Chapter 4
Forensic Geophysics and the Search of Building Interiors, Peat Bogs and Freshwater

Alastair Ruffell and Laurance Donnelly

Abstract Geophysics is one of the assets commonly deployed in the multi-proxy search for targets buried in the ground and concealed in water, most especially associated with criminal activity (e.g. human remains, graves, weapons/explosives/contraband, toxic waste). Here, we review and provide new case studies in three environments: (1) the search for objects inside human-made structures, (2) the search for buried homicide victims and human remains at unknown locations in peat bogs, and (3) the use of water-penetrating radar (WPR) in the detection of human remains in water. The latter section is expanded to the use of WPR as a reconnaissance tool in mapping areas of thickened sediment fill in water bodies, as a possible search area for sunken and then sediment-buried objects. We introduce a new term – 'sinkability' – to convey the concept of subaqueous areas of soft sediment where objects such as human cadavers could reside below the sediment surface.

Keywords Geophysics · Forensic search · Freshwater · Peat bogs · Homicide

4.1 Introduction

The use of geophysics in the search for buried or water-submerged items is now well-established (Buck 2003; France et al. 1997; Nobes 1999, 2000). Early work on the detection of buried cadavers concentrated on the use of ground-penetrating radar (GPR; e.g. Strongman 1992). Subsequent workers advocated a multi-proxy approach for the use of geophysics (Ellwood et al. 1994) or highlighted the use of other methods such as resistivity (Pringle and Jervis 2010). Due to the variable success/failure of all search methods, two themes have emerged: the first being the deployment of multiple search assets (including geophysics; Harrison and Donnelly

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2008) and the second being the use of a desktop study (including an evaluation of the geology, soils, past land use, depth/nature of target, etc.) to choose the most appropriate or 'fit for purpose' geophysical technique to use in the search for buried objects (Donnelly and Harrison 2010; Donnelly 2013a, b; Pringle et al. 2012). Such a desktop study is one of the fundamental principles for the correct application of geophysics (Reynolds 2011). Forensic geophysics had early advocates of GPR (Strongman 1992), followed by electromagnetics or EM (Fenning and Donnelly 2004), resistivity (Pringle et al. 2016) and others: each technique has its own benefits yet rarely is the single solution to finding the target. An exception may be the use of metal detectors (in areas with no other metal) for the location of buried guns, knives, coins, metal boxes, etc. The development and applications of the conceptual geological model (CGM) alongside the evaluation of diggability and the applications of the Red-Amber-Green (RAG) prioritisation system were significant advances in the UK, Italy and elsewhere, for police and law enforcement ground searches for burials (Donnelly 2003, 2013a, b). This, for the first time, enabled police searchers to consider the ground conditions (geology) and the characteristics and properties of the target being searched for so that the most suitable and practicable search asset could then be determined, which frequently included (and now includes) geophysics. In terms of geophysics, this approach facilitated the choice of geophysical instruments that were most likely to provide a high assurance for the presence or absence of a suspected buried target (Donnelly and Harrison 2017). Geological trace evidence underwent a similar evolution, from 2004, when many published articles appeared advocating a specific method (see the chapters in Pye and Croft 2004 for examples), when in reality, a multi-proxy approach to the analysis of something like soil is recommended (Rawlins et al. 2006). Through this evolution, geophysics now has its place in the range of assets available to the forensic geologist when trying to locate a target for excavation and by the forensic archaeologist in the forensic recovery of a buried target. A review of the geophysical methods is available in Pringle et al. (2012), and there is no need to repeat the range and applicability of techniques described in that review. The same comment may be applied to the forensic-based search of water bodies, where individual methods maybe appropriate when conditions determine this but where the multiple use of a desktop study, a range of geophysics, as well as hydrology, detector dogs and divers, is considered the best practice (Ruffell et al. 2017). In reality, searches for items associated with criminal activity or humanitarian rescue are usually time-limited, so the more rapid methods of GPR (Barone 2016; Barone et al. 2016a, b) and EM/metal detection (Pringle et al. 2016; Donnelly and Harrison 2013) have gained significant popularity.

4.2 Recent Advances and Debates

The place forensic geophysics has in a search is now well-established, being based on a desktop study to choose the most 'fit for purpose' technique (Donnelly and Harrison 2013) and as part of a range of methods available to those conducting the search (see above). However, misconceptions still remain, and these are considered here (1) the use of geophysics on, inside and under buildings/structures, (2) the use of GPR/WPR in peatlands/bogs and (3) the geophysical detection of human tissue in freshwater using WPR.

4.3 The Use of Geophysics on, Inside and Under Buildings/Structures

Although this was considered by Ruffell et al. (2014) from a search perspective, comments from co-workers at recent conferences indicate that there is a misconception amongst non-geophysicists that most techniques comprise some kind of frame- or carted-mounted apparatus that is moved around a field or a garden. That sideway-looking geophysics is possible, and thus imaging into walls is perhaps not so apparent to non-practitioners, and if it is, then GPR or metal detectors (EM) tend to be what is thought of. This is fine, except most of the ground-based geophysical methods available can also be used on vertical surfaces, for instance, resistivity has been effectively used by Tsourlos and Tsokas (2011) and Mol and Viles (2013) to image water ingress and (most especially for forensic work) voids inside structures and behind walls. Similarly, ultrasonic surveying was combined with GPR by Cassidy et al. (2011) in order to try and overcome the problems of metal rebars in concrete structures. Another way of using GPR to overcome the issue of metal in structures, or to try and image non-metallic features in concrete, is to survey from the opposite side to the interference, just as it is informative to the non-specialist to hear about sideway-looking geophysical imaging (Fig. 4.1a), so upside-down methods can be used, described below. Common forensic searches may be focussed on objects buried under roads but most especially in the concrete of bridges or beneath newly constructed building foundations, presumably to hamper the authorities wishing to excavate. While it is not easy to close a thoroughfare such as a road or pavement for a survey and excavation, this is more practicable than doing the same on (and in) a concrete bridge. Ruffell and McKinley (2008a, b, p. 290) recount how the location of a well-known missing person in North America (the notorious Teamster Jimmy Hoffa) was suspected to be under a tarmac in a garage forecourt in Massachusetts. Hoffa has variously been suggested as buried inside the concrete of the Brooklyn Bridge or in a farmland near Ohio or Illinois and fed to alligators in Florida. Likewise, some of the victims of the East End gangsters, the Kray brothers, are thought to be in the concrete of the Stratford Flyover, London (*op cit.*). Figure 4.1b shows how, if rebars are present in the bridge deck, a technique such as ultrasonic (Cassidy et al. 2011) or in this case high-frequency GPR may be used upside-down to image the inside of the bridge deck from the reverse side. In the case study presented (Fig. 4.1), non-metallic (basalt fibre; see Yeboah et al. 2013) rebars were imaged using different high-frequency GPR antennas. The 3D outputs are similar to those derived from both conventional ground-penetrating radar on structures (Cassidy et al. 2011) and those from sideway-looking radar (Fig. 4.1a, after

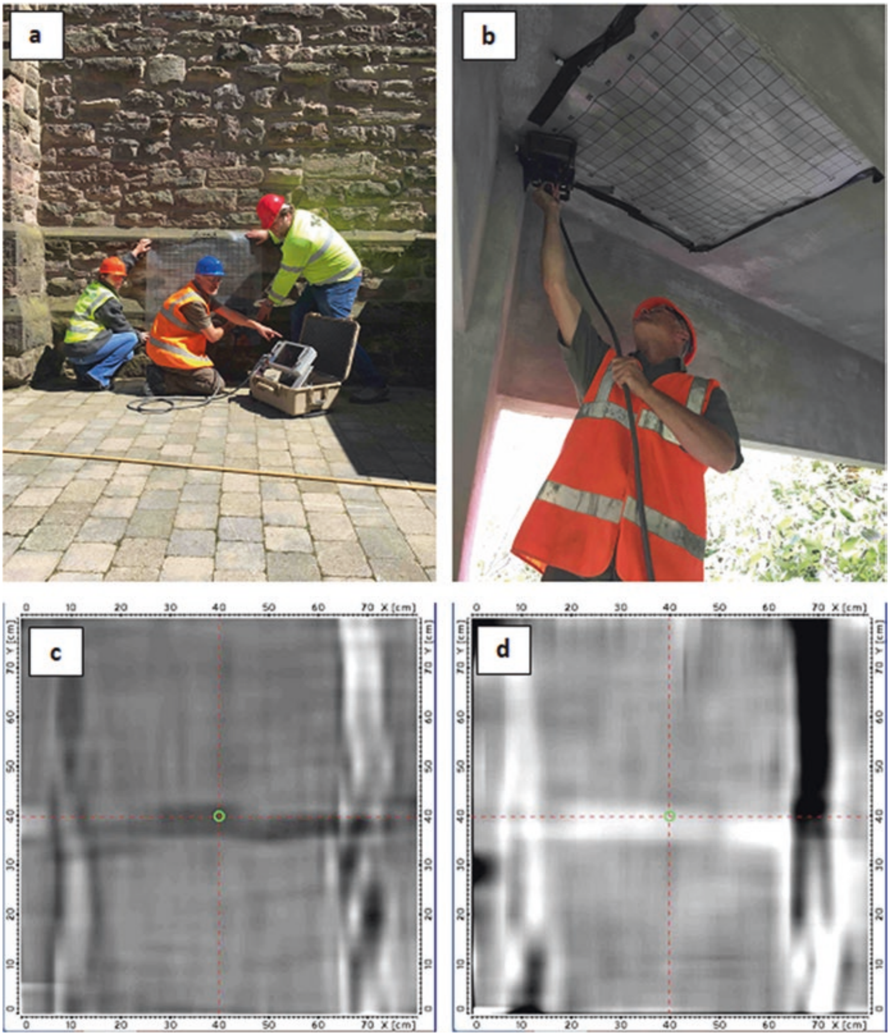

Fig. 4.1 Sideways and upside-down-looking GPR. (**a**) Example of the use of sideways-looking radar to detect voids in an historic masonry wall (Adapted from Johnston et al. 2018) using 1.2 GHz, 1.6 GHz and 2.3 GHz antennas, courtesy of Mike Langton (Mala Geoscience). (**b**) Use of upside-down GPR to image a modern concrete bridge, with basalt-fibre rebars using 1.2 GHz and (this image) and 2.3 GHz antennas, results in (**a**, **c** and **d**). (**c**) Mapped 2.3 GHz output from the survey shown in (**b**), at 10 cm depth, with basalt-fibre rebars. (**d**) Mapped 1.2 GHz output from the survey shown in (**b**), at 15 cm depth, with basalt-fibre rebars (Yeboah et al. 2013). Note the polarity phase change (white/black) with different depths/antennas in (**c**, **d**)

Johnston et al. 2018), which belies the fact that gaining such data is physically demanding, which is probably why this part of the chapter is the first publication on upside-down GPR for forensic searches.

4.4 The Use of Geophysics in Peat (Bogs)

Areas covered in peat (also known as ‘peatlands’ or ‘bogs’) comprise organic-rich to purely organic soils that form in temperate humid climates (Hobbs 1986). They are frequently nonsaline water-logged environments that may contain 90% water and occur throughout Northwest Europe (such as upland Scandinavia, the British Isles and countries with low relief such as the Netherlands), North America (especially Canada and Alaska), upland regions of South America (Colombia, Peru, southern Chile/Argentina) and New Zealand. Peatlands are commonly remote, with large expanses of homogenous landscape. Peat is easily diggable which facilitates an offender’s ability to dig a grave and bury a person or item in a relatively short time (sensu Harrison and Donnelly 2008; Donnelly and Harrison 2013). Their water-logged nature means that some of the techniques used in the search of freshwater are applied, should the target be suitable (magnetometers, GPR, EM, detector dogs). An advantage when searching on peat is that some areas may be surveyed by walking on them: the disadvantages are that peatlands/moors are dynamic environments, subject to rapid change (bogslides) and excavation is extremely difficult/hazardous due the collapse of the sidewalls and water ingress. The location and diggability of peat have resulted in peatlands being the focus of searches for items of forensic interest in places such as Northwest Europe (northern England, Wales, Scotland and Ireland). In Ireland, the work of the Independent Commission for the Location of Victims’ Remains is most pertinent (ICLVR; see Knupfer et al. 2018; Chap. 15 this volume), while Colombia (Molina et al. 2016) describes the use of different geophysical methods in imaging the subsurface for experimentally buried pig cadavers.

Searches may be for weapons, drugs, contraband and, of interest here, human remains in unmarked, shallow, graves. The latter, if buried without metallic objects or clothing, are exceptionally challenging to locate, and the efficacy of GPR in imaging either human/animal burials or non-metallic items (clothing, sacks, bags, ropes, plastic containers) in peat has been the subject of debate at forensic geology and archaeology conferences and other meetings worldwide. In this study, items that replicate those worn by a missing person in northern England were buried in a proximal location to the suspected grave. The case concerns the abduction by serial killers who buried their victims in the same area and in highly comparable geological conditions to our test site. The significance of establishing this control location was to (a) provide the opportunity for the police search teams to become familiar with the operation and deployment of the GPR, magnetometer and electromagnetic instruments in the same geological setting but outside the search area cordon, (b) verify that the GPR and other geophysical instruments were operational and the detection (depth) limitations could be identified (e.g. the target could be buried beyond the depth capable of being detected with the device being tested), and (c) check that the GPR and other geophysical instruments were functional at the start and end of each search phase to provide a high assurance that the target was not present if no anomalies were detected. This case study was undertaken in an area where peat dominates. The peat was observed to contain pipes and voids that facilitate the flow of leachate from the target (Donnelly 2003, 2008). The basal contact of the peat comprises boulders at the interface with the underlying periglacial deposits and derived from in situ weathering of Namurian (Carboniferous) sandstone. This was problematic as the GPR anomalies often were associated with voids and boulders and therefore not the buried target. A detailed understanding of the geology and geomorphological processes from the desktop study, fieldwork and experience is therefore important before GPR is deployed. The blind use of geophysics in such a location could identify natural features such as the peat pipes and boulders as potential forensic targets.

Details of the items worn by the missing person were reported by family members to the police: near-identical items were buried at the control site established a separate target comprised a similar spade. Initial GPR surveys undertaken in the mid-1990s and repeated in the early 2000s were unable to detect the buried control clothing. However, these targets were detectable with ease when tests were repeated in 2015 and 2016. This is not fully understood; however, it is possible that changes in the engineering geological properties and geotechnical characteristics of the reinstated peat after digging and burial of test items and advances in GPR instrumentation enabled the targets to be located. Two generations of GPR antenna were deployed over the control site, both manufactured by Mala Geoscience (Sweden) (Figs. 4.2 and 4.3).

The results show how both the older (manufactured 2006) and newer (manufactured 2016) antennas imaged the clothing and (less surprisingly given the metal content) the spade. A criticism of this experiment is naturally that the location of the targets was known, begging the question as to whether a speculative search of a larger area would have shown anomalies consistent with the homicide victim or indeed the actual items simulated here. The answer lies in the fact that GPR would not be used as the only search tool in such a location as a large upland peat bog but rather be both focussed using the case intelligence, desktop study information and in situ evaluation of the geology/diggability (see above, e.g. Donnelly and Harrison 2013) and used in conjunction with other geophysical methods (e.g. electromagnetics) and other search assets (probing, detector dogs, GIS-based viewshed analysis). Nonetheless, multiple anomalies would be predicted from other buried objects, when these would be prioritised (based on location, geophysical signature, etc.) for the probing and deployment of detector dogs, maybe followed by exploratory invasive excavation.

A second observation by the authors has concerned the poor results from GPR on recent (0–40 years old) homicide burials in peat, yet the overwhelming success when using GPR in the search for unmarked burials resulting from the Irish Potato Famine (1835–1852), both in peat bogs and elsewhere (Ruffell and McAllister

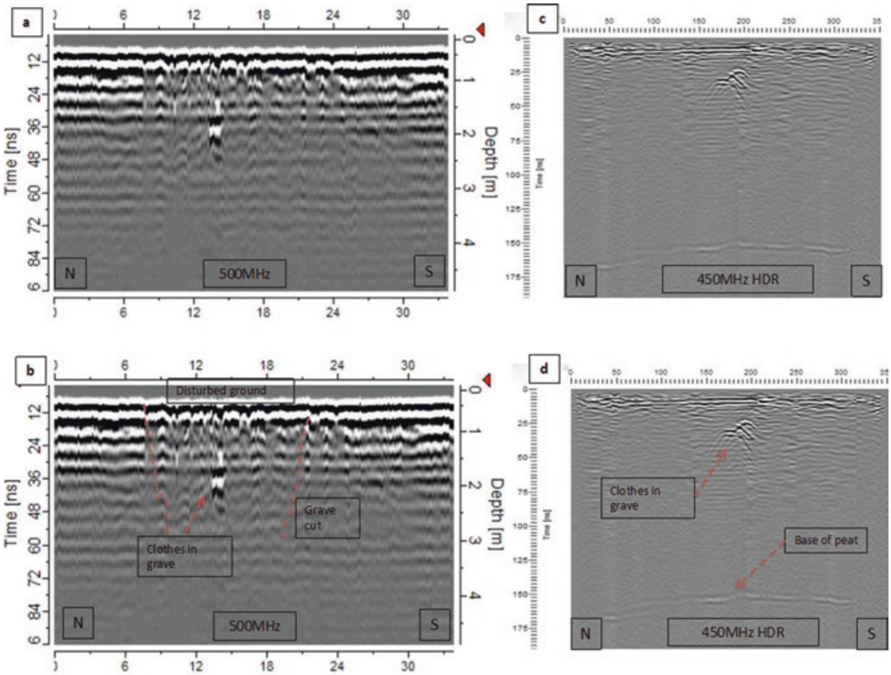

Fig. 4.2 GPR in an upland peat bog, northern England (UK), showing a comparison of an older (manufactured 2006) 500 MHz shielded GPR antenna (Mala Geoscience) and a newer (manufactured 2016) 450 MHz, high dynamic range (HDR) antenna (the latter courtesy of Mike Langton, Mala Geoscience). All data are unprocessed. (**a**) 500 MHz data across a test location where clothing that replicated an actual homicide was buried some 10 years previously in a test pit, dug to emulate a homicide grave. Data gathered in October 2015. (**b**) Interpretation of the data shown in (**a**). (**c**) 450 MHz HDR GPR data across the same clothing burial location shown in (**a**, **b**). Data gathered in November 2016. (**d**) Interpretation of the data shown in (**c**). 500 MHz and 450 MHz data were also collected across a simulated dug grave of the same age, with no contained objects and no GPR anomalies (data available on request)

2014). Jonny Geber (pers comm., 2016) has shown through his work (see Hilts 2013) that victims of the famine were commonly placed in a shroud, with or without a pine coffin, and placed in individual or mass burials, with lime (CaO, calcium oxide) added to both stifle odours and disinfect the site and supress the spread of cholera. A well-known example of this (for the general reader) is the closing scene of the film Amadeus, where lime is thrown on the unmarked grave of Mozart for the same reasons. We conjecture that in the wet climate of Ireland, and especially in the subsurface of peat, this CaO reacted with water to harden and thus create a carbonate carapace over the burials. The success of GPR in surveying such ground may be down to the supra-carbonate cover and underlying burial airgap, providing a good geophysical target (Fig. 4.4). Work by the authors at the homicide burial test site (clothing and spade, described above) on nearby peat pipes shows these natural peatland features as very distinct on GPR profiles.

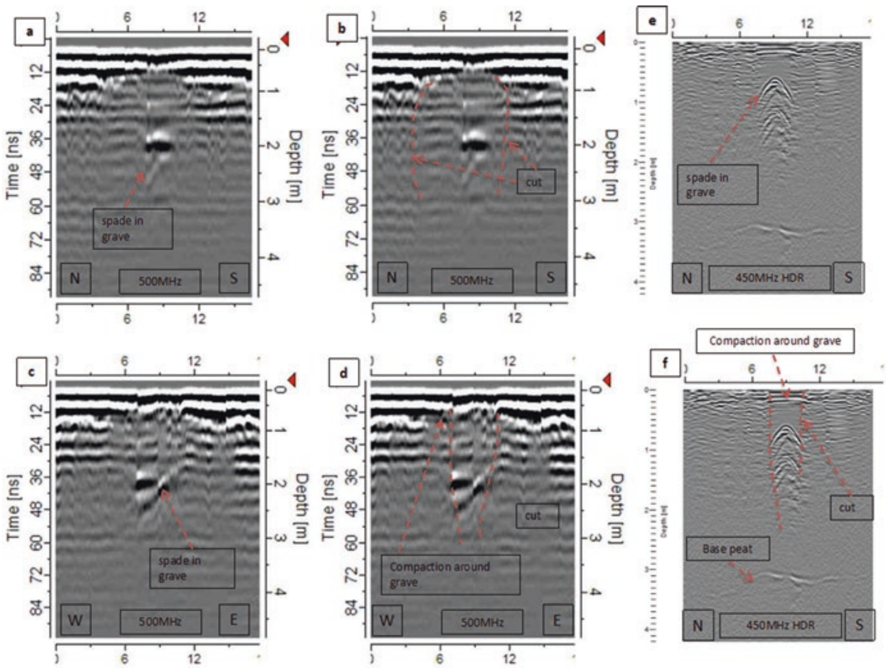

Fig. 4.3 GPR in an upland peat bog in the Pennines, northern England (UK), showing a comparison of an older (manufactured 2006) 500 MHz shielded GPR antenna (Mala Geoscience) and a newer (manufactured 2016) 450 MHz, high dynamic range (HDR) antenna (the latter courtesy of Mike Langton, Mala Geoscience), as in Fig. 4.2. All data are unprocessed. (**a**) 500 MHz data across a test location where a spade was buried some 10 years previously. Data gathered in October 2015. (**b**) Interpretation of the data shown in (**a**). (**c**) 500 MHz data gathered at a right angle to (**a**, **b**). (**d**) Interpretation of (**c**). (**e**) 450 MHz HDR GPR data across the same spade burial location shown in (**a**, **b**). Data gathered in November 2016. (**f**) Interpretation of the data shown in (**e**). As in Fig. 4.2, 500 MHz and 450 MHz data were also collected across a simulated dug grave of the same age, with no contained objects and no GPR anomalies (data available on request)

4.5 The Geophysical Detection of Human Tissue in Freshwater

There are excellent review articles on the use of terrestrial forensic geophysics (Pringle et al. 2012). For the search of water bodies, Ruffell et al. (2017) provide a synopsis of the detection of human bodies (and other objects of forensic/environmental crime interest) submerged in freshwater. These authors surveyed a live person in a swimming pool with a floating GPR or water-penetrating radar (WPR). A criticism of this is that the clear contact shown on WPR may be derived from the residual air held in the submerged person's lungs (see above; air pockets in peat or water provide superb radar targets). This is partly vindicated by observations made when involved in police searches for homicide and drowning victims, wherein the boat-deployed radar was manoeuvred over police divers with air lines or

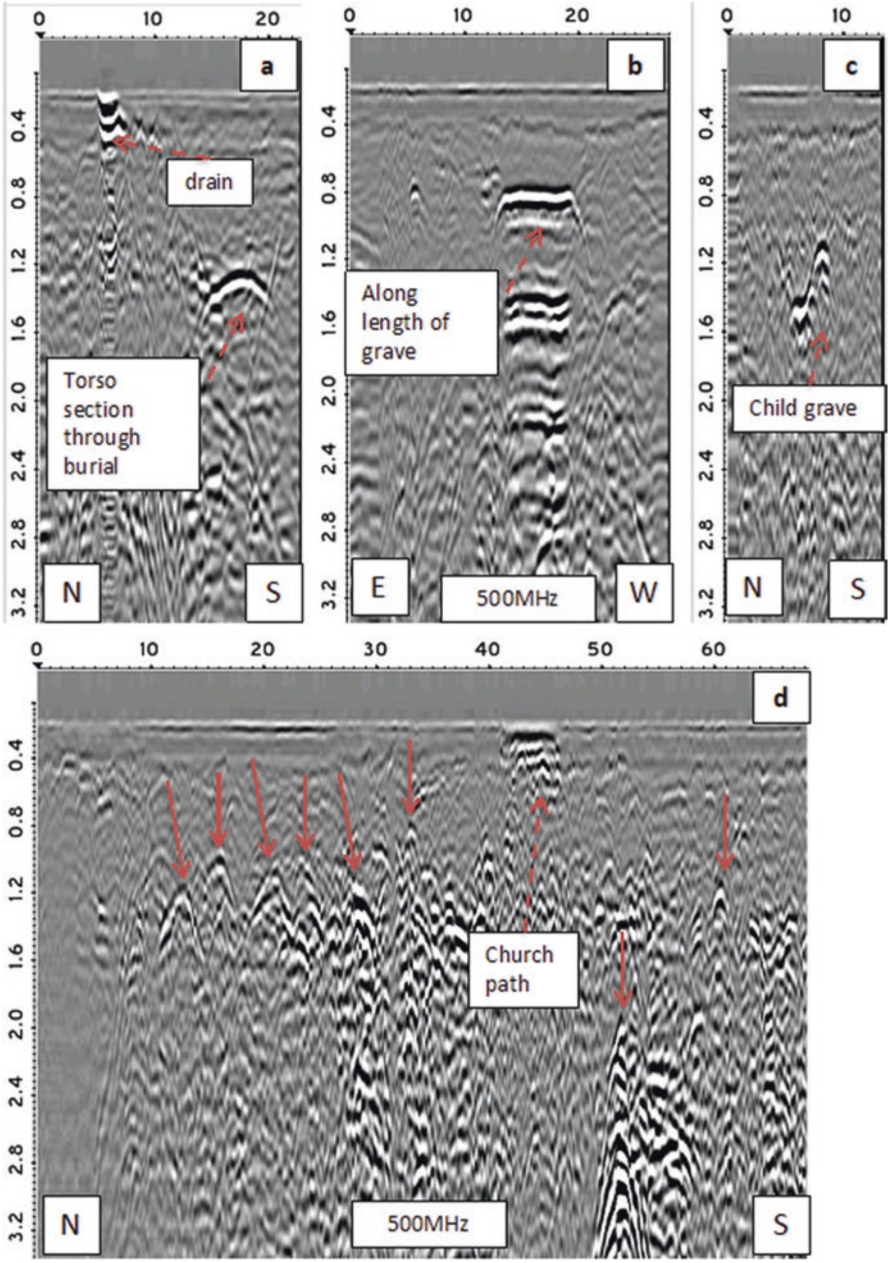

Fig. 4.4 GPR data gathered from a Famine Graveyard (Irish Potato Famine) in a section of a church graveyard in Dowra, County Leitrim, Ireland, where unmarked (no headstone, no wooden crucifix) 'pauper' burials are recorded as 'poor ground' by church authorities. The soil (unknown thickness [from physical probing and 100 MHz regional GPR surveys] but exceeding 11 m) comprises organic-rich lacustrine silts, reworked from adjacent Lough Allen. (**a**) 500 MHz data across a burial, probably around torso location (from the location of a change in vegetation at surface). (**b**) 500 MHz data along the length of an adjacent grave to that shown in (**a**). (**c**) 500 MHz data gathered at a small burial plot (estimated from a slight ground depression), likely an infant or child burial. (**d**) Long GPR section (500 MHz data) through part of the graveyard with supposed burial anomalies marked as arrows

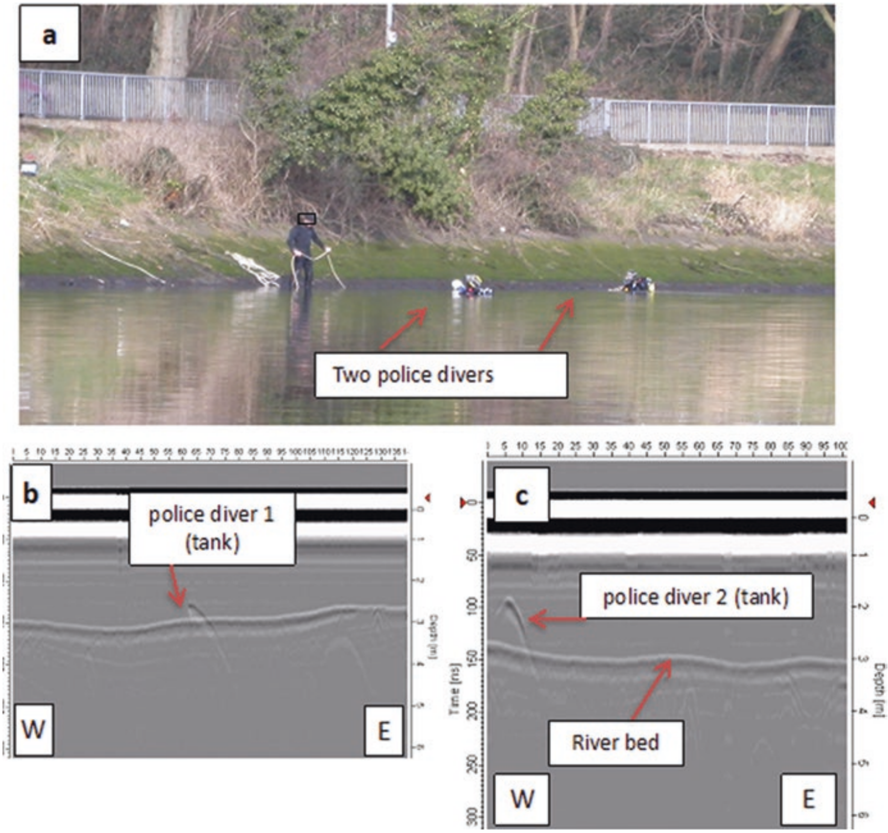

Fig. 4.5 WPR data gathered in the River Lagan, Belfast (N. Ireland, UK), from a 4 m-long inflatable boat with the foot slats removed for maximum antenna coupling to the water: only 4 mm of plastic separate the base of the radar antenna from the top of the water. Data collected as part of a police search for a homicide victim (the body recovered in this location and shown in post-mortem examination by the pathologist to have been murdered 4 months previously). The victim's burntout vehicle was found in a country road lay-by some 10 km upstream of this location. (**a**) The search location, showing the two police divers and the safety officer. Permission to survey the divers obtained. (**b**, **c**) 250 MHz WPR data gathered as the boat was steered over each diver, showing the clear hyperbolae from the position of the diver (visually observed under the boat)

non-metallic air tanks, used in order to deploy waterproof minimum metal-content detectors. Clear hyperbolae were observed over the divers (Fig. 4.5), possibly caused by their air tanks, residual air in their diving suits or (of greatest interest here) the actual human tissue itself, albeit that even this has gas in it (in the blood or from decomposition when deceased).

The question remains: Can human tissue with minimal air/gases be detected by WPR? To answer this question, a scaled experiment was conducted whereby we surveyed real human limbs in plastic and concrete tanks of freshwater at a range of frequencies (1.2, 1.6 and 2.3 GHz), both from above (to simulate WPR from a boat) and from the side (to simulate the search for cadavers in water storage tanks, farm slurry tanks). Water storage tanks are known to have been used as body disposal locations, the best known being the case of Elisa Lam, a student from British Colombia (Canada), whose body was found in the rooftop water tank on the Cecil Hotel, in Los Angeles. The authors have likewise assisted the UK police and search and rescue organisations with searches of farm slurry tanks, concrete water storage reservoirs and beer/cider vats for both victims of homicide and accidental death (usually overcome by fumes). The results of this scaled-down simulation are shown in Fig. 4.6.

Previous to this experiment, we located a sediment-filled concrete tank and surveyed live human legs at 1.6 GHz and 1 GHz, to simulate burial in water-logged sediment. We then surveyed our horizontal live human arm from above by skimming the hand-held antenna over the water surface and our vertical leg by scanning from the side, all with success. The consideration that forensic targets may be in sediment raises a further consideration: Can water-penetrating radar (and other geophysical methods, such as CHIRPS) be used to map sediment thicknesses in water bodies and thus be used as a reconnaissance method? The idea is similar to Harrison and Donnelly's (2008) concept of 'diggability' in terrestrial searches; only here 'sinkability' is considered. Sinkability is suggested to be locations where there is a sufficient thickness of soft sediment in a water body to cover an object. The size of the target will dictate whether sediment thickness could obscure an item from view or sonar: for instance, a small weapon could be covered by a few centimetres of mud/silt/sand, whereas a human body would require some decimetres of sediment cover and a vehicle (depending on size), maybe metres of sediment. The idea here is that should no floating or water-bottom target be found, yet there is a high level of intelligence-based assurance that an object has been hidden in the water body under investigation, then where might search resources be targeted for objects that have sunk into loose and unconsolidated sediment? WPR profiles may not just provide images of water and shallow targets but also sediment thickness (Fig. 4.7a, b). These thicknesses may be digitised or brought into 3D software (Reflex 3D, ArcMap, 3DGeo) as contour plots. Geolocated, such plots can be navigated in real time using a GNSS/GPS or can be redrawn in simple form for non-GIS familiar search teams to use as a way of visualising their search location. The authors have successfully done this for searches of ponds and small lakes; the type of user-friendly output is shown in Fig. 4.8a, b. Such maps are effectively RAG prioritisation diagrams, with access, visibility and sediment thickness promoting high-probability search locations, while visible areas, with thin subaqueous sediment or rock at surface having a low likelihood of containing a sediment-sunken object.

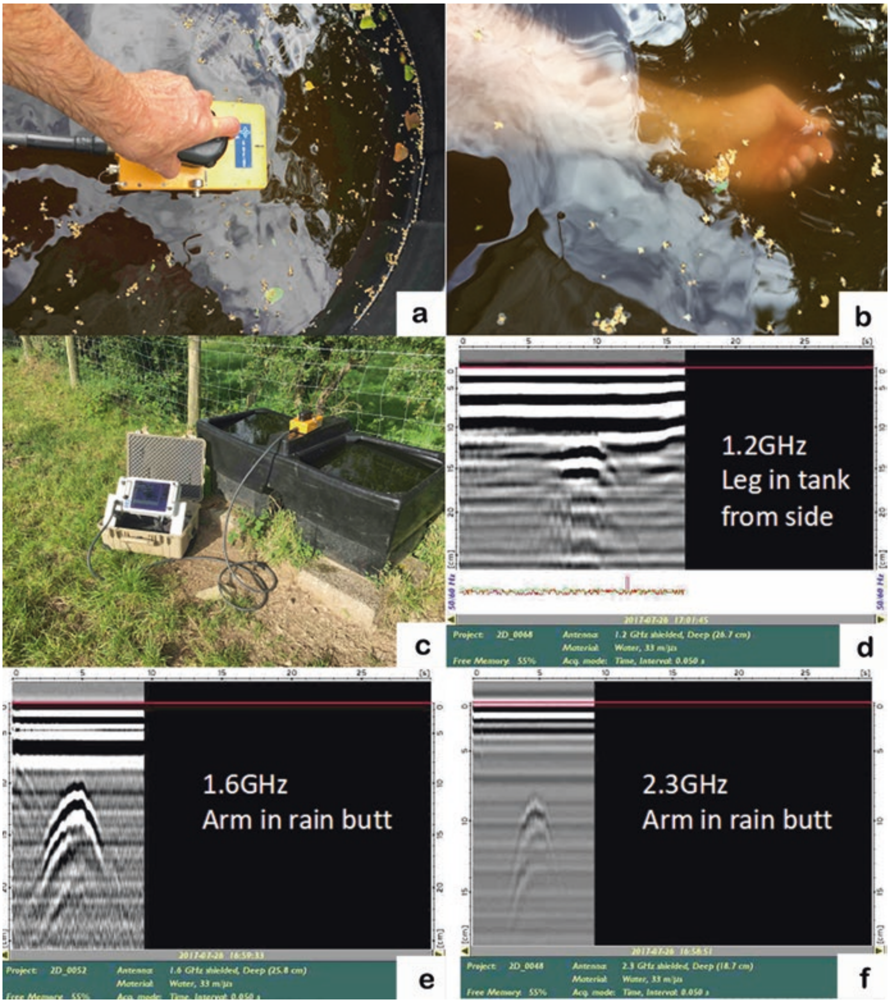

Fig. 4.6 High-frequency WPR data gathered from above and from the side of a plastic rain butt (freshwater rain) and plastic animal drinker (chlorinated drinking water, mixed with rainfall), with live human limbs inserted and the antennas moved across the target(s). (**a**) The rain butt with 1.6 GHz antenna above. (**b**) The live human arm orthogonal below the antenna in (**a**), simulating a boat-borne search. (**c**) The plastic animal drinker. (**d**) 1.2 GHz data gathered (orthogonal) across a live human leg in the animal drinker, to simulate a lower frequency (e.g. 250 or 450 MHz) WPR 'sideways' search of a larger water storage facility, such as a water storage tank (see text for the description of the Elisa Lam case). (**e**) 1.2 GHz GPR data collected on the plastic rain butt over a live human arm. (**f**) 1.6 GHz GPR data collected on the plastic rain butt over a live human arm. (**g**) 2.3 GHz GPR data collected on the plastic rain butt over a live human arm. Other high-frequency WPR experiments and results using different human subjects, targets and locations (e.g. the concrete animal drinker) are available from the authors

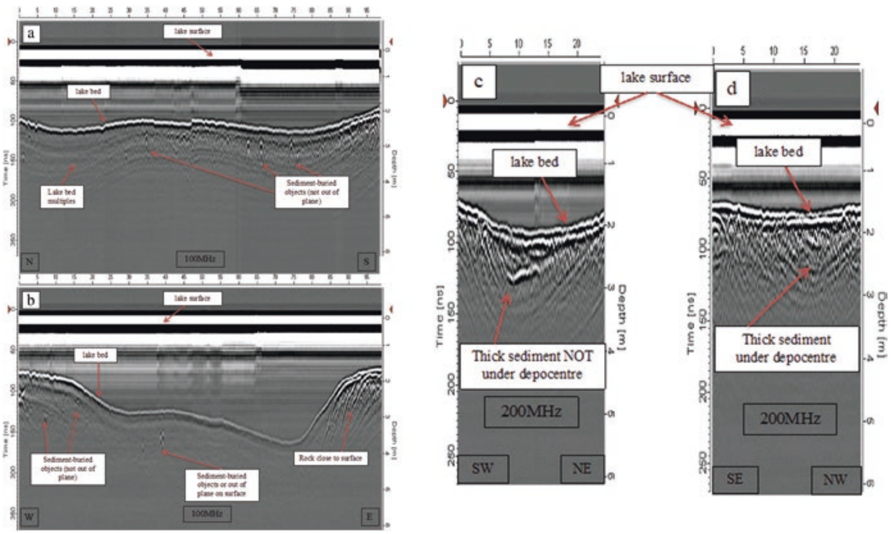

Fig. 4.7 Lake morphology and sediment thickness mapping for search focus. (**a**) Example of a small (100 m diameter) inter-drumlin lake in County Down, N. Ireland (UK), where the centre of the lake is not coincident with the deepest water (which is commonly assumed for searches and coring for palaeoclimate records). (**b**) Example of an asymmetric lake bed, with the radar facies commonly seen in bedrock sub crops (eastern side). (**c**) An example of where the thickest sediment (and thus a likely location for sub-lake bed buried objects) is neither coincident with the deepest part of the lake nor its geographic centre (as in Fig. 4.7a). (**d**) The same WPR survey location as in (**c**), likewise showing the slight offset (in this oblique orientation) between the thickest sediment and the lake depocentre, which are almost coincident

4.6 Conclusions

From experimentation we have replicated and demonstrated criminal casework, stimulated by previous review articles, and provided an overview of how forensic geophysics is being used in nonconventional search locations, such as the inside of engineered structures and on water bodies and peat. This is not to demean the more popular view of forensic geophysics, where buried items are still commonly found in loose deposits under gardens, agricultural fields and unlithified sediments (e.g. floodplains, avalanche slopes, sand dunes). Furthermore, the efficiency of GPR, EM and magnetometry over freshwater and peat suggests that aerial platforms (cf. drones/unmanned aerial vehicles) may soon be deployed for reconnaissance searches of such environments, along with ice and snow (not discussed in this article). More challenging locations, such as mixed clay soils, metal-engineered structures/foundations and abandoned mine workings, also require a desk study and reconnaissance investigations and combination with remote, ground (or water) surveys with other appropriate search methods such as scent dogs, divers and of course eventual excavation and forensic recovery.

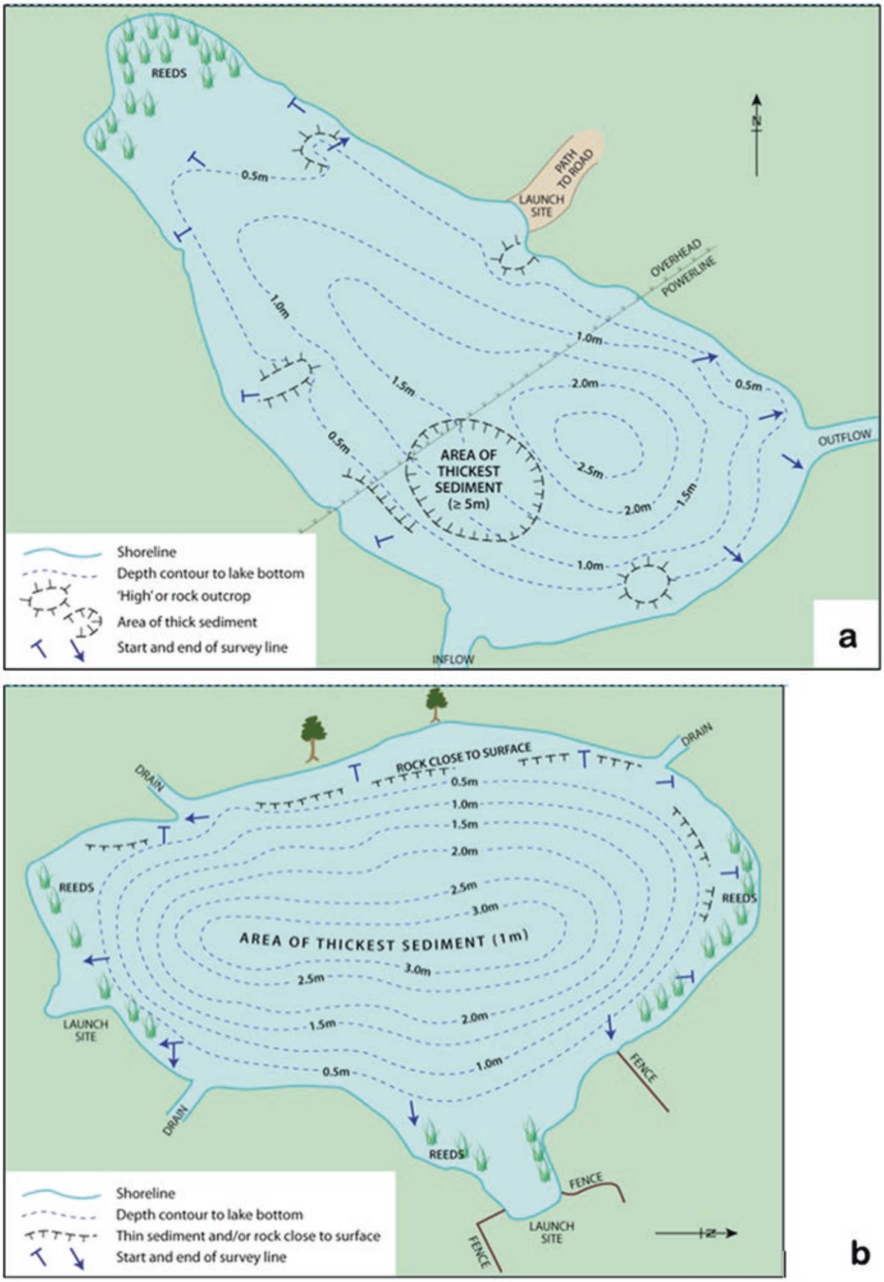

Fig. 4.8 Example of simplified maps of lakes for search personnel. (**a**) Derived from the WPR data shown in Fig. 4.7c, d, showing the dive search team where both the deepest part of the lake is (dashed contours) and the thickest sediment (for buried objects). The mapped length of the overhead powerline (shown) is 42 m, for scale. Such simplified, user-friendly maps are provided for dive personnel to search. The area of thickest sediment ('sinkable area') was probed, using a carbon-fibre probe (50 cm sections) to release sediment gases, allowing boat-deployed scent dogs to be taken over the site. (**b**) Example guide search map of a lake where the deepest water is coincident with the geographic lake centre. The lake is 32 m north to south, for scale

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