**ABSTRACT**

Police witness intelligence stated a murdered adult male “Fred” had been vertically buried in wooded hilly terrain 30 years ago in the Midlands, UK. Conventional search methods were unsuccessful; therefore, the Police requested a geophysical investigation to be undertaken to determine if “Fred” could be detected.

A multi-phased geophysical approach was conducted, using bulk ground conductivity and metal detectors, then follow-up magnetics and GPR survey profiles on EM anomalous areas. A tight grid pattern was used to account for the reduced target size. Relatively high-resolution EM and GPR techniques were determined optimal for this terrain and sandy soil. Geophysical anomalies were identified and the most promising intrusively investigated, this was found to be a large boulder and tree roots.

Study implications suggest careful multi-phase geophysical surveys are best practice and give confidence in cold-case searches. This study yielded a no-body result, effectively saving Police time and costs from further investigations.

**KEYWORDS**: forensic science, geoscience, cold case, GPR, EM, excavation

The use of forensic geoscientific techniques and methods in the search for clandestinely buried objects is increasing; as locating forensically important materials is crucial for criminal convictions to proceed (1). Current forensic search methods to detect both isolated and mass clandestine burials of murder victims are highly varied and have been reviewed elsewhere (1,2), with best practice suggesting a phased approach, moving from large-scale remote sensing methods (3) to ground reconnaissance and control studies before full searches are initiated (4). These full searches have involved a variety of methods, including forensic geomorphology (5), forensic botany (6) and entomology (7), scent-trained search dogs (8,9), physical probing (10-12)), thanatochemistry (13,14) and near-surface geophysics (15-23).

Forensic search methods vary widely; for example, in the U.K., a search strategist is usually involved in a case at an early stage to decide upon the highest probability of search success (4), whereas in other countries, a search may not be methodical, investigations may not be standardized, and a variety of techniques may be undertaken, depending upon local experience (24). Metal detector search teams (11,25,26) and specially trained search dogs (8,26,27) are both commonly used during either initial investigations or as part of a phased sequential program. Forensic investigators have been increasingly using geoscientific methods to aid in civil or criminal forensic investigations, predominantly to assist search teams or for trace evidence analysis purposes (28-30). One key and high-profile “target” for forensic search teams to detect and locate is human remains buried within clandestine graves (4,26,31).

Searches generally start from large-scale remote sensing methods (32,33), such as, aerial and ultraviolet photography (30,34), thermal imaging (34), to ground-based observations of vegetation changes (11), surface geomorphology changes (5), soil type (4) and depositional environment(s) (30), near-surface geophysics (1), diggability surveys (4) and probing of anomalous areas (10,12) before topsoil removal (11), and finally controlled excavation and recovery (26,35,36). A typical search will only use a few of these techniques, depending on the circumstances in the individual case.

Near-surface geophysical methods rely on there being a detectable physical contrast between the target and the background (or host) materials (see (37)). Near-surface geophysical surveys have been used to try and locate clandestine graves in a number of reported criminal search investigations (17-23,25,26,38-42). Geophysical surveys collected over simulated burials have also been undertaken to collect control data (e.g. (15,43-46)). These control studies have shown that the geophysical responses in active cases could be predicted, although responses seem to vary both temporally after burial and between different study sites. A few studies have also collected repeat (time-lapse) geophysical surveys over controlled experiments (e.g. (18,47-57)), which have documented temporal changes in geophysical responses over their study periods.

Case background

Intelligence received and assessed by Staffordshire Police suggested the presence of a criminal clandestine burial over 30 years ago at an isolated, rural location. This intelligence included witness testimony that identified the location, the nature of the crime (that a male “Fred” had been shot in the head) and the mode of burial was thought to have been vertical, presumably to avoid detection. The authors are not aware of any other forensic cases where a body has been proven to be buried vertically – usually they are found buried horizontally at shallow depths, typically 0.5 m below ground level (bgl) (Fig. 1).

Police Service ground search teams examined the area and specialist victim recovery dog (VRD) teams had also been deployed, although the VRDs had not pinpointed a specific site. The support of the UK’s National Crime Agency (NCA) was sought and the National Search Advisor then facilitated the involvement of experts in the application and deployment of near surface geophysics as part of a blended search operation. One particular ring of trees near to other landmarks, recalled by the witness, was designated as the search area. The authors were then approached in order to assist the investigation, initially using available remote sensing data and historical information, before a phased geophysical and intrusive ground investigation approach was utilised, near to the landmark where the witness had indicated the alleged burial.

The aims of this paper are therefore; *firstly,* to document the geoscience investigations that were undertaken to search for Fred and *secondly*, discuss how such scientific investigation findings can aid Police Services in future cold case searches.

FIG 1 here.

**Methods**

*Desk study*

The survey area, situated ~100 m above sea level, was on an eastward-facing slope above a small stream, with thick sandy soil (up to ~30 m from nearest borehole records) overlying Triassic Kidderminster Formation sandstone and conglomerate bedrock (Fig. 2). The local climate is temperate, which is typical for the Midlands of the UK. Historical maps, acquired back to 1900, evidenced that there had been no changes/structures within the study site in the last 117 years. Three GoogleEarth™ satellite images were also available of the study site, all showing no changes albeit significant-sized, mature deciduous trees were present and growing at the study site (Fig. 2).

*Site reconnaissance*

A site reconnaissance, for orientation purposes, was initially conducted, which confirmed the ~20° slope, difficult ground and 11 mature deciduous oak trees to be present on the identified 26 m x 21 m site, as well as fallen dead oak. There were also no observable potential above-ground sources of interference (e.g. metal fences, power cables, etc.) for geophysical surveys (Fig. 3). A soil auger survey was also used to extract 0.75 m of top soil within three locations in the survey area which confirmed that, beneath about 0.05 m of fallen organic matter, the soil was a dry, oxidised sand, with a strong brown colour (7.5YR/5/6 on the Munsell chart). The soil also contained numerous quartz pebbles.

FIG 2 here.

FIG 3 here.

*Trial geophysical surveys*

Trial geophysical surveys, comprising two profiles, were also undertaken using electro-magnetic conductivity, ground penetrating radar (GPR) and electrical resistivity equipment, in order to determine their suitability and effectiveness at the survey site. These showed generally good results, with 250 MHz GPR showing good penetration depths, 500/1000 MHz frequency data showed numerous near-surface anomalies that were, most probably, associated with either large oak tree roots or sandstone cobbles. A Bartington™ MS2D magnetic susceptibility meter, with 20 cm survey loop, was used to collect ~100 5s readings (also each sampling position was repeated three times) to determine the abundance of magnetic minerals within the soil; results averaged 533 x 10-6 SI which is reasonably high for soil – presumably due to igneous clasts being present in the bedrock sediments. In contrast the resistivity surveys, using a Geoscan™ RM15-D resistivity meter with both 0.5 m and 1 m-spaced probes and with the widest remote probe spacing possible, showed that soil resistances were too high for resistivity data to be collected at this site.

*Metal detector surveys*

The specified 26 m x 21 m survey area was then carefully surveyed using a Bounty Tracker™ IV metal detector, in order to identify whether there was any surface metallic debris present onsite. Surface metal debris would interfere with any magnetic surveys being collected and may also prove to be of evidential value. Although data processing can remove their signatures from magnetic and conductive datasets (see (59) for details who undertook this at Stonehenge to remove surface anomalies created by 1970s festival debris from an EM dataset), it is simpler to identify and carefully remove surface metallic objects before conducting geophysical surveys, whilst also potentially recovering items of forensic significance.

*Bulk ground conductivity surveys*

A Geonics™ EM31-Mk2 conductivity meter, with 3.6 m-separated coils and linked to a Garmin™ 60 GPS unit for data spatial positioning, was initially calibrated and ‘nulled’ before being used to collect in-phase and quadrature EM values on ~1 m spaced sample positions over the site using the Horizontal Mode (HMD) orientation (see (60) for details), which should penetrate ~8 m below ground level. This technique is commonly used for initial surveys as it is relatively quick to acquire EM data and pinpoint anomalous areas for further, higher resolution, geophysical investigations (see (1,17)).

A GF Instruments CMD Mini-explorer™ conductivity meter, which contained three separated coils at 0.32 m, 0.71 m and 1.18 m respectively, and was used in ‘high frequency’ mode which gave these coils effect depths of 0.5 m, 1 m and 1.8 m respectively. It was initially calibrated and then used to collect in-phase and quadrature values on 0.5 m spaced data points on the 21 m x 26 m survey grid. To the authors knowledge this instrument has not been used on a forensic search before, although it has been used in archaeological settings (61). Equipment advantages are that it recorded three different coil spacings at each measurement position on the data logger, which effectively measured three different depth ranges, 0 m - 0.5 m, 0 m – 1 m and 0 m - 1.5 m respectively.

EM downloaded data was processed by: (1) initial EM31 spatial positioned by Trackmaker31 v.121 before, (2) EM data despiking to remove isolated anomalous data points and, (3) importing into ARCGIS ArcMAP™ v.10 software and a digital, colour contoured surface generated using minimum curvature through the Geostatistical Analyst extension before finally, (4) being converted to a mapview image before being annotated in Coreldraw™ v7 graphics software.

*Magnetic gradiometry surveys*

A Bartington™ Grad601 magnetic gradiometer was initially calibrated before being used to collect gradiometry data at 0.25 m spaced intervals between 7 m and 16 m on the survey grid. This dataset was collected after the EM surveys, so was used to check the isolated anomalies located in the EM datasets, and identify if they were magnetic or not. The magnetic data was downloaded before the same EM data processing steps 2-4 were undertaken.

*GPR surveys*

Following the initial trials, Sensors&Software PulseEKKO™ Pro GPR equipment, using 250 MHz dominant frequency with fixed antenna spacing, a constant 0.05 m radar trace spacing and repeat 32 ‘stacks’, were used to survey the 52 0.5 m spaced survey ‘X’ lines. Ideally this would also be undertaken on ‘Y’ cross-lines but was not due to time constraints. 2D GPR profiles were processed using Reflexw™ v.8.5 software. Each profile underwent a series of standard sequential data processing steps (see (60)): (1) correct for maximum phase, (2) move start time, (3) dynamic correction, (4) bandpass Butterworth 1D filter; (5) background removal 2D filter; (6) Gain function, which boosts deeper reflections within the profiles. Profiles were then (7) imported into graphical software and anomalous positions identified, before being incorporated into mapview positions.

**Results**

*Metal detector*

The initial metal detector surveys identified and recovered six metal objects within the study area, including a metal drink can top, nail, rock, foil and a metal bolt. This bolt looked of forensic interest, so was further analysed. Detailed binocular microscopy image analysis was carried out, along with scanning electron microscopy with energy dispersive analysis to determine the metal composition (Fig. 4). The mass of the bolt was measured to determine whether the cylinder was solid or hollow. Based on the examination of this item, it was suggested to be a metal expansion bolt, possibly keeping a trailer door shut (Fig. 4).

FIG 4 here.

*EM surveys*

The EM31 1,267 datapoints collected for this study was generally very geophysically quiet, with quadrature values being -0.47 mS/m min, 0.02 mS/m average and 0.48 mS/m maximum (0.02 SD) conductivity values, and in-phase values being -2.11 ppt minimum, -0.56 ppt average and -1.03 ppt maximum (0.02 SD) conductivity values respectively. There were large conductive low anomalies, with respect to background values, at the north-west of the survey area and large high anomalies, with respect to background values, in the survey site centre and to the south-west of the survey site (Fig. 5). However, the comparatively widely spaced data points and poor resolution made this instrument not optimal to find any clandestine burials in this study.

FIG 5 here.

The EM CMD 2,587 data points collected for the three depths were variable, for the 0-0.5m dataset, in-phase -3.33 ppt min., 12.06 ppt average, 23.15 ppt max. (1.04 SD) and quadrature -1.81 mS/m min, -1.5 mS/m average, -1.3 mS/m max (0.07 SD), for the 0-1m dataset, in-phase -2.14 ppt min., 1.74 ppt average, 7.95 ppt max. (0.62 SD) and quadrature -1.08 mS/m min, -0.94 mS/m average, -0.84 mS/m max (0.05 SD), and for the 0-1.5m dataset, in-phase 2.07 ppt min., 3.15 ppt average, 7.4 ppt max. (0.38 SD) and quadrature -1.2 mS/m min, -0.88 mS/m average, -0.67 mS/m max (0.06 SD) respectively. EM isolated high anomalies, with respect to background values, were observed in the in-phase data to the south-east of the study area and on the western boundary (Fig. 6). Where anomaly positions were present at all three depth datasets, this gave more confidence that an object may be present at the respective location. The CMD quadrature data proved less useful in this case study (Fig. 7).

FIG 6 here.

FIG 7 here.

*Magnetic gradiometry surveys*

The magnetic gradiometry 1,326 data points had -0.1 nT minimum, 3.7 nT average and 18.5 nT maximum values (1 SD), with one isolated high anomaly, with respect to background values, at the north-east of this dataset (Fig. 8).

FIG 8 here.

*GPR surveys*

The 2D GPR processed profiles showed 29 isolated half-hyperbolic reflection anomalies in the near surface that would be present if a near-vertical burial was present within the survey area (Fig. 9); Small anomalies, very close to the surface were, most probably, tree roots or cobbles (Fig. 9).

FIG 9 here.

FIG 10 here.

*Geophysical summary*

After the initial EM surveys and the follow-up magnetic, metal detector and GPR surveys, the resulting datasets were interpreted and summarised to identify promising areas for subsequent intrusive investigation (Fig. 11). One area stood out with EM, metal detector and GPR anomaly present within a relatively small area (see Fig. 11); this was decided to be subsequently intrusively investigated.

FIG 11 here.

*Intrusive investigations*

Following a review of the geophysical datasets, permission was given by the Police Service for the priority area identified (Fig. 10) to be forensically investigated. Leaf litter and debris was cleared away from the area of interest, exposing the surface soil. On visual inspection there was no evidence of ground depression, which is often indicative of a grave site (1). An area approximately 2 m x 3 m was cordoned off, a plastic tarpaulin placed a short distance away. Any soil removed from the site was placed on the tarpaulin, should it need to be examined at a later date. Digging implements such as spades and shovels were then used to start removing the surface layers within the cordoned area. It was noted that the soil was very compact, indicating that there had been no recent disturbance, either human or animal. When approaching a depth of ~0.4 m, the authors switched to hand trowel’s and began carefully removing layers of soil using a horizontal rather than vertical digging action to avoid damaging any potential evidence. This continued until objects were uncovered at a depth of ~0.5 m. On inspection it was noted that the anomaly consisted of a large (~0.4 m cm diameter) tree root and a ~0.3 m diameter sandstone boulder (Fig. 11). No other items, or indeed evidence of previous digging, were visible down to 1 m bgl so the hole was refilled with the excavated material.

FIG 12 here.

**Discussion**

Every case is unique as discussed by many others (see (1,2)), but the case study presented here illustrates the advantages of the use of forensic geoscience techniques in the assistance of cold case investigators, to assess, characterise and then carefully conduct invasive examinations of specified survey areas, as few other studies have done, although note Nobes’ (17, 22,23) efforts.

This case was especially challenging due to the time (30+ years) since the victim was thought to have been buried, the difficult rugged and wooded terrain (although the cases described by (22,23) were in similar terrain), and, most importantly, the burial style, thought to be a vertical burial (Fig. 1a), which the authors have not seen in any other case study. The burial style made the horizontal ‘footprint’ target of the suspected clandestine burial very small, again making any identification of a grave to be problematic even in ideal conditions. The presence of numerous magnetic igneous clasts in the soil also made interpretation of magnetic surveys difficult due to numerous non-target anomalies being detected.

This case has demonstrated deployment of multi-geophysical surveying techniques, using initial geophysical trials, before phased sequential deployment of relatively low-resolution EM (EM31) methods, followed by higher resolution EM (CMD) methods, magnetic gradiometry and medium-frequency GPR methods. Relatively high resolution EM and GPR techniques were determined to be optimal in this rugged wooded terrain and sandy soil survey site. A full GPR grid should be collected at other sites as this would give higher confidence in GPR results rather than only surveying in one direction. The presence of tree roots was also problematic in giving false positives as other researchers have shown (17). Initial metal detector surveys also swept for surface metallic debris that would reduce geophysical ‘clutter’ from subsequent surveys, as well being of potential evidential material as other authors have shown (e.g. (21)). Combining different techniques gives more confidence in targeted anomalous areas for subsequent intrusive investigations (as (17) documented).

Obviously, no human remains were found in this cold case investigation. This is due to two reasons; (1) either ‘Fred’ was within the survey area specified and was not geophysically detectable using the search methods employed, or (2) he was not present in the specified survey area. If (1) was true, then other methods may have been useful to employ, for example, a more sensitive metal detector, or indeed a multi-frequency GPR system, collecting GPR on an xy grid orientation, with the caveat that many more tree roots/boulders may be identified as geophysical anomalies. A more rigorous intrusive investigation phase could also have been undertaken, extensive probing and victim recovery dogs being run over the area, or indeed removing the top 30 cm of leaf litter within all of the specified survey area, to look for evidence of disturbed ground/grave cut as (1) reviews as best practice.

Further work should include a controlled experiment of a vertically buried pig in a similar depositional environment and soil type, in order to determine if it is possible for geophysical survey techniques to detect it at various stages of decomposition, and which method is optimal, including equipment configurations, which is commonly undertaken for other burial styles (see, for example, (51,52,57)).

This case was not time limited as it was a cold case, hence a phased, multi-site visit and multi-geophysical technique approach was appropriate. In contrast, a ‘live’ active missing person case (see, for example, (62)), would have a similar methodology but with the recognition of the time constraints, perhaps data would be processed onsite between techniques and results reviewed, which should have the caveat that this may reduce the potential detection rate if done in haste. As with any live case, the deployment strategy and choice of search techniques must remain flexible to accommodate a changing intelligence picture.

This paper demonstrates that geophysical methods can be used appropriately to assess, characterise and pinpoint subsequent anomalous areas within a specified survey site for intrusive investigations to test with a high degree of assurance whether or not a body is present within such a rugged and wooded terrain. The widespread adoption and routine use of forensic geophysical support methods could, and should, be utilised by forensic search practitioners at local, national and international levels.

**Conclusions**

This study has importantly illustrated how a multi-phase geophysical survey of a cold case location can aid specialist search officers, in this case confirming that no body was buried within the identified survey site of interest. In the case presented, the target of interest was a murder victim who was vertically buried over 30 years ago. Relatively high resolution EM and GPR techniques were used and were determined to be the optimal method in the rugged wooded terrain and sandy soil. A report was subsequently forwarded to the Police Service, providing the study findings and leading to the closure of the investigation. This study emphasises the fact that forensic geoscience multi-phased surveys should be commonly utilised. Such a multi-phase approach by cold case investigators, when they are looking to identify the location of missing remains, may save police time.

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**List of Figures**

FIG. 1**.** *Schematics of murder victim clandestine burial depositional scenarios. a. this case of a vertical body and b. more typical horizontal body burial style. Note there is a smaller (plan view) target size of this case compared to the typical burial scenario.*

FIG. 2**.** *GoogleEarth sequential images of the study site (white box) taken in: a. 31/12/2003, b. 31/12/2010 and c. 27/05/2017.*

FIG. 3. *Photograph of the study site (looking north) showing the hilly deciduous wooded terrain, rucksack for scale (modified from (58)).*

FIG. 4. *Metal object recovered by the metal detector survey. a. annotated photograph with weights and dimensions. b. Scanning electron microscope image and energy dispersive spectra for flakes removed from the surface of the object. c. likely modern equivalent.*

FIG. 5. *Processed and annotated bulk ground conductivity EM31 in-phase (left) and quadrature (right) contoured datasets, black dots indicating sample positions. Rectangular outline shows relative position of Figs. 6-11 (modified from (58)).*

FIG. 6. *EM CMD Mini-explorer in-phase data results for a. 0-0.5 m, b. 0-1 m and c. 0-1.5 m respectively. Black dots indicate sampling positions. High/low anomalous locations, with respect to background values, are indicated (modified from (58)).*

FIG. 7. *EM CMD Mini-explorer quadrature data results for a. 0-0.5 m, b. 0-1 m and c. 0-1.5 m respectively. Black dots indicate sampling positions. High/low anomalous locations, with respect to background values, are indicated (modified from (58)).*

FIG. 8. *Magnetic gradiometry data collected over part of the survey area. Black lines indicate sampling positions. High/low anomalous locations, with respect to background values, are marked (modified from (58)).*

FIG. 9. *GPR 2D 250 MHz processed selected profiles showing features of interest. As the GPR data was collected in a grid pattern, horizontal time slices could be generated, with the 10 ns – 20 ns shown in Figure 10.*

FIG. 10.*GPR 10 ns – 20 ns time-slice data over the study site. Note the two negative amplitude anomalies are where two large trees were present within the survey area, precluding data being collected at these locations.*

FIG. 11. *Summary diagram giving the geophysical anomaly locations from the respective EM geophysical surveys (CMD, GPR and metal detector) undertaken on the study site (see key and text for details).*

FIG. 12. *Photograph of the excavation of geophysical anomaly A1 (Fig. 10 for location); a large tree root and sandstone boulder were discovered at ~0.5 m depth bgl.*