J Forensic Sci, Jan. 2003, Vol. 48, No. 1
Paper ID JFS2002165_481
Available online at: www.astm.org

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Searching for Graves Using Geophysical Technology: Field Tests with Ground Penetrating Radar, Magnetometry, and Electrical Resistivity*

ABSTRACT: Field experiments were conducted using three types of geophysical equipment in a variety of situations. The goal of the study was to ascertain the relative utility of this technology for non-geophysical expert forensic professionals searching for buried human remains. The study concludes that the equipment should be used with caution after a critical evaluation of specific field conditions, and more refinement of technical methods and skills should be developed.

KEYWORDS: forensic science, forensic archaeology, geophysics, ground penetrating radar, magnetometry, electrical resistivity, unmarked burials

The theoretical potential of geophysical techniques to assist in forensic investigations is compelling, and some researchers have reported success using geophysical equipment to pinpoint buried human remains (1–6). However, many forensic experts are intimidated or confused by geophysical equipment and the data generated by it. The fact that positive results are generally published more frequently than negative or ambiguous results contributes to a problematical lack of realistic evaluation (7). Furthermore, members of local police forces and the lay public tend to consider remote sensing to be a kind of "magic wand." In reality, the utility of these methods has not yet been fully established. The U.S. Army Central Identification Laboratory, Hawaii (CILHI) has recently examined the benefits and limitations of using remote sensing techniques in forensic contexts by applying three types of geophysical equipment in various field situations.

The equipment utilized in this study included a Geophysical Survey Systems, Inc. SIR® System-2 Ground Penetrating Radar (GPR) machine, a Geometrics, Inc. model G-585 MagMapper cesium magnetometer, and a basic electrical resistivity kit manufactured by GMC Instruments, Inc. GPR devices use two antennae, one that introduces electromagnetic waves into the ground and another that measures the reflection of those waves off subsurface strata and features. The data are displayed on a computer screen connected remotely to the antennae via an electrical cable. Subsurface characteristics such as natural stratigraphic boundaries, tree roots, buried objects, and cultural features can be detected by interpreting the data displayed on the screen (8–10). Magnetometers essentially measure the earth's magnetic field in a given location. Since many subsurface anomalies have a magnetic signature that differs from the field surrounding them, disturbances (such as graves) can be detected by noting variations in the field (9–13). Electrical resistivity is a method by which an electrical current is introduced into the ground through metal probes, and the subsurface material's resistance to electrical conduction is measured. Subsurface anomalies are detected by taking a series of readings, using one of a variety of specific array configurations, then plotting and comparing the measurements (9,10,12,13).

A series of expedient field tests was conducted with the goal of determining whether or not this technology can be used to find unmarked burials more quickly and cost-effectively than traditional archaeological methods. The study was also designed to ascertain whether or not an anthropologist with a reasonable amount of training on the equipment would be able to apply it effectively to field problems. The ultimate objective is not to obviate excavation through negative results, but rather to narrow down areas of potential investigation through positive results in order to save time.

Field Methods and Results

Over the course of approximately one year, the author became familiar with the equipment and manuals, attended a week-long workshop organized by the National Park Service (Recent Advances in Archaeological Prospecting Techniques 2000), and embarked on a series of field projects that provided the opportunity to test and compare the practical application of these three pieces of equipment. Each of the field situations is summarized here, along with a discussion of findings.

The Punchbowl

The National Memorial Cemetery of the Pacific, otherwise known as the Punchbowl, is a large veterans' cemetery located near

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* This work was supported in part by an appointment to the Research Participation Program at the CILHI administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and the CILHI.

The opinions and conclusions presented here reflect those of the author alone.

Presented as a paper (*Remote Sensing for the Rest of Us)* at the 66th Annual Meeting of the Society for American Archaeology in New Orleans, April 18–22, 2001.

Received 7 May 2002; and in revised form 29 June 2002; accepted 4 July 2002; published 13 Nov. 2002.

downtown Honolulu, Hawaii, in an extinct volcanic cinder cone. Burials in the Punchbowl include hundreds of unknown soldiers from the Korean War. Their metal coffins were originally placed in approximately 2 m deep trenches, positioned in closely spaced rows. The Punchbowl was used as a testing ground for the geophysical equipment to see if it could effectively detect a series of graves that were scheduled for exhumation. GPR and the cesium magnetometer were used, but due to time constraints, only minimal resistivity data were collected.

At the Punchbowl, grass grows in a sandy clay loam exogenous fill that covers the natural volcanic sediment. A 30 by 30 m grid (approximately six headstones long and four headstones wide) was established, and the GPR was run over the graves perpendicular to the known coffin orientation using 400MHz and 900MHz antennae in both automatic and custom settings. Readings were interpreted "real time" (the data screen was interpreted as it was collected) by two separate investigators. The magnetometer was used with a single sensor, oriented at a 90° angle, and measurements were taken both perpendicular to and parallel to the known coffin orientation. Magnetometer data were also interpreted "real time" using visual and audio signals. A smaller 4 by 6 m grid was established, incorporating portions of three graves, and resistivity data were collected using the Wenner array—four electrodes equally spaced in a straight line at 1 m intervals (12).

Neither of the investigators monitoring the GPR screen was able to discern readings that distinctly indicated graves. When the antennae were run over top of the stone grave markers, these created a visible signature, but nothing that clearly delineated the graves or metal coffins themselves. It may be that the coffins are spaced too closely for the GPR to differentiate between them.

Magnetometer data, interpreted real time, revealed no clearly interpretable pattern. One complicating factor may have been the presence of metal flower holders, located at each grave marker, which invariably added noise to the data. A conclusion reached through this initial experiment was that magnetometer data should not be interpreted in the field, but rather translated into a simple contour map using computer software; this strategy was applied to subsequent tests in other locales.

Ideally, data are collected over a large area so that anomalous patterns can be delineated, but the simple resistivity kit used in this study proved rather time-consuming and labor intensive for a large area survey. Time constraints dictated that only minimal resistivity data were collected, but the tentative pattern was similar to the GPR results—a generalized field of similar readings that did not necessarily demarcate individual graves.

The Punchbowl tests resulted in negative data; graves are known to exist in the survey area, but none were clearly detected using geophysical tools. It was nevertheless a valuable exercise because it called attention to issues such as antenna settings, software data processing, time budgeting, and consideration of potential sources of noise that would need to be addressed in future field tests.

Fort Hood, Texas

The geophysical equipment was incorporated into a cemetery mapping project at Fort Hood, Texas. One area investigated at Fort Hood was a small (4 by 4 m) plot of land enclosed by a barbed wire fence that appeared to be a potential site for unmarked graves. The matrix at this location was a relatively coarse sandy gravel. GPR was run north and south using both a 400MHz and a 900MHz antenna in automatic settings (400D and 900TAVD). The magnetometer was not used because of assumed interference from a surrounding metal fence, and resistivity data were not gathered because of time constraints. Observation of the GPR screen revealed no apparent subsurface anomalies that might indicate a grave. These findings were supported by excavation, conducted several months later, which indicated that no graves were present. The enclosure may simply have been used to contain livestock. In retrospect this negative data served as a useful comparative sample for other locations at Fort Hood that did in fact contain burials.

Data were collected in a small family cemetery where the placement and configuration of gravestones left some doubt as to how many individuals might be buried and exactly where the graves were located. The site matrix consisted of loamy clay mixed with limestone gravel. A 7 by 6 m grid was established over the cemetery, marked at 1 m intervals. The GPR was run north-south, perpendicular to the assumed graves, using a 400MHz antenna. Resistivity data were collected using the Wenner array in 1 m intervals. Collection of resistivity data over the 7 by 6 m area took two people approximately 2 h. Resistivity data were used to produce a basic Surfer® (14) contour map, which indicated several anomalous areas (Fig. 1). The magnetometer was not used because of assumed interference from the surrounding metal fence. After geophysical data collection, a shallow 5 m long, 50 cm wide trench was excavated running north -south across the three assumed graves. This excavation confirmed the presence of three grave shaft features (Fig. 1), interpreted as such based on their shape, coloration, sediment consistency and position in relation to the extant footstones. Excavation ceased once these features were discovered and no human remains were disturbed.

The GPR screen revealed some ambiguous anomalies (Fig. 2), along with at least one hyperbolic reflection (Fig. 3). A hyperbolic image can result from radar waves reflecting back to the antenna as it approaches a subsurface object, passes over it, and then moves beyond it (8). The other anomalous reflections presented significant substance for interpretation, but no confident conclusion was reached. Excavation revealed that the hyperbolic reflection did indeed correspond to a grave; however, the other anomalous reflections corresponded to areas both with and without graves. Interestingly, the one clear GPR anomaly corresponded to the relatively subtle feature of an older (ca. 1884) grave, but not the more obvious feature of the newest (ca. 1923) grave.

Another larger cemetery, containing graves dating from the mid 1800s through 1994, was tested at Fort Hood to determine if a large area of the cemetery, which had almost no head stones, might in fact contain unmarked graves. A 40 by 20 m grid was set up over the area where suspected unmarked graves were located, and the GPR was run north-south using a 400MHz antenna. The magnetometer was not used because of assumed interference from the surrounding metal fence, and resistivity data were not collected because of time constraints given the large area to be covered. The soil was a silty loam.

Contained in the 40 by 20 m grid were two apparent gravestones showing no writing or dates whatsoever, which may have been placed at the earliest period of use for the cemetery (the mid 1800s). The GPR was run over these graves twice using different automatic settings, but the operators were unable to detect any potential anomalies. After geophysical data were collected, a small trench was excavated over these suspected graves to a depth of approximately 20 cm, where pit features, presumably grave shafts oriented east-west, were clearly visible. Excavation ceased once these features were discovered and no human remains were disturbed. The GPR was also tested over a 1994 grave, and in this case a detectable reflection was evident on the data screen (Fig. 4).

Besides the cemeteries in Texas, the GPR and magnetometer were expediently tested on a trench that a local Cultural Resource

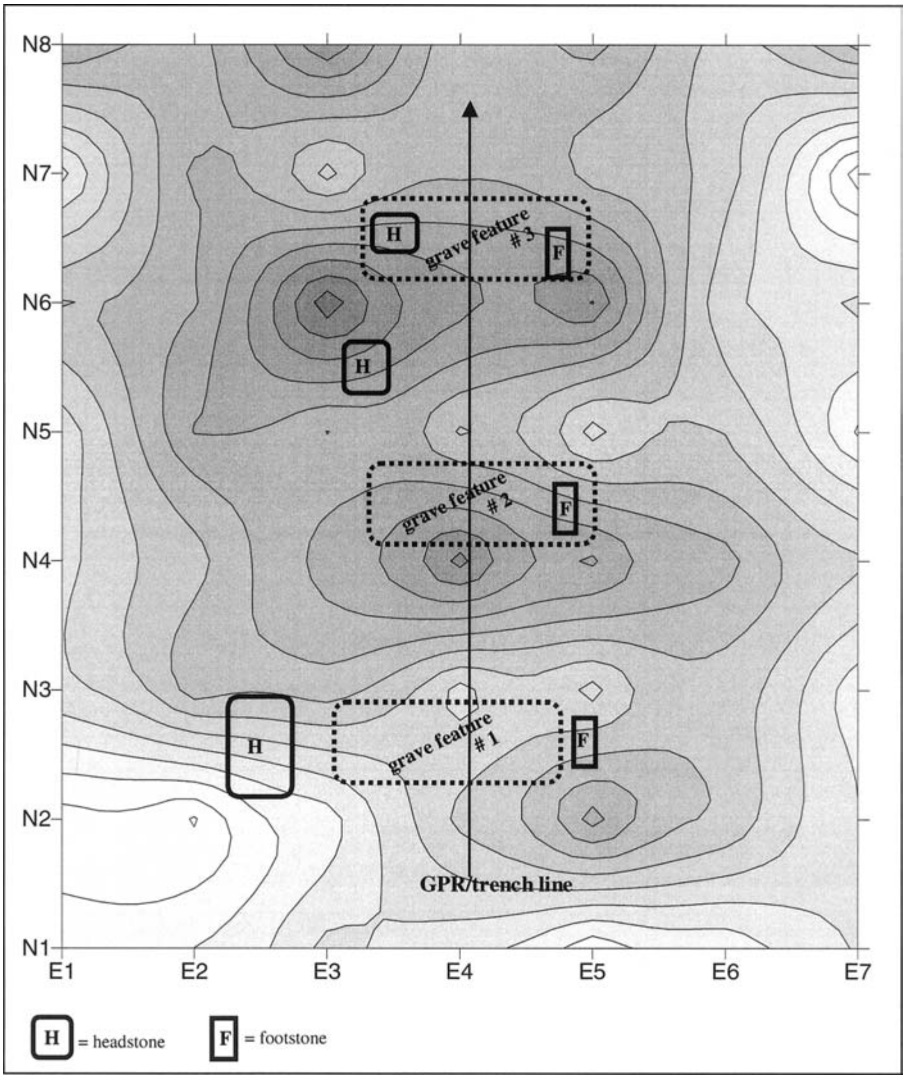

FIG. 1—*Cemetery site map including contours that represent resistivity data. Darker areas indicate higher resistivity values. Grave feature locations were judged based on excavation of a small test trench. "GPR/trench line" corresponds to the location of both the excavated trench and the data displayed in Figs. 2 and 3.*

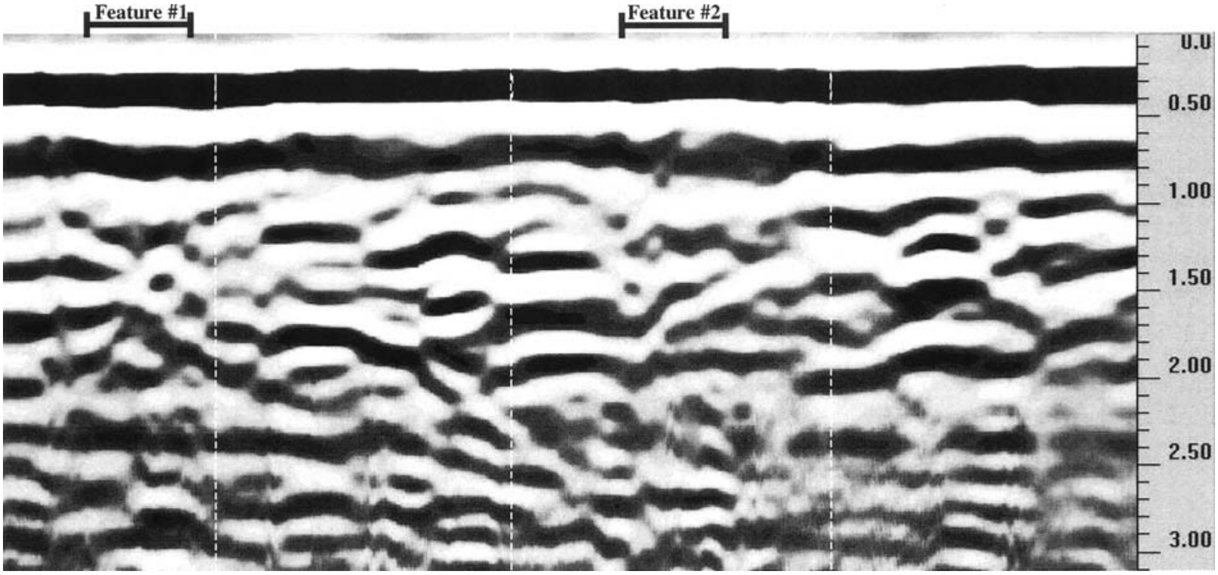

FIG. 2—*Section of GPR profile from 400MHz antenna in 400D setting. This part of the transect was run across the two southernmost grave features (#1 and #2; see Fig. 1). Numbers on the right estimate depth in meters. White dashed lines mark horizontal 1 m intervals.*

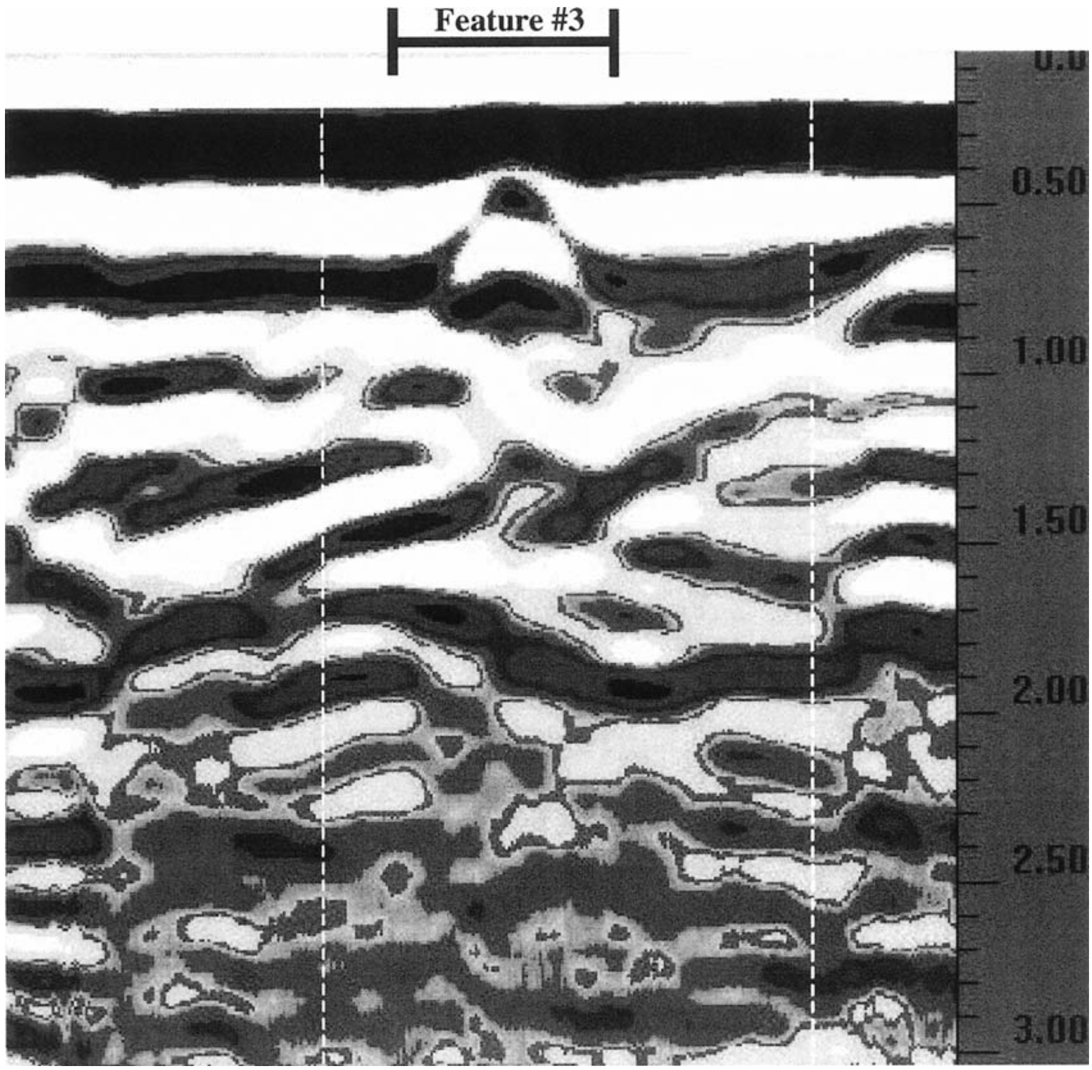

FIG. 3—*Continuation of same GPR profile as Fig. 2. Numbers on the right estimate depth in meters. White dashed lines mark horizontal one-meter intervals. Note hyperbolic reflection of grave feature #3 (refer to Fig. 1).*

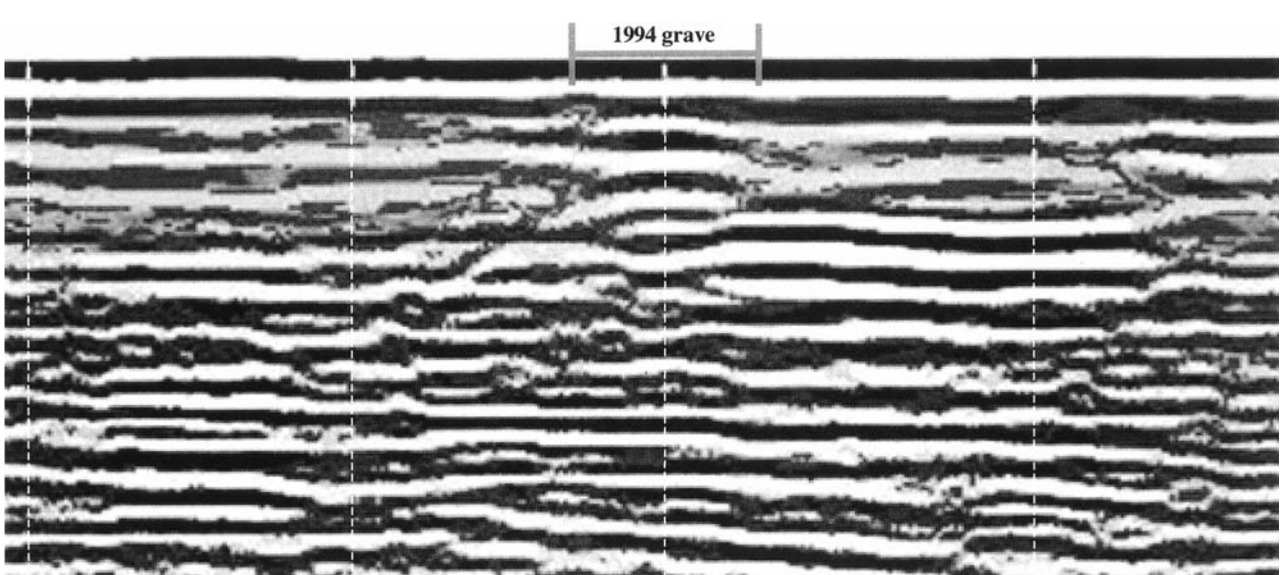

FIG. 4—*Section of GPR profile over 1994 grave. Both "deep" and "shallow" automatic settings were used. These data are 400MHz "deep" setting. Note faint hyperbolic reflection. White dashed lines mark 2 m intervals on ground surface.*

Management (CRM) company had excavated and backfilled several days before. The test trench had been excavated to 2.5 m deep, 1.5 wide in silty clay loam. A 10 by 10 m grid was established over part of the trench. The GPR was run east-west, perpendicular to the trench, using the 400MHz antenna in two different settings, and the magnetometer was run both north-south and east-west. Magnetometer data were then processed using MagMap software. This particular area presented an ideal scenario from a pure testing standpoint in many ways: little or no interference, undisturbed sediments, and a clearly defined feature of known dimensions. Considering these factors, it was surprising to find that the operators were unable to detect the trench with either the GPR or the magnetometer, even when the latter data were processed through imaging software.

Murder Investigation

The equipment was used to assist local police with a murder investigation. An individual was allegedly murdered several years ago, but police have not found the body. A tip suggested that the victim may have been buried in the yard of a private residence, so the detectives sought assistance in trying to locate a possible grave there. The yard measured approximately 15 by 20 m and was made up of a fine volcanic pebble matrix with some larger rock inclusions, overlain by a 10 cm deep layer of humus/grass.

The GPR was run with the 400MHz antenna and several anomalies were detected. Resistivity probes were set in the Wenner array at 1 m intervals. Readings were entered into a spreadsheet, and calculated resistivity values were plotted on a Surfer® (14) contour map. Magnetometer data were collected despite the presence of numerous noise sources such as power lines and large quantities of metal trash piled up along the edge of the yard. These data were processed through MagMap software. Not surprisingly, considering the high degree of magnetic noise at the site, the resulting contour map contained little interpretable information.

When the resistivity and GPR data were plotted on an overall site map (Fig. 5), comparison revealed several locations where both types of equipment detected anomalies. The entire yard was subsequently excavated both by hand and with a backhoe, beginning with the geophysically determined areas of highest suspicion. In one of the anomalous locales, two dog skeletons were discovered, wrapped in plastic trash bags and buried approximately 15 cm deep. In another locale, a plastic diaper was recovered from just below the surface. A large (approximately 3 by 3 m) area of anomalous readings turned out to be the house's buried cesspool. Some areas pinpointed by geophysical analysis revealed no clear source of anomaly. No murder victim was discovered.

Discussion

Table 1 presents a summary of results for each piece of equipment in the locales where they were applied.

Using the GPR "real time" simply by viewing the data screen in the field proved ineffective, primarily because of concerns about reliability and consistency. While the GPR was used to detect several known anomalies, it failed to produce clear evidence of others. Software designed to show an enhanced representation of radar data might improve interpretive ability. The simple resistivity kit used in this study provided adequate data, but a model that allows for faster data collection and processing would be essential for most forensic investigations. Interpreting magnetometer data "real time" was not a reliable method, but the use of data processing software might improve its utility. Sources of noise and interference—particularly prevalent in plane crashes, battle sites, or urban areas—should be carefully considered before the magnetometer is applied.

The murder investigation illustrates the issue of cost effectiveness. A traditional approach to this case would have involved an excavation of the entire area under suspicion. Instead, geophysical methods were used first, in an attempt to pinpoint locations of higher and lower probability. This took approximately three days to accomplish. In the end, a complete excavation of the suspect area was undertaken regardless. Therefore, the use of geophysical equipment in this case actually proved more costly in terms of both time and money.

Given the right mix of conditions, geophysical techniques may be effective in pinpointing subsurface features such as burials; however they should not be used to *exclude* prospective areas of investigation. Ideally, they offer a tool to narrow down the most promising places to *start* searching for an unmarked grave using standard archaeological techniques.

TABLE 1—*Summary of findings.*

Equipment	Location	Summary
GPR	Punchbowl Cemetery	No graves detected. Coffins may be too closely spaced to differentiate between them.
	Livestock enclosure, TX	No graves or anomalies detected. Subsequent excavation confirmed absence of features.
	Small cemetery	Anomalous reflections visible on data screen, including one that corresponded to a grave, but others that did not (Figs. 2 and 3).
	Large cemetery	1994 grave detected (Fig. 4); older graves not detected.
	CRM trench	Recently backfilled 1.5 m wide, 2.5 m deep trench not detected.
	Murder investigation	Anomalous reflections corresponded to dog burials, buried diaper, cesspool, and several with no apparent source (Fig. 5).
MAG	Punchbowl Cemetery	Real time interpretation revealed no clear pattern. Noise generated by metal flower holders at each grave marker.
	CRM trench	MagMap contour map did not display pattern that corresponded to the known dimensions of trench.
	Murder investigation	Noise from high concentration of metal trash, power and phone lines contributed to inconclusive data.
Resistivity	Punchbowl Cemetery	Time constraints dictated only minimal data collection. Coffins may be too closely spaced to differentiate between them.
	Small cemetery	Contour map of data presents tentative evidence of graves (Fig. 1).
	Murder investigation	Anomalous areas corresponded to dog burials, buried diaper, cesspool, and several with no apparent source (Fig. 5).

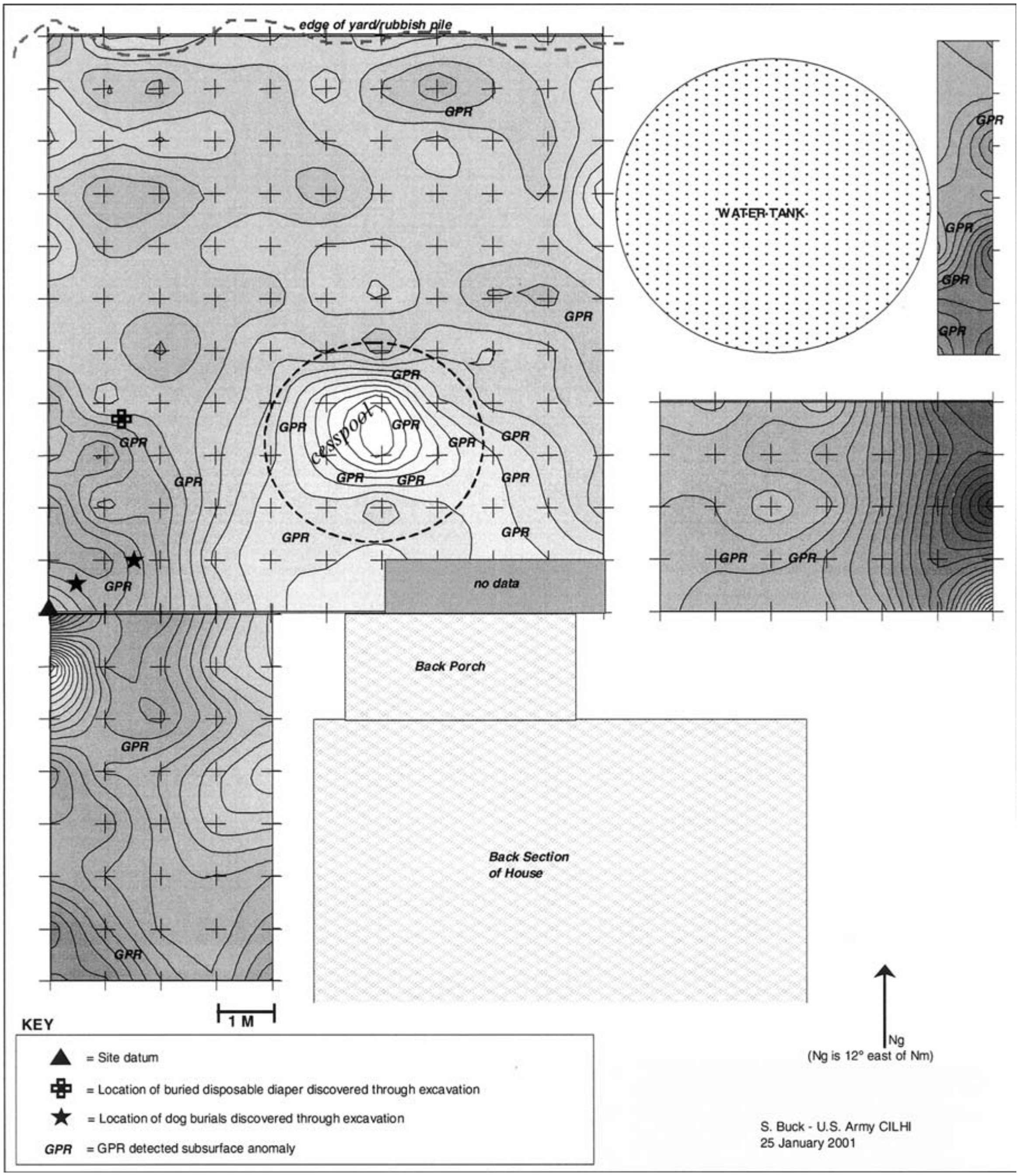

FIG. 5—*Murder investigation site map incorporating both resistivity data (contour lines) and GPR-located anomalies. Darker areas indicate higher resistivity values.*

Geophysical technology, particularly GPR and magnetometry, present complex data that can be highly confounding. The average forensic anthropologist or archaeologist, with a limited geophysical background, cannot expect to master the use of geophysical technology fortuitously. The use of geophysical equipment in forensic situations, however, should not be discarded as hopeless; further experimentation should be carried out and problematic issues presented so that they can be addressed and improved upon. Negative or ambiguous results should be published so that geophysical experts can develop new ways to overcome challenges.

Acknowledgments

This research was supported in part by an appointment to the Research Participation Program at the CILHI administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and the U.S. Army CILHI. The author would like to thank Mr. Messner and Mr. Castignetti of the National Memorial Cemetery of the Pacific, and the Fort Hood Cultural Resource Team, particularly Stephanie Bandy, Karl Kleinbach, SFC Jim Nutt, Gavin Smith, Kristen Wenzel, and Mike Wilder. Thanks are also due to colleagues who offered a variety of assistance: Derek Benedix, Greg Berg, John Byrd, Denny Danielson, Helen Dockall, Greg Fox, Mark Leney, Peter Miller, James Pokines, and Richard Schumann. The input of the anonymous reviewers who commented on the first draft of the manuscript is greatly appreciated.

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