some authors (e.g. [26]) have determined low frequency GPR antennae could be used in some clay-rich soils to identify likely burial positions. GPR data processing also requires a good understanding of radar theory, and specialist operators or training of non-specialists; either of which is costly.

An opportunity arose to assist in the detection of unmarked burials in three geographically spread U.K. graveyards by separate archaeology and clergy approaches. Using these study results and the wider literature, the overall aims of this forensic archaeology geophysical paper are: Firstly identify the locations of any unmarked graves and/or burial plots/vaults within the respective survey areas. Identified remains could then be exhumed and re-interred elsewhere by archaeological teams (if necessary). Secondly to compare GPR and resistivity geophysical equipment configurations, data acquisition strategies and processing methods to determine best practise for unmarked burial detection in burial grounds. Thirdly to provide examples to assist with determining the effect of differing soil type on geophysical surveys and burial detection. Fourthly and finally, to quantify the variety of burial styles present in these cases, their geophysical responses and comparison to clandestine burials of murder victims.

2. Case study 1: St. James’ Church, Newchapel, Staffordshire, UK

2.1. Case study 1: Background

St. James’ Church in Newchapel village (SJ 8623 5450) lies ~220 m above sea level on a hill in the north-east of Stoke-on-Trent, UK (Fig. 1). A clay-rich soil overlay the Carboniferous Coal Measures Formation sandstones bedrock geology. However, three boreholes drilled for site investigation (Fig. 1 for location) found the top 2 m bgl comprised predominantly of ‘made ground’, gravelly clay, occasional brick and coal fragments, with an average moisture content of 16% [52]. A stone chapel was on site by 1573 but was rebuilt in brick in 1766 and 1777, and again in 1878–1915 due to mining subsidence [53]. Burial within the churchyard was underway by 1722, although earlier interments may have taken place. The burial ground was periodically extended between the late 18th and early 20th century. In 2004 planning permission was granted for a community hall over part of the graveyard (Fig. 1). An existing plan identified 18 separate grave plots, within the proposed development area, each marked by a memorial stone (Fig. 1 and Table 1). It was estimated that these plots represented the burial of up to 68 individuals, interred between 1821 and 1966.

After memorials had been cleared, an archaeological team was on site during removal of ~1.4 m of mechanical soil clearance within the development area. This operation not only revealed the presence of several known burials (Fig. 1), but also two unmarked graves (marked A and P in Fig. 1). Geophysicists at Keele University were subsequently contacted to help identify any additional unmarked burials within the area.

2.2. Case study 1: Geophysical data collection and processing

Upon arrival on site, three of the burials exposed within the survey area were already being archaeologically excavated (Fig. 2). A N-S orientated survey grid was established with 0.5 m spaced lines, avoiding both areas of archaeological excavations and