Case Report

Electrical resistivity survey to search for a recent clandestine burial of a homicide victim, UK

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1. Introduction

Common practice in forensic searches for clandestine burial site(s) can include a variety of conventional and geoforensic search methods, e.g.; remote sensing [1-2], site walk-overs [3], cadaver dogs [4], methane [5] and soil probes [6-7], near-surface geophysics, which includes metal detectors [8-11], geochemical surveys [5] and mass excavations [12]. Current UK search best practice suggests creating a conceptual target (and geological) model of the suspected burial site, using available site, case, intelligence and other information, prior to undertaking fieldwork to maximise the chances of detection (see [13]).

Near-surface geophysical surveys have been shown to be successful at locating near-surface buried remains, albeit dominated by the Ground Penetrating Radar (GPR) method [9, 14-18]. However, whilst generally accepted to have the highest resolution, GPR investigations may not be suitable in certain sites, for example in large survey areas or where soils have very high clay contents that rapidly attenuates radar signal that results in poor penetration depths being attained [19]. In such cases, electrical resistivity geophysical surveys could be used instead to identify anomalous areas for follow-up investigations (eg higher resolution GPR surveys and/or intrusive investigations). Resistivity surveys have been undertaken in criminal investigations [11,20], graveyards [21-22] and controlled experiments [23-25]. Successful target detection has been found to be predominantly due to elevated conductivity levels of decomposing body fluids relative to background values [22,25,-26]. Elevated elements [27-29] and volatile organic compounds [30-31] amongst others have also been reported within ‘grave soil’.

2. Background

2.1 Geographic location-description

The suspected burial site was located in north Wales in the United Kingdom, around 50 m above sea level (**Fig. 1**). The local climate is temperate, which is typical for the UK. Local meteorological station data show that average total monthly rainfall varied between 44 to 91 mm, with a 2008 monthly and yearly average of 65.7 mm and 788 mm respectively. 2008 average monthly air temperatures ranged from 5.8 ºC to 12.5 ºC, with an overall average of 9.1 ºC.

The survey area was within field H, one of a series of rural, open grassy fields, separated by deciduous hedges with isolated mature oak trees (**Fig. 1-2**). These search fields were determined by covert Police surveillance of the chief suspect’s movements. An old borehole record on the survey site showed the Carboniferous (Westphalian) Etruria Formation mudstone bedrock to be present ~20 m below ground level (bgl) with overlying alternations of clay-rich Devensian Age glacial till, sand and gravels forming the soil that is typical of this part of the UK. The local water table was 1 m bgl recorded in the borehole. The surrounding region had been heavily coal-mined during the 19th and 20th Centuries, with numerous shafts sunk, although the last closed in 1968. A few relict spoil heaps remain in the area, albeit mostly now mostly landscaped (**Fig. 1-2**). Preliminary site reconnaissance confirmed the local soil to be not only very clay-rich and water-logged, but also contained numerous varied sized (typically pebble- to cobble-sized) sandstone and mudstone rocks on the surface, presumably due to past coal-mining activities.

2.2 Forensic case investigations

At the time of the geophysical surveys (18th to 20th November 2008), the suspected victim had been reported missing for 10 months or ~345 days based on Police Service intelligence best estimates. Using [32] methodology, this would equate to approximately 3,600 Accumulated Degree Days (ADD), based on local averaged daily temperature data. The suspected female victim was slight in stature although around average height (1.7 m). Police intelligence suggested the victim may have been buried, and could be either clothed, naked, wrapped in plastic sheeting or within a suitcase. A metal spade may also have been present with the body; therefore a separate search team were using conventional metal detectors to progressively search the targeted fields. Previous unsuccessful searches for locating the victim in fields A-I (**Fig. 1**) had used a variety of methods, including conventional site walk-overs (pin-pointing local topographic variations and physical probing) and use of trained victim recovery dogs.

2.3 Geophysical survey type

Due to both the significant search area and the very high clay soil content precluding a GPR survey, an electrical resistivity survey was instead trialled within a Police-specified area within field H, centred on a field entrance (**Fig. 1**). This area was decided to be investigated first, with the premise that all the targeted fields needed to be investigated, concentrating on the areas around all the field(s) entrances.

The potential body deposition style is also important for electrical surveys as, depending upon site conditions, a wrapped or enclosed body can produce a significantly different resistivity affect when compared to a naked one [25]. However, regular geophysical monitoring of simulated clandestine burials, using pig cadavers on a test site, allowed predictions of the potential anomaly size and amplitude to be made with respect to background values (**Fig. 3**). The simulated burial electrical resistivity surveys imaged a resistive low (-3 Ω) anomaly over a naked cadaver and a comparatively smaller high resistivity anomaly (+3 Ω) over a wrapped cadaver when compared to background values (**Fig. 3**). Note however these anomalies do vary over time post-burial in both anomaly size and amplitude when compared to background values. The wrapping around the pig cadaver was also semi-permeable; therefore an early resistivity survey was used to compare with the survey datasets. The simulated grave soil type (sandy loam) was also quite different from the survey area (clay). The pig cadavers were also a slightly larger size than the suspected victim, and were buried approximately one month before the suspected victim. Previously developed robust data processing allowed user-specified but automatic quantification of any resistivity high and low anomalies from background values to be identified (see **Fig. 3** and [25]).

3. Method

A Geoscan™ RM-15 multiplex resistivity meter with a 0.5 m constant spaced, twin-probe configuration, with 1 m spaced, reference probes placed 16 m from the closest grid corners, following standard procedures was used [33]. Stainless steel probes were 0.1 m long and each penetrated ~0.05 m into the ground at each sample position. Due to the potentially small target and significant search area (~400 m by ~20 m), a 0.5 m by 0.5 m sample spacing was used. Although the resistivity equipment used required data to be acquired in a grid, it did allow three adjacent sample point measurements to be acquired and automatically digitally recorded at each position, thus significantly speeding up data collection. Care was taken, however, to ensure any resistivity anomalies were not due to any small rocks or metal detector team digging holes encountered during surveying; where necessary sample positions were not acquired or were re-acquired, although these corresponded to only ~10 resistivity sample positions.

As the cable connecting the reference probes to the mobile probes was ~50 m long, it was necessary to move the reference probes before starting some grids. The mobile probes were left in the last position; the remote probes were then repositioned as described above (i.e. 16 m from the grid edge) with their spacing varied until the same resistivity value observed at the previous remote probe position was obtained. Some of the 30 m by 30 m survey grids needed to be rotated from a linear base-line so as not to miss any areas; this also meant some grid overlap (**Fig. 4**). 10 resistivity grids comprising 21,667 sample points were collected over three days by a two-man field team.

Resistivity grid corner points were located using Leica™ 1200 Real-Time Kinematic (RTK) differential Global Positioning System (dGPS) equipment, with an average measurement (XY) accuracy of 0.018 m being recorded. Where necessary (eg beneath a tree), the corner points were mathematically calculated using the closest surveyed sample position. Shallow water-filled holes left within the survey area by the metal detector teams were also surveyed to check that any subsequent resistivity anomalies were not due to these holes. A field entrance gate-post and other static reference points were also surveyed each day to check system accuracy, merge different survey day co-ordinate datasets and translate geophysical sample positions from their local grid to standard UK Ordnance Survey (OSGB) co-ordinates. The field boundary and associated road edge were also surveyed. All survey positions were then digitally integrated with topographic (1:10,000) Ordnance Survey/EDINA™ supplied maps within ArcGIS™ ArcMap 9.1.3 software.

Resistivity data grids were processed using the open source GMT computer software. A minimum curvature gridding algorithm [34] was then used to create a digital gridded surface from each raw resistivity grid (x,y,z) data, using 0.5 m by 0.5 m sized cells for each grid. Removal of long-wavelength site trends from resistivity data is a standard processing technique (see [19]) and has been shown to aid grave location [23-25]. Data site trend removal was achieved by fitting a third order polynomial surface to the gridded datasets and then subtracting the polynomial surface from the gridded data. Individual processed data grid images were then rotated where necessary and merged with the surveyed grid corner point positions within CorelDRAW v.12 software.

Analysis of the simulated test site data (**Fig. 3**) suggested that a similar-sized body buried for a similar time period at 0.5 m below ground level (bgl) will produce a well constrained relative resistivity anomaly of at least ±3 Ω in detrended and normalised data collected in early winter. The GMT software allowed resistivity contours to be user-specified; therefore ±3 Ω anomalous areas were identified within the data grids. ±2 Ω anomalous contours were also generated to check any potential suspect areas that were not identified with the ±3 Ω contours. Identified anomalies were initially sub-divided and prioritised (A-C where A is the highest) into: (A) possible grave locations; (B) probably due to geological/soil variations (any anomaly >4 m in any direction) and; (C) anomalies probably due to resistivity grid edge effects and small anomalies (the latter <0.5 m areally). Finally the (A) anomalies were further analysed and separated into high or low priorities, with high priority anomalies being of a similar constrained areal size and relative resistivity amplitudes with anomalies measured over simulated graves as previously discussed.

4. Results

There were 25 identified priority (A) anomalies, 74 identified (B) anomalies and 22 identified (C) anomalies over the survey area totalling 121 anomalies (**Fig. 4** for grid 4 example). Of the priority (A) anomalies, there were 7 designated high priority as discussed in the method section that were suggested to be further investigated (**Fig. 5**). Four were positive (A10, A51, A67, A69) and three were negative (A28, A59, A115) resistivity anomalies with respect to background values (**Fig. 5-6**). Both the local grid and UK OSGB anomaly centre point co-ordinates were supplied to the forensic search teams; if intrusive investigations were then undertaken, it was recommended that a ~1m^2 and ~1 m deep excavation should be undertaken at each supplied high priority position.

Grids 1, 2, 7a, 7b, 8, 9 and 10 had relatively few resistivity anomalies, with only one high priority (A) negative anomaly being identified (A115), although it should be noted that this position was adjacent to metal detector team excavated holes (**Fig. 5**). Large resistivity anomalies were present (A1, A1, A97, A105, A114) which were most probably related to either soil moisture changes or different near-surface material being present (**Fig. 5**). There were also linear high resistivity anomalies present through Grids 1, 7a, 7b and 8 which were probably man-made ground works or utility services. The 4A anomaly was most probably due to vehicles compacting the soil in the field entrance gate area.

Grids 3, 3a, 4, 5 and 6 contained many more resistivity anomalies (**Fig. 5**). Anomalies A10, A28, A51, A59, A67, A69 and A74 were designated as high priority (A) anomalies due to their constrained and comparative areal size and resistivity amplitudes to the simulated grave resistivity anomalies. The negative A28 anomaly looked particularly promising as a potential target position. The large anomalies 18A, 23A, 29A, 38A, 47A, 48A, 56A, 66A and 75A were most probably again related to either local soil moisture changes or different near-surface material being present. The low priority high resistivity anomalies present beside the hedge boundary may have been due to the presence of mature oak tree root systems as suggested by other authors [11], although the trees were not surveyed so this cannot be confirmed.

5. Discussion

Every suspected clandestine burial site will be unique, having a different burial style and environment (eg size and associated organic content, depth bgl, wrapping, burial date and time of emplacement), soil types with varying proportions of natural and anthropogenic materials, varying soil conditions (porosities, textures, moisture content, stone content and compaction), micro-climate and associated temperature variations, vegetation, etc, which would all affect potential detection rates (see [13,26,27,35-36].

Conventional searches for clandestine burials of suspected murder victims are always unique; there will always be case specific intelligence, psychology, victim and site variables as well as operational experience, manpower and time available and of course available funds. Traditional search approaches will generally be used first, with trained victim recovery dogs and physical probing of local variations in topography or other suspect areas. However, if these are not successful, such as in this case, then complementary forensic geoscience approaches should be utilised. These are now becoming more standardised, with a sensible hierarchical and sequential methodology being proposed as best practice [5,13]. Bulk ground resistivity surveys have been under-utilised to-date for forensic searches, probably due to their perceived poor resolution (especially compared to GPR) and lack of previous success. However, recent research on simulated clandestine burials have shown their potential at detecting both naked and wrapped burials, although the chances of detection vary depending on the Post-Burial Interval (PBI), time of emplacement [11,23-25], soil type, burial environment and many other variables. Detection of naked targets are primarily due to conductive decompositional fluids [24-26] and wrapped targets due to objects restricting induced electrical ground currents (see [19,25]).

This study shows that recent advances in field equipment and data processing software has meant that bulk ground resistivity surveys are now relatively quick to collect and quantitatively analyse to pinpoint suspected locations for further investigation. This study covered the 400 m by 20 m search area in two days, sampling every 0.5 m. This search area would take a comparative GPR team several weeks to cover. Resistivity equipment are also comparatively much cheaper than GPR equipment to hire, purchase or commission surveys. This resistivity survey produced a total of 121 anomalies for further investigation. Although this total is relatively high, the total area of these anomalies is much less than the original full search area. Further investigation of these anomalies would be required, and this may be most successfully achieved using a different search method. Therefore, we suggest that the best use of resistivity surveys is to narrow down rough target area(s), before higher resolution geophysical surveys (eg GPR or Electrical Resistivity Imaging, see [37]), or searches using physical probes or trained victim recovery dogs, or conventional excavations over these area are undertaken.

It would also be recommended that a geophysical survey be undertaken prior to metal detector search teams being employed; there were numerous small excavations left by these teams as well as survey flags marking un-excavated targets that needed to be negotiated and therefore increased survey time.

The use of a user-specified threshold to identify anomalies aided, but did not replace, human interpretation of the resistivity data in this study. This technique simplified the interpretation of the data to the decision of classifying the identified anomalies as either high or low priority, based on their relative size and amplitude in the processed data. Another advantage was that it prevented potential anomalies, which satisfied the specified criteria, were not missed as might have occurred with simple manual data interpretation. However, this analytical technique also carried some risk. If the resistivity response of a grave did not exceed a chosen anomaly threshold then it would not be identified, and the survey would not lead to a grave being located. To reduce this risk, the anomaly threshold was chosen based on resistivity data collected over a simulated grave with a similar target size, likely post-burial interval and timing of emplacement (see Fig. 1 and [25]). Allowances for potential errors were also included, as the resistivity anomalies measured over the two simulated graves exceeded the chosen anomaly threshold by ~24% and ~100% for the naked and wrapped targets respectively (see [25]). Hence, it was thought highly unlikely that the grave would not have been detected by the procedures detailed in this study.

A further limitation with this study was that the 0.5 m fixed-mobile probe spacing also limited the typical resistivity depth penetration to ~1 m bgl [33], if a victim was buried deeper than this then this survey configuration may not have detected it. Additionally local utility services and ground works maps were not supplied; therefore any associated resistivity anomalies could not be discounted.

The priority anomalies were not further investigated as, following an unsuccessful attempt by the chief suspect to recover the body; the victim was recovered 0.3 m bgl in the corner of a field adjacent to Field E (marked in **Fig. 1**). The discovery site had been previously searched by a victim recovery dog team. The chief suspect was subsequently convicted of murder. The authors believe that had the priority anomalies been investigated, this would have lead to the area being ruled out quickly and efficiently, and would have allowed the search to focus elsewhere.

6. Conclusions

This case study showed that, following unsuccessful conventional searches, including trained victim recovery dogs and physical probing of local topographic variations, a trial resistivity survey was undertaken within a 200 m by 20 m search area over a two day period. A resistivity sample spacing of 0.5 m by 0.5 m was achieved using a 0.5 m fixed-offset, four-probe equipment configuration. The subsequent resistivity grid datasets were site detrended and merged. Resistivity anomalies were automatically identified by GMT software that were comparable with resistivity anomaly aerial sizes and amplitudes (±3 Ω) obtained from simulated clandestine burial studies. Seven high priority anomalies were identified within the dataset, four were high resistivity and three were low resistivity with respect to background values. Simulated resistivity datasets observed high resistivity anomalies over wrapped pig cadavers (providing a barrier to electrical current), and low resistivity anomalies over naked cadavers (due to conductive decompositional fluids). These anomalies were suggested for further investigation with other lower priority anomalies. However, the victim was subsequently recovered in an adjacent field before the anomalies were further investigated and the chief suspect was sentenced to life in prison.

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8. Role of the funding source

The EPSRC and RSK Stats Ltd. had no involvement with the project.

9. References

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10. Figure Captions:

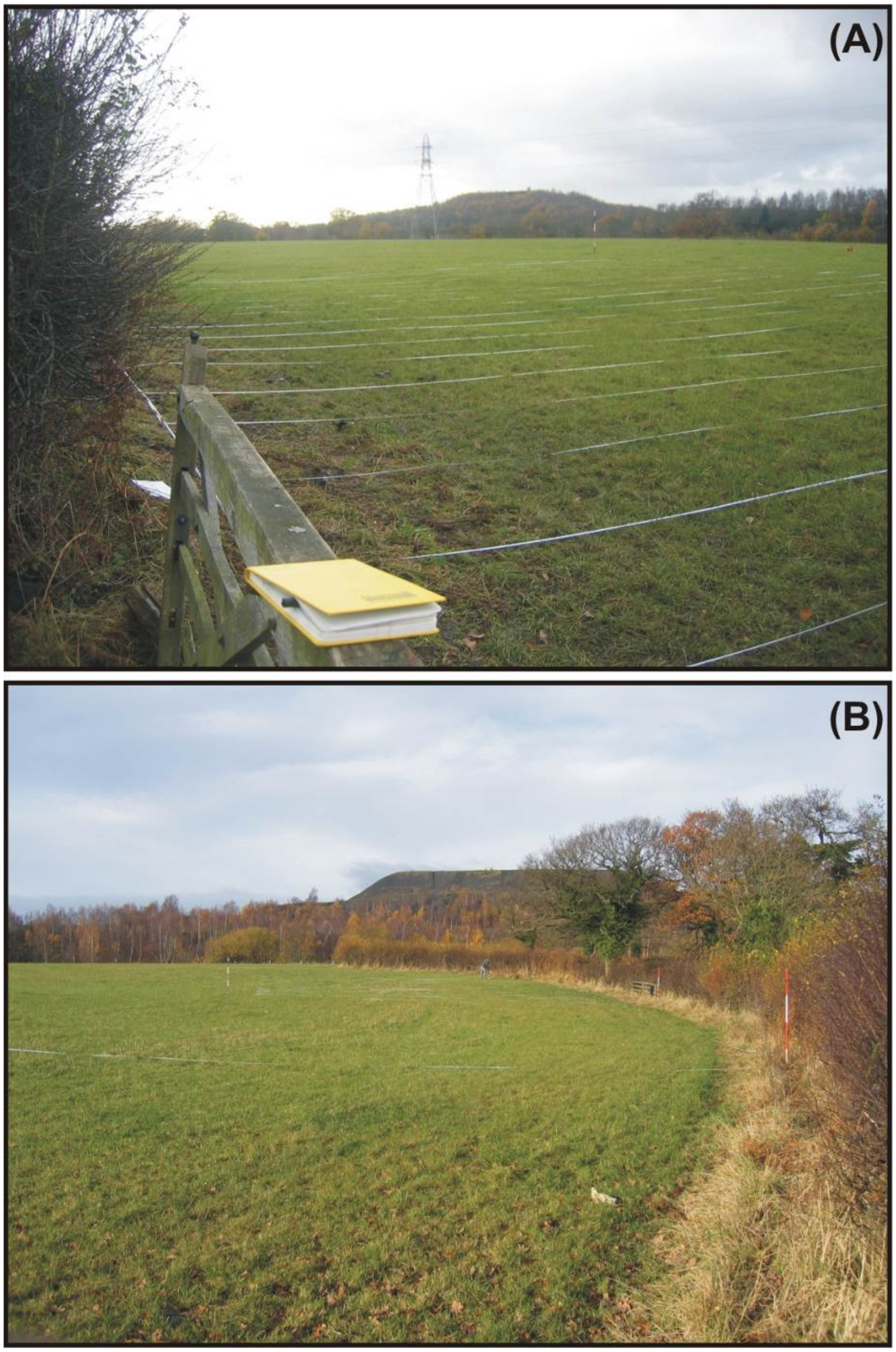

Fig. 1. Site map of the priority fields (A-J) required to be searched (location map inset). The resistivity survey area and field entrance positions and eventual victim recovery site are also marked. Image supplied by Ordnance Survey/EDINA service. © Crown Copyright Database 2007.

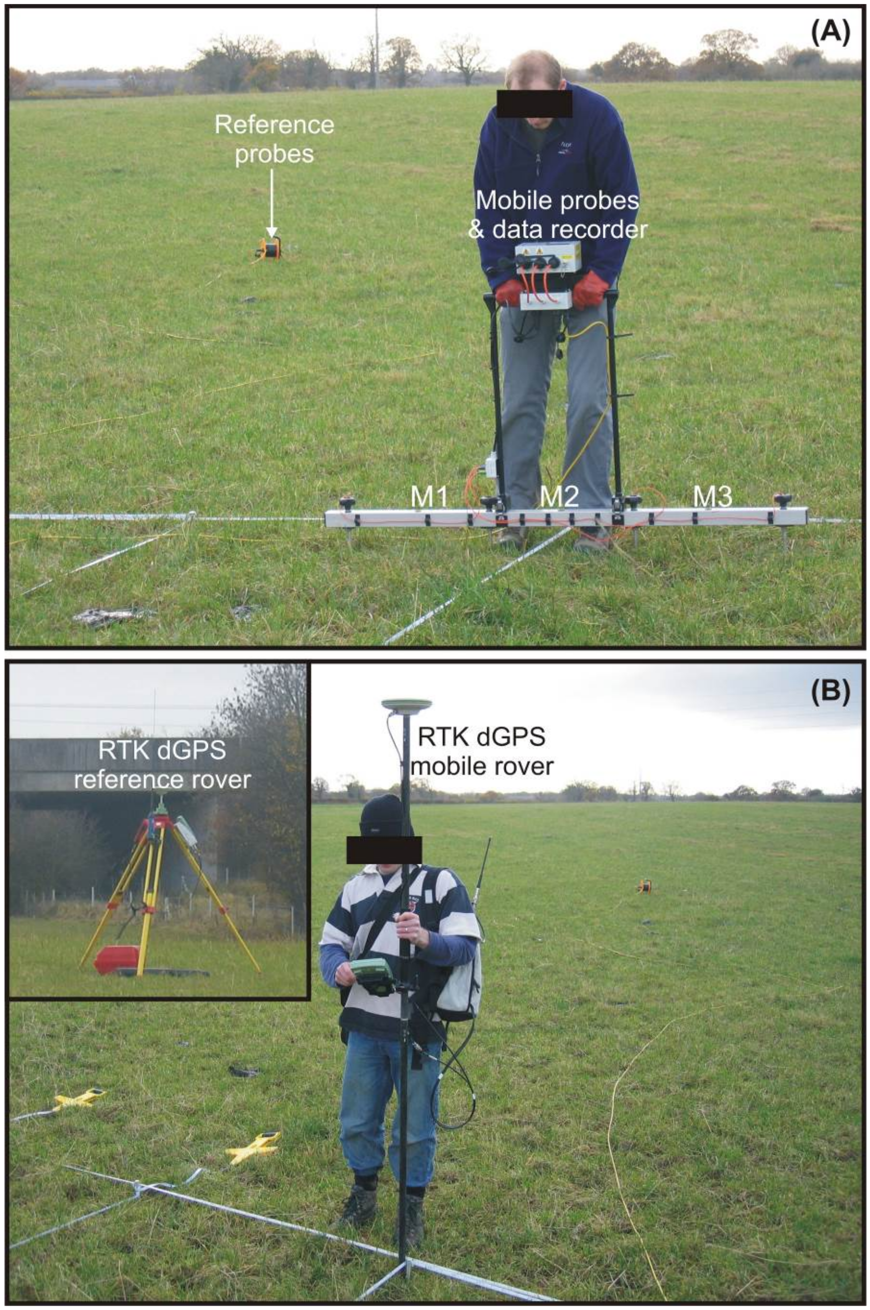

Fig. 2. Survey photographs showing (A) view from field H entrance and (B) field H with relict coal-mine spoil heap in background (see Fig. 1). Isolated deciduous trees were present within field margin hedges. 1.5 m spaced survey tapes and 2 m high survey poles are marked for scale.

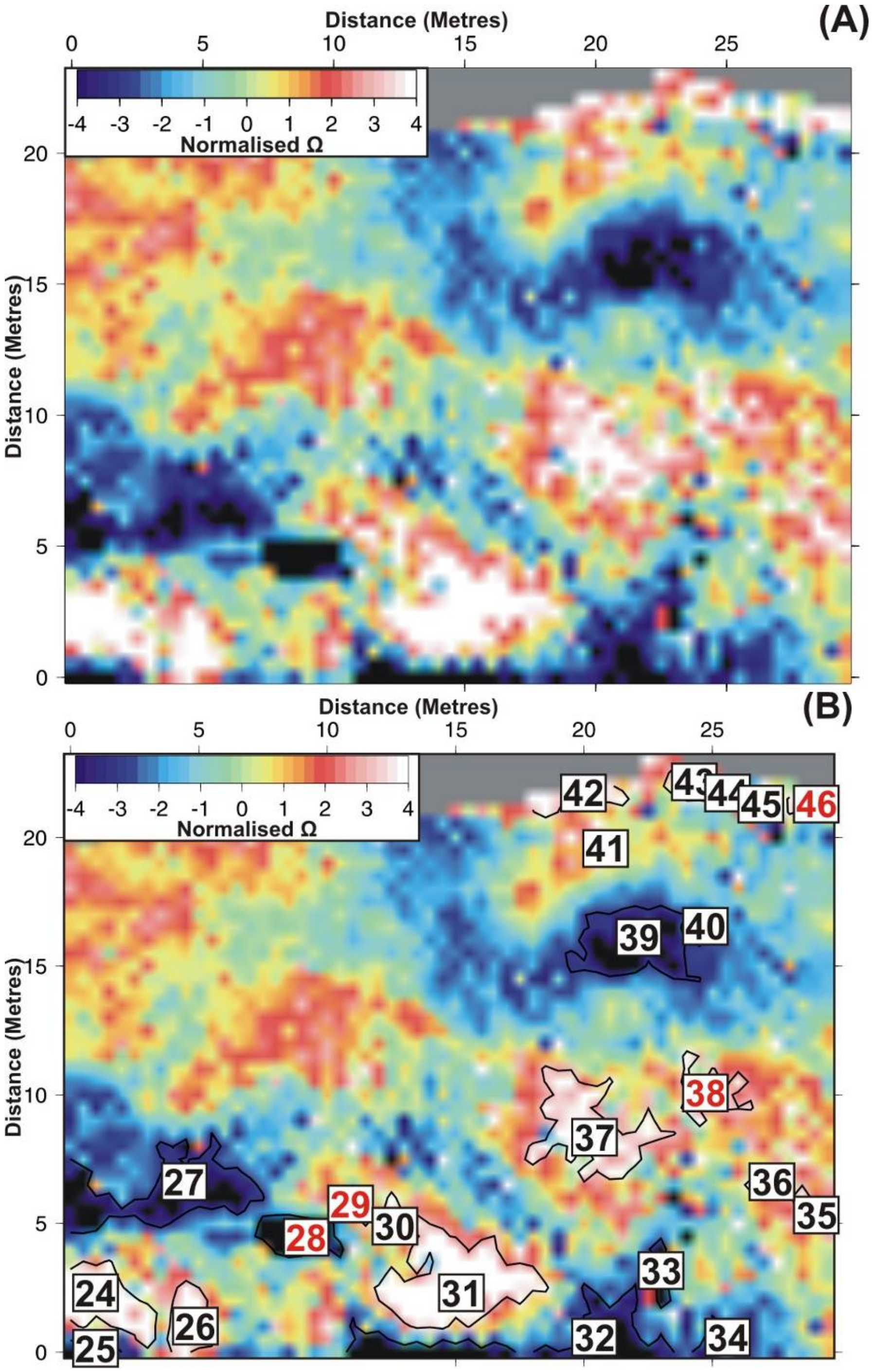

Fig. 3. Bulk ground resistivity data over simulated clandestine graves. (A) Map of burial positions (and types) with (B) resistivity data collected 10 months and 1 month post-burial over the naked and wrapped cadavers, with ±3 Ω contours shown (see text). Modified from [25].

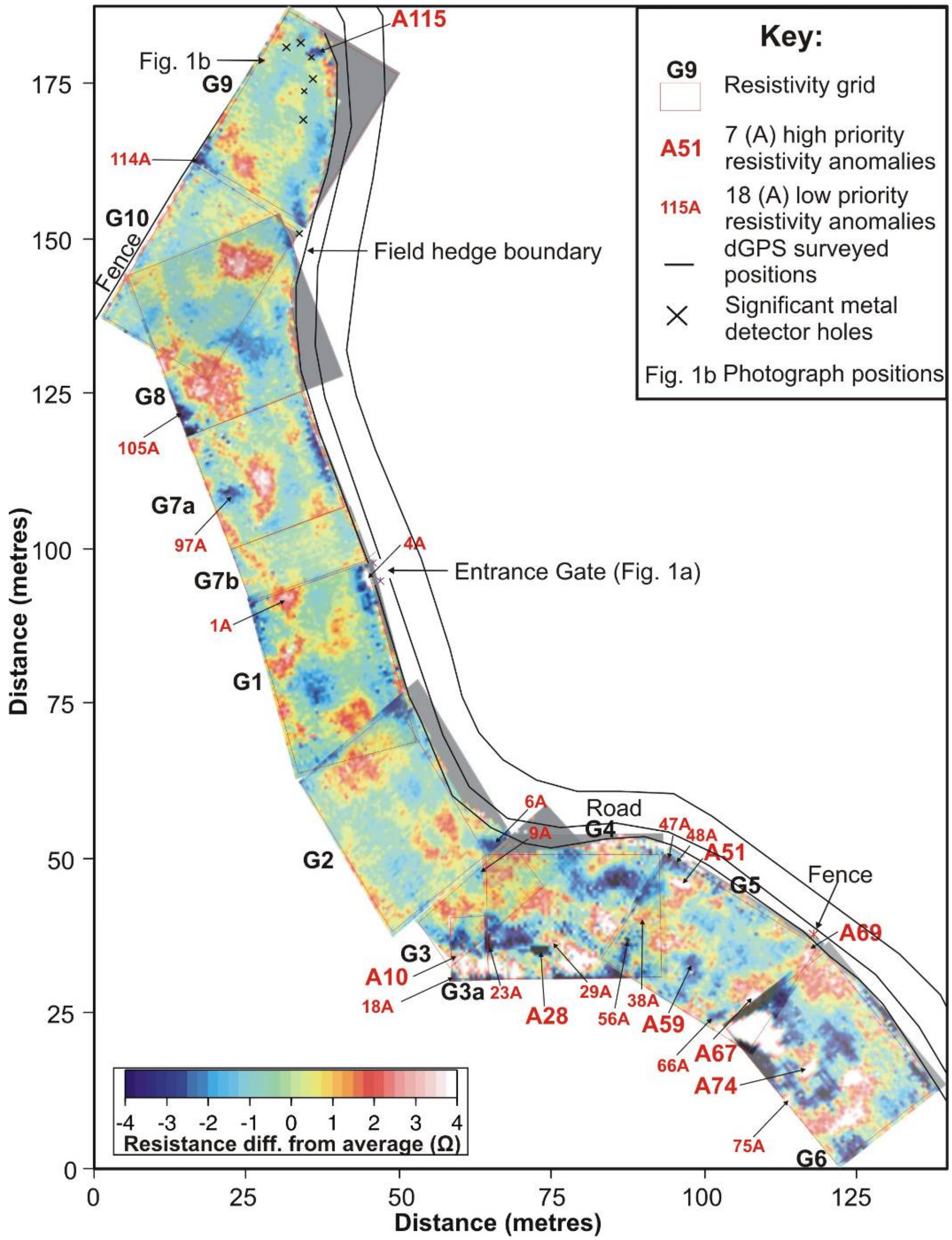

Fig. 4. Mapview of merged processed resistivity survey grids (**Fig. 1** for location). Priority (A) anomalies and other survey data are labelled (see key and text).

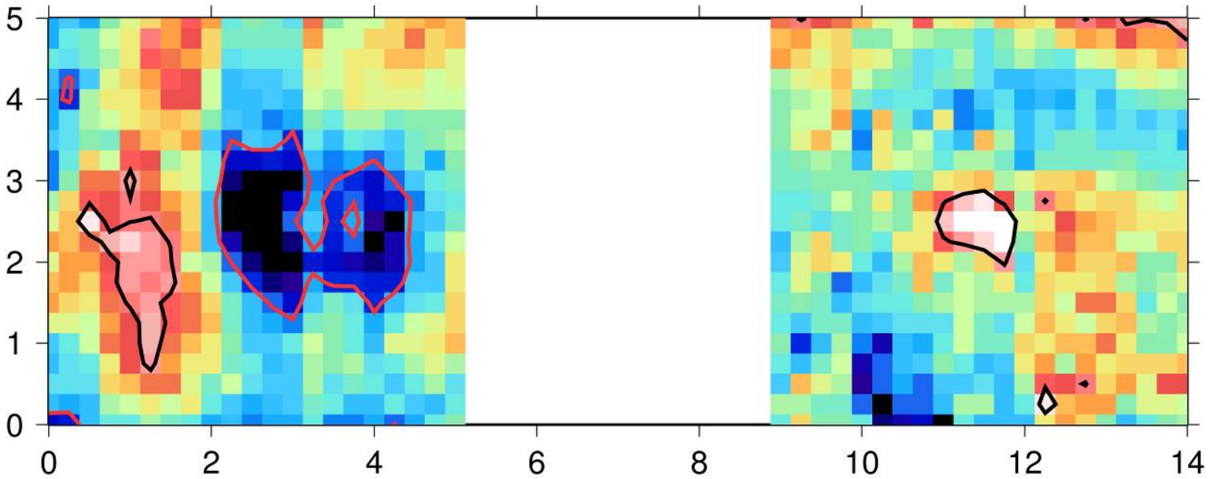

Fig. 5. Mapview resistivity image close-ups of the two simulated clandestine grave anomalies and the seven high priority survey anomalies. Respective anomaly survey grids are in brackets, with generated ±3 Ω resistivity contours shown (see **Fig. 4** for location and text for details).