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Searching for the IRA "Disappeared": Ground-penetrating Radar Investigation of a Churchyard Burial Site, Northern Ireland

ABSTRACT: A search for the body of a victim of terrorist abduction and murder was made in a graveyard on the periphery of a major conurbation in Northern Ireland. The area is politically sensitive and the case of high profile. This required non-invasive, completely non-destructive and rapid assessment of the scene. A MALA RAMAC ground-penetrating radar system was used to achieve these objectives. Unprocessed and processed 400 MHz data show the presence of a collapse feature above and around a known 1970s burial with no similar collapse above the suspect location. In the saturated, clay-rich sediments of the site, 200 MHz data offered no advantage over 400 MHz data. Unprocessed 100 MHz data shows a series of multiples in the known burial with no similar features in the suspect location. Processed 100 MHz lines defined the shape of the collapse around the known burial to 2 m depth, together with the geometry of the platform (1 m depth) the gravedigger used in the 1970s to construct the site. In addition, processed 100 MHz data showed both the dielectric contrast in and internal reflection geometry of the soil imported above the known grave. Thus the sequence, geometry, difference in infill and infill direction of the grave was reconstructed 30 years after burial. The suspect site showed no evidence of shallow or deep inhumation. Subsequently, the missing person's body was found some distance from this site, vindicating the results and interpretation from ground-penetrating radar. The acquisition, processing, collapse feature and sequence stratigraphic interpretation of the known burial and empty (suspect) burial site may be useful proxies for other, similar investigations. GPR was used to evaluate this site within 3 h of the survey commencing, using unprocessed data. An additional day of processing established that the suspect body did not reside here, which was counter to police and community intelligence.

KEYWORDS: forensic science, ground-penetrating radar, inhumations, scene of crime, geophysics

The IRA (Irish Republican Army) and Provisional Irish Republican Army (PIRA) are often used synonymously although the latter formed in 1969 following the decision of a paramilitary group of the original IRA grouping to pursue a course of armed insurrection against the British State, its soldiers and supporters. For this work, I use IRA as most people are familiar with this term. A limited, but nonetheless brutal part of the IRA campaign of the Troubles (1969–1997) involved the abduction, occasional torture, interrogation, and sometimes eventual murder of those considered to be obstructing the IRA campaign. Loyalist paramilitary groups have also abducted, murdered and hidden the bodies of those likewise seen as opponents of their activities. Thus the total collective number of Republican and Loyalist "Disappeared" is unknown, with the IRA admitting to their involvement in the abduction of nine people (1). Of the commonly cited victims of these activities, by the end of 2002 only two bodies had been found. The IRA called a series of ceasefires to their campaign through the 1990s, culminating in the 1997 ceasefire and consequent "peace" situation in N. Ireland. As part of this peace process, the IRA publicly expressed willingness to disclose the whereabouts of the "Disappeared" and the Independent Commission for the Location of Victims' Remains was set up by support groups, church and community leaders. The spirit of openness extended to members of the public who had previously remained silent. Compassion for the victim's families, decreasing threats of retribution against complicity with the British State and increased security force intelligence led to numerous indications of where the bodies of the "disappeared" may be.

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In early 2003, a grave in a church graveyard on the outskirts of a major conurbation of N. Ireland was identified from police intelligence as a possible burial site of a frequently investigated murder of one of the "disappeared" (Fig. 1). The area is here described in intentionally vague terms. The location of the graveyard was some few hundred metres from a Nationalist housing estate where the humanitarian intentions of the search could have been misinterpreted by residents not friendly to the security forces. Thus rapid, non-invasive investigation techniques were required in order to establish ground conditions, and to assess the likelihood of a burial or re-burial anytime from 1972 to the time of investigation (2003). For this, ground-penetrating radar (GPR) technology was chosen as a rapid method available locally. However, other techniques, especially electrical tomography could also have been used. Interpretation of the GPR data results were required on site, making this a test case of whether raw GPR data, or at best data analyzed on site with limited processing could be used in real-time for such investigations. The required rapid, subtle, and non-invasive response precluded use of military technology, i.e., cadaver dogs (2), probe (3), or long-term geochemical sampling such as capture of volatile organic compounds formed as a by-product of the decomposition (4,5). Investigation by physical probe was given very serious consideration, following the recommendations published by Douglas Owlsey (3). However, the sensitivity of the case, public access to the site and religious beliefs of the local community suggested that the effects of the probe could be misunderstood. In contrast, the GPR equipment used here had been utilised for a geotechnical site investigation of a nearby quarry by the author one month previous to this study. In this work, it became apparent that the peculiar nature of the equipment would not be connected by the local community to a search for the victim of paramilitary murder.

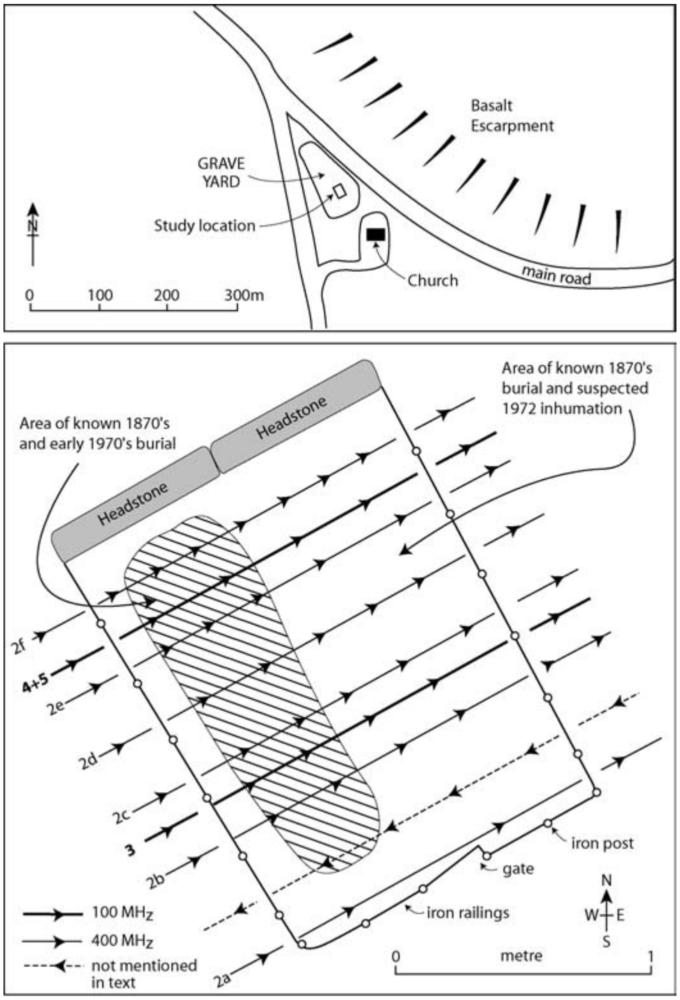

FIG. 1—*Maps of the study area. Upper, general location of the church and graveyard. Lower: location of GPR lines over the known (left or southwestern side) and suspected (right, or northeastern side) parts of the graveplot.*

Likewise, the presence of investigators was kept to a minimum and the surveys undertaken at daybreak in winter in order to avoid attention.

Proxy Case Studies on Which Interpretations Were Based

GPR has become one of the main geophysical tools of the geophysicist involved in the search for buried organic remains (2,6). Prior to 1992, GPR was used by law enforcement search teams and the military, throughout the world (Gary Olhoeft, pers comm, 2003) but was rarely documented, except in general terms in newspaper articles. Strongman (7) published a series of case studies from controlled environment burials, using 5 year old bear carcasses as well as actual crime scene profiles. Owsley (3) evaluated GPR against other geophysical devices and concluded that a physical probe was still a better device for use in the detection of soft ground around inhumations and buried objects. Miller (8) followed the Strongman (7) approach, with an evaluation of test sites against actual case studies. The application of GPR technology was at an impasse until 1996, as new technology and small, ruggedised laptop computers and data loggers were developed. A rush of papers in 2000 reflects these advances and their application to actual forensic cases (9), historic mass burials (10) and to the experimental responses of buried corpses (11). The development of other geophysical techniques such as resistivity and magnetometry has caused a re-evaluation of GPR in comparison with other devices (12). Many of the early problems with GPR have now been solved: the development of shielded radar antennae has made usage in forests and urban environments possible. The range of antennae available (25 MHz to 1000 MHz) now allows investigation of large subsurface features such as walls, foundations, moats, channels and mass-graves to small (centimeter-scale) objects and features such as plastic landmines, cracks in walls and pavements or even the neonate inhumations. Wet, clay-rich and wet, salt-impregnated ground still cause difficulty in obtaining images of the subsurface where the large-scale disturbances of nature need to be separated from those made by humans. In problematic situations, extensive post-acquisition processing (13), other geophysical methods, penetrative investigative techniques (14), cadaver dogs and geochemical sampling are required (15,16).

Site Description

The site comprised a large (2 m high, 1.5 m wide) double headstone, with iron railings on the remaining three sides of the plot. Heavy vegetation was present suggesting limited disturbance over the past year or more. This vegetation (ivy, wild budleigh) was cleared as part of a wider clearance of the graveyard. Thereafter, no changes to the site could be made in this investigation, including any deep or regular invasive probing. Following vegetation clearance, reading of the headstones indicated two burials in the southwestern plot, in the 1870s and 1970s and one burial (1860s) in the northeastern plot, where intelligence suggested the victim could be buried (Fig. 1). Thus the site contained an internal control: although completed legally, and probably to greater depth, the ground disturbance associated with the known (south-western) 1970s burial should show similar features to any (probably shallower) adjacent placing of a murder victim to the northwest. From examination of graves being dug in the rest of the graveyard, it was determined the site topsoil may extend to 20 to 30 cm depth, with mixed subsoil to 1 m, glacial till to about 2 m (the base till surface being uneven), resting on Palaeogene basalts and dykes. This allowed some ground-truthing of the GPR data without resort to velocity surveys.

Methods

Ground-penetrating Radar: Concepts

GPR detects dielectric permittivity contrasts in the ground through the directional input of high-frequency electromagnetic waves from an antenna, their reflection back to surface and detection by a receiving antenna. The time taken for the waves to travel to the target dielectric contrast and back can be converted to depth, should the intervening radar wave velocity structure be known or can be calculated. By sequentially moving antennae over a target, the reflected waves can be placed alongside one another to produce a radargram, or combined image of the 2-D structure in time or depth (following conversion). The amplitude of the reflected radar waves is dictated by the dielectric contrast: this signal may be attenuated by intervening materials between the object or surface and the antenna. Therefore, with depth, even very significant changes in radar response may be somewhat suppressed. Isolated objects that have a different dielectric contrast to their surroundings may generate large amplitude waves that are termed "bright." As the antennae pass over such objects, they may generate hyperbolae. Radar antennae are commonly elongate, generating radar waves in a widening arc from their long axis. Thus when moved in parallel to the antennae axis, the radar waves may reflect from a larger subsurface area (the so-called footprint) than when moved with the antennae at right-angles to survey direction. Reflections are generated when the radar waves reach the subsurface interface of differing dielectric properties, be this a water table, soil or rock stratigraphy, or anthropogenic materials. Radar waves also travel horizontally from the transmitting antenna, which in open ground simply dissipate with distance. However, in areas with structures, especially those that have a significant dielectric contrast to their surroundings, interference from such surface objects can create artefacts on the radargram. When isolated objects are passed during a traverse, a series of hyperbolae may be generated that appear like a subsurface object but are simply out-of-plane reflections. Such isolated objects may be pylons or vehicles in urban locations or a ski pole or metal stake when in open ground. If surveys are conducted in enclosed surroundings such as chambers or tunnels then the radar energy may simply dissipate or it may continually reflect back to the antenna, creating a series of horizontal artificial reflections known as multiples or ringing on the record. Wave velocity has an inverse relationship with dielectric permittivity: the dielectric constant of the penetrated materials will result in different reflected wavelets whose amplitude can be displayed in color or greytone intensity on the radargram. In the case study presented, based on regional drift and solid geology and the dug graves, soil, glacial till, basalt and human materials are expected to be observable on radargrams. The upland, impermeable nature of the area (glacial till on basalt escarpment) results in streamflow fed from soil, with no regional water table.

Ground-penetrating Radar: Data Acquisition

Data were collected following a prolonged (2 months with less than 100 mm measured precipitation data from Meteorological Office, Belfast International Airport, 16th July, 2003) dry period of February using a MALA RAMAC GPR system fitted with 100, 200 and 400 MHz unshielded antennae. Shielding of antennae should be considered in urban environments where adjacent structures can operate as secondary antennae, causing "ringing" on the generated profiles. This was expected on these data, as a result of the iron railings (set in concrete) and large (2.5 m high) headstone. 100 MHz profiles were generated on a stepsize of 5 cm with fifteen readings per step: antennae were parallel to acquisition direction to allow passage under the railings. Two hundred and 400 MHz data were collected at a stepsize of 5 cm with antennae in both parallel and normal orientations. Surveys were begun outside the graveplot, covered both the known 1860s/1970s burials and the suspect site, then continued outside the plot (Fig. 1). Nine lines with an 18 m total line length for each antenna type were collected in total. Data was viewed as raw output and then with a variety of limited processing sequences. These comprised application of automatic gain control, filtering of noise, trace averaging, application of custom gain and topographic correction, which were applied variably on site (for rapid evaluation) to produce the most "realistic" output. Raw and processed 200 MHz and 400 MHz data appeared essentially similar and thus examples of 100 and 400 MHz data are shown here. These higher and lower frequency data are the main geophysical reasons for presenting the information derived: previous studies have recommended 200 or 225 MHz antennae for similar investigations. Here I suggest that through data processing and in the wet, clay-rich soil of this location, 400 MHz data give good definition at shallow levels and 100 MHz data provide excellent information on the regional stratigraphy and deeper geology.

Results

400 MHz Data

A collapse or synclinal feature is observed along the length of the known (southwestern) 1970s burial (Fig. 2*a*, 2*b*). This feature becomes broader toward the headstone end of the plot ("burial?" on Fig. 2*c*–*f*). Glacial till stratigraphy is evident throughout the area, traceable from outside and into the plot. Line 2a (Fig. 2) has had a high bandpass filter applied and is effectively the same in appearance as the raw field data. Thus no averaging of the traces has been applied and the data "jump" where the iron railings were crossed. The dish-like appearance of the known 1970s grave at the southwestern side of the plot contrast with the smaller bright object at about 40 cm depth in the suspected grave (Figs. 2*a*, 2*b*), where no syncline (the proxy indicator of a collapse) or hyperbolae (the proxy indicator of the upper surface of a coffin or chamber: [7,8]) were detected. Line b (Fig. 2*b*) has a high bandpass filter applied and topographic correction. The bright objects (small areas with large amplitude wavelets) in the suspect grave area can be seen, and the dish-like area of the known 1970s grave continues north, suggesting the presence of an elongate hollow. Line c is similarly filtered (Fig. 2*c*) with the traces averaged (eleven times), creating smoothing of the profile. This has been done merely to show the difference between averaging and the limited processing of Lines a, b and d. The dish structure associated with the known 1970s inhumation is narrow in the centre of the plot and only one bright object in the suspect area remains. The same filters and averaging on Lines e and f work particularly well, with the asymmetric dish structure associated with the burial shown clearly. Disturbed reflections can be seen at about 2 m depth in all the 400 MHz data.

100 MHz Data

Two examples of 100 MHz data are shown, one as raw data (on which initial assessment of the plot was made), the second as raw and processed data. Figure 3 (location 3 on Fig. 1) shows the raw data with no processing. The value of the control grave is here exemplified, with the surface soil stratigraphy generating multiples into the known 1970s grave that do not occur outside of the graveplot, nor in the area (even at shallow depths) of the suspected burial. This same restriction to the location of multiples is seen on other 100 MHz lines, and may extend along the length of the grave.

At this point in the discussion, I am effectively replicating the field procedure. Thus, it is wise to follow the methodology in order to evaluate the choices made in data interpretation, processing, and thence information passed to the intelligence authorities. At this point, raw, field data were viewed (Fig. 4*a*) and a preliminary interpretation given. The processed data (Figs. 4*b* and 4*c*) shows the stratigraphy of the known (1970s) grave, again with no similar features at the suspect location, confirming the first interpretation. Application of custom gain and trace averaging (Fig. 4*c*) accentuates the data at shallow ($<$1 m) levels, ably differentiating glacial till, soil of the grave area, and markedly different topsoil above the 1970s grave. This radar character is not evident at the suspect location.

Discussion

The 400 MHz data have proven unusual when compared with previous studies (above) that mainly describe hyperbolic reflections

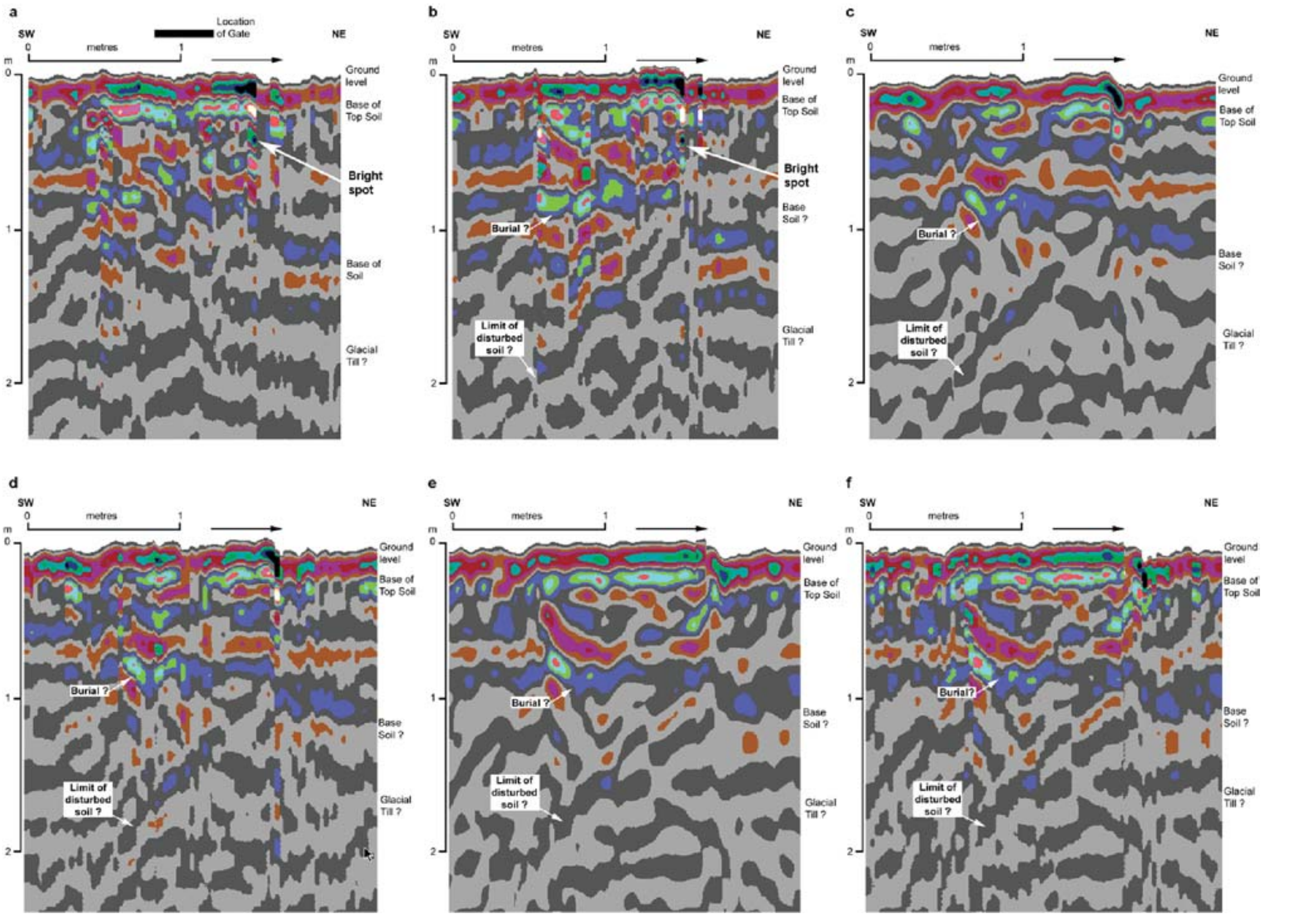

FIG. 2—*400 MHz data collected over the known (left, south-west side) and suspect (right, north-east side) burial locations. Locations on Fig. 1. 2a. & 2b. filtered and topographically-corrected lines showing the known burial and associated sub-soil disturbances and bright spot of unknown origin in the suspect burial location. 2c. Filtered, averaged and topographically-corrected line through the centre of both the known and suspect burial. The supra-burial collapse is here narrow and the bright spot is missing. 2d. filtered and topographically-corrected data. 2e. filtered, averaged and topographically-corrected line at the head of the known and suspect locations showing the broad collapse and associated disturbance associated with the known burial. 2f. filtered and topographically-corrected data to show the smoothing effect of averaging. Depths to individual layers are only estimated as no velocity survey was conducted at this site.*

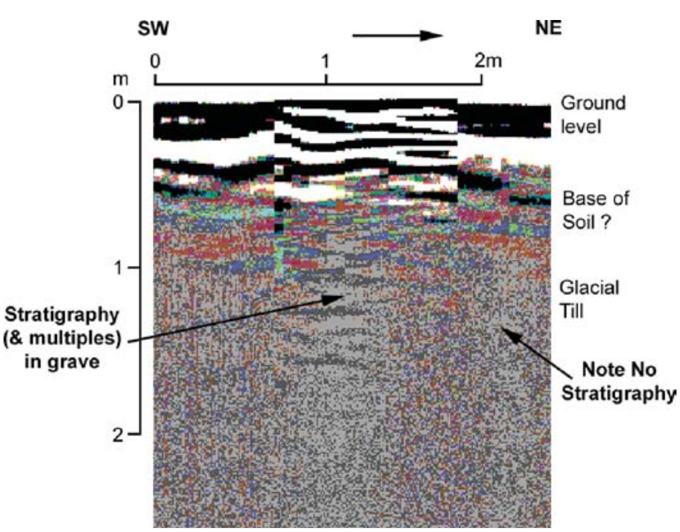

FIG. 3—*Unprocessed 100 MHz data through the centre of both the known and suspect burials, showing the multiples in the known grave that acted as a control for further fieldwork.*

from real and simulated inhumations. Instead, we generated no such hyperbolae from any coffin still present: instead our data shows the opposite, a synclinal collapse at shallower levels (1 m) than burials are known to have been made (2 m). This may be a collapse product of a decayed coffin in a wet climate: we know from interviews with the gravedigger and priest that the 1970's burial was made in a wooden coffin and that pine coffins are the most common choice in this area. The 400 MHz data did not show either collapse or hyperbolae at any depth in the area of the suspected burial. The unprocessed 100 MHz data proved useful in confirming the location of the known burial (restricted location of multiples) and the absence of any deep disturbance over the suspect location. The multiples in the suspect location could have been caused by the radar signal reflecting back from the metal railings. Why this is restricted only to the area with no recent burial may simply be that the more coherent soil here allows the continual sideways reflections to bounce back to the antenna: perhaps in the disturbed areas, the energy from ringing in the data is simply absorbed by the sediment. Buck (12) suggests that higher frequency antennae are recommended for this type of investigation, due to the size of the target. However, processed 100 MHz data have also proven useful in this study. This shows the geometry of the known burial site, including the likely platform on which the gravedigger made his

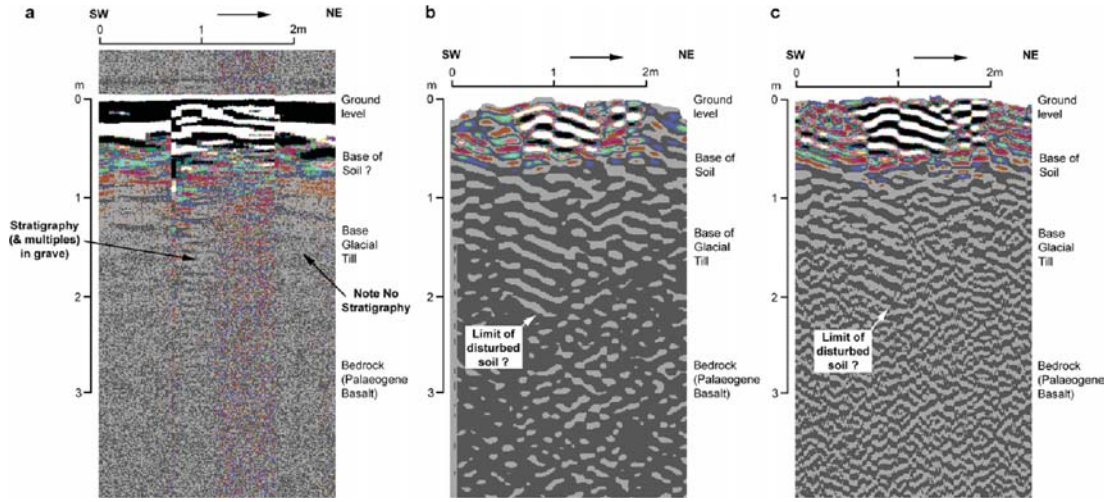

FIG. 4—*100 MHz data collected over the known (left, south-west side) and suspect (right, north-east side) burial locations. 4a. unprocessed data, with continuation of the multiples identified on 100 MHz data to the north-east. 4b. filtered, averaged and topographically-corrected data. 4c. filtered, averaged, custom gain applied and topographically-corrected data. The geometry of the grave, the nature of the imported soil and geometry of imported soil can all be seen clearly. Depths to individual layers are only estimated as no velocity survey was conducted at this site.*

excavations in the 1970s (Fig. 5). The GPR response of the deep disturbance to the known inhumation suggests that reworked glacial till lies in this area. At shallow levels, the unusual character of the topsoil shows this material to be different to the surrounding soil. This difference may come from imported soil, soil mixed on site or both, all of which would create a different radar response. The internal reflections of this surficial material suggest it was placed or reworked in the shallow part of the grave from the western or southwestern side, on account of inclined surfaces dipping to the east and northeast. Together, these characteristics allow us to reconstruct the digging and infill of the known 1970s grave, with possible deep (3 m depth) disturbance and a platform to the northeast being made. Infill with different material to the rest of the gravesite was made, probably from the west. This contrasts with the suspect area, where no deep disturbance is seen and no import of new material, nor reworking of the previous grave material is in evidence.

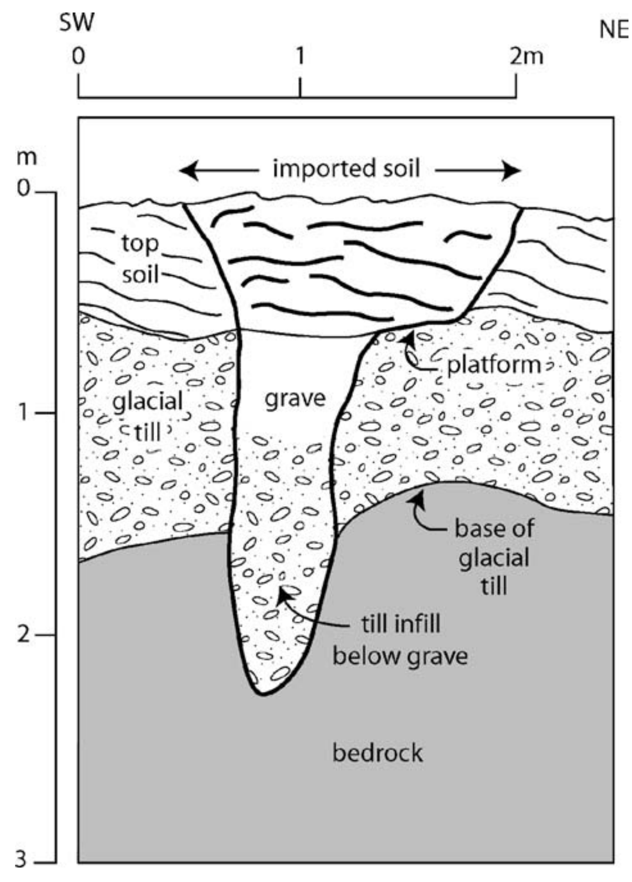

FIG. 5—*Cartoon interpretation of Fig. 4c, showing the site stratigraphy, the geometry of the known grave platform and soil infill, and limits of imported soil, as interpreted from the dielectric contrast in radar character. This suggests that the gravedigger, during* bona fide *work in the 1970s, initially dug an area of 1.5 m width to about 50 cm to 75 cm depth. He then used this area to dig the thinner (70 cm wide) grave, possibly excavating or moving some material of similar dielectric character to over 2 m depth, the common depth for graves in this area. Following burial, the grave was infilled with material excavated from the site (same dielectric contrast to surrounding till and subsoil). After this, material of significantly different dielectric character was introduced from left to right (southwest to northeast), possibly some time after the original burial and maybe after the coffin had collapsed. No disturbance in the suspect location is predicted.*

Conclusions

- GPR data, examined and processed on site, confirmed the presence of a collapse or synclinal hollow at the known 1970s inhumation. No similar features were seen over the suspect area.
- Processed 100 MHz data show the structure of the known 1970s burial, including deep disturbance, a platform and unusual surficial material, possibly introduced by the gravedigger from the western or southwestern side of the plot. If correct, the latter is a remarkable conclusion to be drawn from GPR data as it predicts the past movement of material from the direction of the inclined reflections. This is essentially a sequence stratigraphic approach (17) to forensic geophysics. Again, no similar deep or shallow disturbance can be detected over the suspect location.
- On-site, a provisional conclusion was reached that no inhumation was likely at the indicated location: this contradicts witness intelligence. The aim of the study was to make this recommendation based on raw data or with very limited processing: this was achieved.

- Subsequent searches elsewhere to this work discovered the victim who was supposedly buried at the study location, vindicating the results presented here. The original intelligence may have been mistaken or referred to some other covert activity. Considerable financial, time and emotional costs were saved in this study.

Acknowledgments

Discussions with Raymond Murray, Tom Davitt, Brian Lavery; Brian Miskimmin, Val Semple, Rick Schulting, Eileen Murphy, Clark Davenport, Harry Jol, Gary Olhoeft and others have proven very useful in this work. The associated investigators and priest of the church cannot be named, but they know who they are and are thanked for aiding resolution to this sensitive humanitarian investigation.

References

1. http://news.bbc.co.uk/1/hi/uk/355300.stm accessed 24 March 2004.
2. Saferstein RE. Criminalistics: An introduction to forensic science. 7th ed. Upper Saddle River, New Jersey: Prentice Hall, 2001.
3. Owsley DW. Techniques for locating burials, with emphasis on the probe. J Forensic Sci 1995;40(5):735–40.
4. Murray RC, Tedrow JCF. Forensic geology: Earth sciences and criminal investigation. New Brunswick, New Jersey: Rutgers University Press, 1975.
5. Ruffell A. Remote detection and identification of organic remains: an assessment of Archeological potential. Arch Pros 2002;9:115–22.
6. Pye K, Croft D, editors. Forensic geoscience: Principles, techniques and applications. London: Geological Society, Special Publications, 2004; 232.
7. Strongman KB. Forensic applications of ground penetrating radar. In: Pilon J, editor. Ground penetrating radar, geological survey of Canada, Paper 90–4, 1992;203–11.
8. Miller PS. Disturbances in the soil: Finding buried bodies and other evidence using ground penetrating radar. J Forensic Sci 1996;41(4): 648–52. [PubMed]
9. Nobes DC. The search for "Yvonne": A case example of the delineation of a grave using near-surface geophysical methods. J Forensic Sci 2000;45(3):715–21. [PubMed]
10. Davis JL, Heginbottom JA, Annan AP, Daniels RS, Berdal BP, Bergan T, et al. Ground penetrating radar surveys to locate 1918 Spanish Flu victims in Permafrost. J Forensic Sci 2000;45(1):68–76. [PubMed]
11. Hammon WS, McMechan GA, Zeng XX. Forensic GPR: finite-difference simulations of responses from buried human remains. J App Geophys 2000;45(3):171–86.
12. Buck SC. Searching for graves using geophysical technology: Field tests with ground penetrating radar, magnetometry, and electrical resistivity. J Forensic Sci 2003;48(1):5–11. [PubMed]
13. Kulessa B, Ruffell A, Glynn D. Geophysical investigation of abandoned salt mine hazards. J Env Geophys 2003;14:21–4.
14. France DL, Griffin TJ, Swanburg JG, Lindemann JW, Davenport GC, Trammell V, et al. A multidisciplinary approach to the detection of clandestine graves. J Forensic Sci 1992;37(6):1445–58.
15. Cheetham P. A practical and effective, high-resolution, symmetrical response and reduced near-surface noise multiple potential electrode resistivity array configuration for the detection of clandestine graves. In: Pye K, Croft D, editors. Forensic geoscience: principles, techniques and applications. Conference Abstracts, 2003; Geological Society of London, 3–4 March 2003;17.
16. Davenport GC. Remote sensing applications in forensic investigations. Hist Arch 2001;35:(1).
17. Ruffell A, Geraghty L, Brown C, Barton K. Ground-penetrating radar facies analysis and electrical tomography: application to the Archaeology of Clonmacnoise Castle, Ireland. Arch Pros 2004;11:24–36.

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