Lawrence B. Conyers

Ground-Penetrating Radar Techniques to Discover and Map Historic Graves

ABSTRACT

Ground-penetrating radar is a geophysical technique that can be used to identify and map features commonly associated with historic graves, including intact or partially collapsed coffins and vertical shafts. Data are collected by moving radar antennas that transmit pulses of energy into the ground along parallel transects within grids, recording reflections of those pulses from significant discontinuities within the ground. Visual analysis of radar reflection profiles can be used to identify both coffins and the vertical shaft features commonly associated with human burials. Spatial analysis of the reflection amplitudes within a grid consisting of many profiles (when converted to depth using site-specific velocities) produces three-dimensional maps of these burial features. The identification and mapping of graves can identify remains for possible excavation and study, and the results can also be used for statistical and spatial analysis when integrated with historical records. If identified by these methods, previously unidentified graves can be preserved in areas threatened by construction or erosion.

Introduction

Locating, studying, and sometimes excavating historic period graves can produce a great deal of information about the past not otherwise available from archival documents or other data sources. If the goal is to study skeletal remains for osteological or molecular studies, the first step must be identification of the graves of interest. Many historic cemeteries are poorly maintained and often threatened by erosion, development, and agricultural operations, making the identification of graves important if they are to be preserved. Sometimes unmarked graves need to be identified so that human remains may be removed if threatened by construction or even to make way for additional burials when cemeteries expand their boundaries or fill in areas that appear to be vacant.

Geophysical techniques such as ground-penetrating radar (GPR) can be used to located unmarked graves and recover other information about historic period cemeteries. GPR can often determine grave attributes such as depth of burial, grave size, type of caskets and their orientation; numbers of graves in certain locations; and the spatial distribution of graves within certain areas of a cemetery. This information can then be integrated with birth and death records, information found on headstones, or other historical documents to provide a database on the lives and behaviors of the individuals buried there. Often this information is not available by other means.

Some Euroamerican cemetery characteristics such as the depth, orientation, and spatial distribution of grave shafts have changed over time. Often they reflect the economic background, ethnicity, and religious, social, or aesthetic values of both the dead and those doing the burying (Farrell 1980). Although in some cases these characteristics are well documented (Crissman 1994; Sloan 1995) they have not generally been applied to the study of specific communities or integrated with historic records, especially in older cemeteries where grave markers are moved or missing. GPR has the potential to precisely map these graves and add an important data layer to any historical study involving burials and burial practices.

Lacking geophysical means, finding historic graves using traditional probing or excavation methods has often been a "hit or miss" task for most archaeologists. Attempts to locate these subsurface features using visual analysis of surface soils or vegetation changes are also fraught with problems. Head- and footstones that were once present in many historic cemeteries are often deteriorated, relocated, or missing. Written documentation about grave locations is often incomplete, inaccurate, or absent. Falling trees can uproot underlying sediments as well as human remains; animals can burrow into graves; and the wood associated with coffins and surface markers quickly rots with little or no trace. Often there is little to assist researchers in locating graves other than vague memories about where burials were located or poorly drawn sketch maps.

Archaeologists have attempted to locate graves by inserting probes in the ground in

Historical Archaeology, 2006, 40(3):64–73.

an attempt to detect soil changes, voids, or areas that might be less compacted (Killam 1990). Some have resorted to dowsing, with little success (Barrett and Besterman 1968; Reese 1985; Van Leusen 1998) or employed psychics (Goodman 1977), and a few have even attempted to use dogs, purported to have acute senses of smell, that are trained to sniff out human remains (Killam 1990).

A more reliable method that has been used to locate and then map historic graves is the use of geophysical devices that can measure physical and chemical changes in the ground. These changes may be related to grave shafts, coffins, void spaces, and even the human remains themselves (Bevan 1991; Nobes 1999; Davenport 2001). The most common of these are magnetic gradiometry, electrical resistivity, GPR, and electromagnetic conductivity. Magnetic methods use passive devices that measure small changes in the Earth's magnetic field that are influenced by changes in soils and buried materials below the surface. These changes can result from the presence or absence of metal in coffins or even minute differences in soil and sediment types that exist between grave shafts and undisturbed adjacent materials. The other three most commonly used geophysical methods use tools that transmit energy into the ground and then measure how that energy is affected by changes in the ground related to the presence or absence of graves, grave goods, and soil changes. The resistivity method transmits an electrical current into the ground and measures the differences in voltage between the transmitting device and a recording device some distance away. When mapped spatially, changes in these resistance readings can be related to the presence or absence of graves. A similar method of energy transmittal is used in electromagnetic (EM) conductivity, where an EM field is induced into the ground and measurements are taken, which indicate how that field is affected by the underlying deposits. GPR is also an active method that transmits pulses of radar energy of differing frequencies into the ground and measures properties of the reflections derived from buried materials in the ground.

All of these geophysical methods collect data along a series of transects within a grid, which can be interpreted individually as two-dimensional profiles or as a group to spatially map differences in ground conditions that might be related to the presence of graves. The differences in the readings within the grid, when mapped spatially, can often be related to burial phenomena, such as the presence or absence of artifacts associated with human remains or geological changes that can be related to grave shafts. The human remains themselves cannot generally be detected since there is not enough contrast between them and the surrounding material.

GPR is one of the best methods to map graves because it is capable of measuring both physical and chemical changes in the ground in three dimensions; therefore, depth as well as the spatial distribution of graves can be determined (Bevan 1991; Davis et al. 2000). This can be accomplished because radar pulses are transmitted from a surface antenna and reflected off buried discontinuities. The returning pulses are measured in elapsed travel time. When time is converted to distance (using measurable velocities common to each site), depth in the ground can be readily determined. In addition, radar energy is readily reflected from any discontinuity in the ground, including soil compaction changes, mineralogical differences, sediment size distinctions, void spaces, and the type and concentration of associated artifacts. Amplitudes of the reflected waves can also be precisely measured, indicating differences in material properties within the ground, producing an additional measurement that is valuable in locating subtle buried features.

GPR systems are compact and easily transported to and from the field. A typical system consists of a radar control system and associated computer, antennas, and a power source (Figure 1). Grids of data (up to 40 x 40 m) can be collected in a day, depending on the transect spacing and the number and complexity of surface obstructions. Reflection data are easily transferred from the GPR system to a laptop computer for immediate analysis, with preliminary results often available just hours after collection.

Grave Characteristics

Physical anthropologists have long concerned themselves with finding human remains, whether intentionally buried or covered and preserved by natural means. A large body of literature

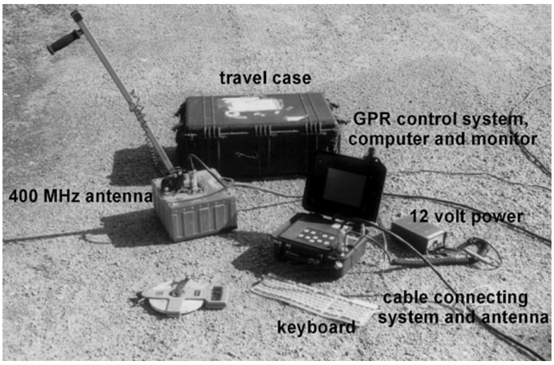

FIGURE 1. This Geophysical Survey System Inc. (GSSI) Subsurface Interface Radar (SIR) system model 2000 with antenna and carrying case. (Photo by author.)

addresses the detection of human remains for forensic purposes, both anthropological and criminal (Imaizumi 1974; Boddington et al. 1987; Killam 1990). Addressed here is the use of GPR techniques to detect and map inhumations that were deliberate burials, usually in cemeteries, and not those that might have been the result of flood events, drowning, or other natural actions.

Most historic period Euroamerican burials in North America are primary interments, with and without coffins, placed horizontally, without changes in position since burial. There are, of course, many other deliberate burial types that were common throughout the world as well as North America. For example, secondary interments occurred where bones were collected after decomposition of the soft flesh and then reburied or where many individuals were buried in one grave, including ossuaries and other mass graves of this sort. In these cases, human remains are rarely in an articulated anatomical position and associated grave goods can be jumbled and are difficult to detect geophysically. Multiple interments are also common in military battlefield contexts where several bodies might be located in one grave. These can also be quite complex. Only those more common singular graves where human remains were buried once and not reinterred or highly disturbed are discussed here.

Each such grave has four distinct physical features that can potentially be imaged using GPR techniques: (1) the natural soil or substrate below and surrounding the grave shaft, (2) the buried coffin or human body and its associated artifacts, (3) the backfill used to fill in the vertical shaft, and (4) the surface layers of sediment or soil that have accumulated on that shaft after interment. Of these four features, the contact between the shaft and the surrounding material, coffins containing remains, and sometimes associated artifacts are what can be readily imaged using GPR. When human bodies, coffins, urns, or any other grave goods are placed in the ground, a vertical shaft is excavated through surface soils and underlying sediment or rock units, producing an aerially distinct and often recognizable feature that can be seen in GPR reflection profiles. During excavation of a grave, the natural substrate and surface soils are almost always placed on the ground nearby and then returned to the grave shaft after interment. The excavated material that is used to backfill the shaft is highly altered during this process, becoming less compact and more homogenized, losing any natural stratigraphy that might have existed prior to digging. Backfill material will then settle over time, sometimes leaving a natural depression on the surface but also producing settling structures within the shaft that can be distinctive.

If graves are placed in horizontally layered material, the backfill material can be quite apparent as the natural stratigraphy is disturbed during digging, and the zone of truncation is readily visible in profile. The backfill material lacks any natural stratigraphy and the interface between it and the surrounding material can be readily identified in both excavation faces and GPR reflection profiles (Figure 2). In areas where weathered bedrock is shallow or the ground is composed of gravelly or cobble-rich sediment, there can be a good deal of "clutter" in both the disturbed area of the grave shaft and the adjoining undisturbed material, making vertical definition of grave shafts much more difficult to discern. The same is true in homogeneous fine-grained soil and sediment that has little natural stratigraphy. In this case, little physical differentiation exists between shaft backfill and natural substrate.

In cases where individuals were placed in coffins or other containers, these will have deteriorated over time and partially or totally collapsed, producing subsurface and surface slump features. These surface depressions will often slowly fill in with sediment and soil will

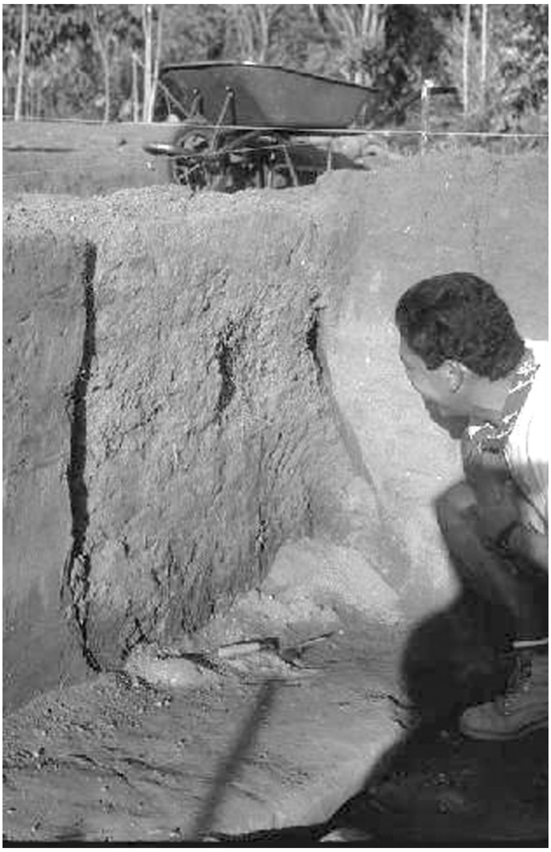

FIGURE 2. A primary interment with distinct vertical shaft walls incising through naturally layered soil and sediment layers. (Photo by author.)

form, leveling the ground surface and making surface identification of these graves difficult. More substantial caskets constructed of oak or metal can remain intact for a much longer time, producing a noticeable void space in the ground that is readily detectable with GPR. The same is true for burial vaults made of brick or stone, which often preserve void spaces surrounding human remains for centuries. Burials within buildings, such as under the floors of churches or in small family shrines and mausoleums, will also preserve coffins and associated remains for a very long time. The void spaces beneath building floors are often distinctly visible on GPR profiles.

The range of primary interment characteristics, soil and sediment differences, climate and soil chemistry factors, and many other variables often make challenging the detection and mapping of graves using GPR. Usually GPR will detect at least the contact between the vertical shaft backfill and the substrate and also the void spaces in completely or partially intact coffins. If there has been a good deal of postinterment disturbance of burials due to human or animal and plant disturbance, normal grave features can be highly altered, making detection challenging by any method, including geophysics.

GPR Method

GPR data are acquired by transmitting pulses of radar energy into the ground from a surface antenna and reflecting that energy off buried objects, features, or bedding contacts. At a paired receiving antenna the elapsed time from when pulses are sent and then received back at the surface as well as the strength of that energy are measured and recorded. When collecting radar reflection data, surface radar antennas are moved along the ground in transects within a surveyed grid, and a large number of subsurface reflections, called traces, are collected along each line. Often GPR recording systems can be programmed to collect at a density of one trace, or even more, every 5 cm along the surface transects. When reflection traces are stacked together along one transect line, a reflection profile is created that illustrates a cross-section of the ground much like what might be visible in a trench wall (Figure 3).

As radar energy moves through various materials in the ground, the velocity of the propagating waves will change depending on the physical and chemical properties of the material through

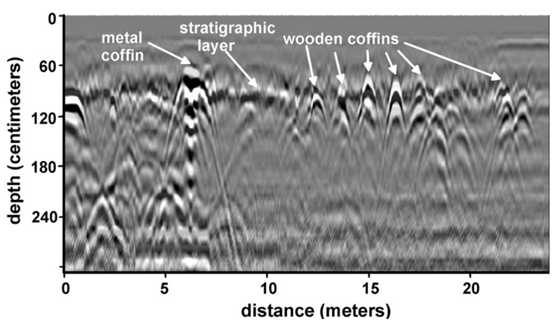

FIGURE 3. Reflection profile from a cemetery with wooden coffins interred between 1898 and 1921. One metal coffin is identifiable by the alternating strong reflections below it. (Drawing by author.)

which they are traveling (Conyers 2004:26). At each velocity change a portion of the propagating wave will be reflected back to the surface to be detected at a receiving antenna that is usually paired with the transmitting antenna. The remaining energy will continue into the ground until it is absorbed and dissipated. The greater the contrast in electrical (and to some extent magnetic) properties between any two buried materials at an interface, the stronger the reflected waves will be that travel back to the surface, and the greater the amplitude of recorded signals (Conyers 2004:49).

History of Ground-Penetrating Radar

Radar devices that transmit energy into the ground, as opposed to searching for objects in the air, were first experimented with in the 1920s to determine the depth of ice in glaciers (Stern 1929). The ground-penetrating aspects of radar technology were then largely forgotten until the late 1950s when U.S. Air Force radar technicians on board airplanes noticed that their radar pulses, used to determine altitude, were penetrating glacial ice when flying over Greenland. A number of mishaps occurred because airborne radar analysts detected the bedrock surface below the overlying ice and interpreted the bedrock instead of the ice as the ground surface, resulting in crashes. In 1967, the first prototype GPR system (similar to those used today) was built by NASA and sent on a mission to the moon in an attempt to determine surface conditions prior to landing a manned vehicle (Simmons et al. 1972).

One of the first archaeological applications of GPR was conducted at Chaco Canyon, New Mexico, in an attempt to locate buried walls at depths of up to one meter (Vickers et al. 1976). A number of experimental traverses were made, and the resulting reflection profiles were analyzed in the field. It was determined that some of the anomalous radar reflections represented the location of buried walls. These early studies at Chaco Canyon were followed by a number of GPR applications in historical archaeology that successfully located buried building walls and underground storage cellars (Bevan and Kenyon 1975). In these early studies what were described as radar "echoes" and "reverberations" were recognized as having been generated from the tops of buried walls. Depth estimates were made, using approximate velocity measurements obtained from local soil characteristics.

These initial successes were followed by other GPR studies in the 1970s and 1980s that also successfully delineated buried walls, floors, house platforms, and other buried archaeological features. Most initial successes were primarily a function of the very dry matrix material surrounding those buried archaeological features that was almost "transparent" to radar energy propagation, allowing for deep energy penetration and producing relatively uncomplicated reflection records that were easy to interpret.

Throughout the late 1980s and early 1990s GPR continued to be used successfully in a number of archaeological contexts, mostly as what could be called "anomaly hunting" exercises. Unprocessed or partially processed GPR reflection profiles were viewed as paper records or on a computer screen as they were acquired. Interesting anomalous reflections, which could possibly have archaeological meaning, were then excavated. This type of acquisition and interpretation method led to mixed results, with some successes and notable failures, often leaving many archaeologists with the impression that GPR was a "hit or miss" method at best. In the early 1990s GPR manufacturers began to market systems that could collect reflection data as digital files, thereby storing large amounts of reflection data for later processing and analysis. About this same time, inexpensive and increasingly powerful personal computers were also becoming available that could process these digital data in ways that had not been previously possible.

Recently, the application of two-dimensional computer simulation and three-dimensional processing techniques have shown that even radar data that does not yield immediately visible reflections when viewed in the field can still contain valuable reflection data when computer processed (Goodman 1994; Goodman et al. 1995; Conyers 2004:138). Computer enhancement of raw GPR reflection data and three-dimensional visualization of buried sites is now becoming widespread as researchers increase their familiarity with some of the recent GPR computer-processing techniques (Conyers et al. 2002; Conyers 2004:150).

GPR has not commonly been used to map graves, as they are not usually aerially extensive, can be quite subtle features, and their characteristics vary greatly from site to site. Some notable exceptions are the historic cemeteries mapped by Bruce Bevan (1991) in the eastern and middle United States and those in permafrost in Norway (Davis et al. 2000). Somewhat less successful but nonetheless encouraging results were recently obtained at Texas and Hawaii military cemeteries (Buck 2003) and Maori burial grounds in New Zealand (Nobes 1999).

The success of GPR surveys in historical archaeology is largely dependent on soil and sediment mineralogy, clay content, ground moisture, depth of burial and surface topography, and the type of surface soils present. Electrically conductive or highly magnetic materials will quickly absorb radar energy and prevent its transmission into the ground. The best conditions for energy propagation are therefore dry sediments and soil, especially those without an abundance of clay, which can sometimes be very conductive.

The depth to which radar energy can penetrate the subsurface and the amount of resolution that can be expected in the subsurface are partially controlled by the frequency (and therefore the wavelength) of the radar energy transmitted (Conyers 2004:42). Standard GPR antennas propagate radar energy that varies in frequency from about 10 MHz to 1,000 MHz. Low frequency antennas (10–120 MHz) generate long wavelength radar energy that can penetrate up to 50 m into the ground in certain conditions but are capable of resolving only very large buried features. In contrast, the maximum depth of penetration of a 900 MHz antenna is about 1 m or less in typical materials. Its reflected waves are much shorter and can potentially resolve features with a maximum dimension of a few tens of centimeters. A tradeoff exists between depth of penetration and subsurface resolution. Most GPR surveys used to detect and map historic graves use antennas that range in frequency between 900 and 300 MHz, which produces good resolution data at depths between about 1 m and 3 m, respectively.

Data Collection and Data Analysis

To collect GPR reflections, paired antennas that generate the propagating radar waves and then record the resulting reflections are moved along the ground surface in transects, usually at a minimum of 10 m in length, with a transect spacing of 50 cm or less. Often a survey wheel is attached to the antennas, which will automatically record the horizontal location for all reflections that are recorded along each transect. Reflections that are received back at the surface from buried interfaces are usually recorded along many transects within a grid so that adequate spatial differentiation exists between burial features and natural soil and sediment substrate. Most stratigraphic layers, void spaces, and interfaces between coffins and backfill material, all of which are common to most historic graves, will reflect radar energy back to the surface.

The most efficient GPR collection method is to establish a grid across a survey area with reflection profile transects spaced between 25 cm and 1 m apart, depending on the subsurface resolution needed, the amount of ground to be covered, and the time budgeted for the survey. In GPR collection the elapsed time between pulse transmission, its reflection from interfaces in the ground, and subsequent recording at the receiving antenna is measured for each reflection in each trace as well as the reflected wave's amplitude. The received reflections are then amplified, processed, and digitally recorded for immediate viewing on a computer screen and saved on some kind of storage medium for later postacquisition processing and display.

Distinct and often continuous horizontal reflections visible in reflection profiles are usually generated at a subsurface boundary such as a soil unit, stratigraphic layer, bedrock, or sometimes the water table (Figure 3). Reflections recorded later in time are those received from deeper in the ground. Hyperbolic shaped *point-source reflections* are generated from distinct *point features* in the subsurface, which in cemeteries are usually casket tops or sides and void spaces within intact or partially collapsed caskets. Similar hyperbolic reflections can also be produced by buried stones, tree roots, or tunnels created by burrowing animals, creating anomalous reflections that can often be confused with those of caskets. Point-source reflection hyperbolas occur because GPR antennas generate a transmitted radar beam that propagates from the surface into the ground in a conical pattern, radiating outward as it travels deeper in the ground (Conyers 2004:57). Some radar energy will be reflected from buried objects that are not directly below the antenna. Only when the antennas are directly on top of the buried object will the radar reflections be recording the exact location and depth of the object. Reflection hyperbolas that are visible in reflection profiles (Figure 3) are generated because energy will be recorded from a buried point source prior to the antenna being directly on top of it, and antennas will continue to "see" the objects after they have passed. In the resulting hyperbola, only the apex denotes the actual location of the buried source. The arms of the hyperbola denote the reflected energy that traveled the oblique wave paths to and from the buried point source.

Metal- or lead-lined caskets produce both hyperbolic reflections and a series of distinct stacked reflections below the apex of the hyperbolas (Figure 3). This occurs because metal is a perfect radar energy reflector and almost all radar energy is reflected back to the surface from metal objects, which will then return back into the ground from the soil-air interface, only to be reflected back again, often many times along these same pathways. This creates a series of stacked high-amplitude reflections, indicative of a significant amount of buried metal in the ground. Narrower hyperbolas lacking in multiple reflections below their apexes are usually wooden caskets or the remaining void spaces from collapsed caskets. Smaller hyperbolas are often generated from smaller caskets, such as those of child burials.

In some cemeteries without caskets or with deteriorated wooden caskets, little remains from the primary interment to reflect radar energy back to the surface, and no distinctive hyperbolas will be generated. Bones or small amounts of metal from grave goods may still be present, but they are usually either too small or do not contrast enough either physically or chemically from the surrounding matrix to produce significant radar reflections. In these cases only the contact between vertical grave shaft and the natural substrate will be visible in reflection profiles as distinct truncation of the undisturbed adjoining material (Figure 4). Sometimes a near-surface slump of soil into the grave shaft can be discernible in reflection profiles.

Three-dimensional images are very useful in the analysis of historic cemeteries, which can be readily constructed from GPR reflection data when many profiles are collected in a grid. This mapping technique is accomplished by producing amplitude slice maps at defined horizontal layers within a grid of reflection data (Conyers 2004: 148). When abundant data are recorded along closely spaced transects in a grid and when good depth penetration of energy is obtained, a three-dimensional "cube" of reflections can be computer analyzed. The mapping of radar amplitudes is important because the degree of reflection, when mapped spatially, can show the distribution of physical and chemical differences in the ground that often are the product of buried grave goods and human remains. High-amplitude reflections often indicate substantial differences in coffin types, such as those composed partially or wholly of metal. Lower amplitudes can denote the location of wooden caskets. The amplitude slice-map method is usually more precise and less time consuming than attempting to visually identify many reflections of importance in each reflection profile in a grid, as there can often be tens or even hundreds of potentially important reflections. Computer processing of these reflec-

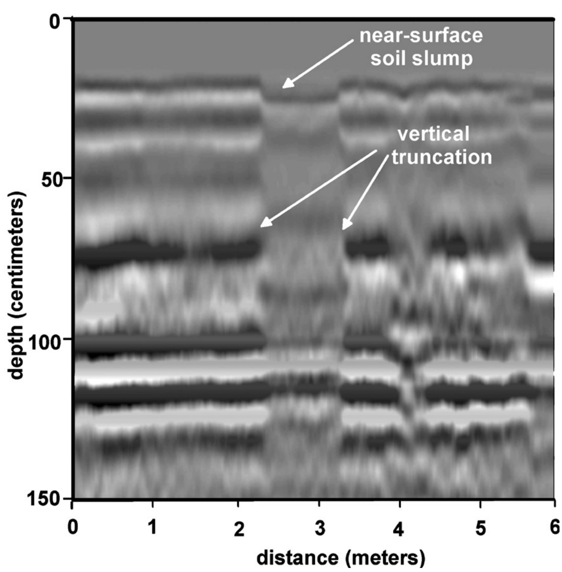

FIGURE 4. A likely grave shaft at the Chumash Indian Cemetery, La Purisima Mission, Lompoc, California. No casket is present, and any human remains at the bottom of the shaft are invisible in this reflection profile. (Drawing by author.)

tions compares digital data in a way the human brain cannot, producing complex databases, profiles, and maps of the spatial variation of both distinct and subtle reflections.

Amplitude slice maps are computer generated by comparing and spatially mapping all reflected wave amplitudes at defined depths in all profiles within a grid. Digital values of reflection amplitudes at each location in each profile are compared to those in adjacent profiles and then spatially interpreted, gridded, and mapped throughout a grid. The complete GPR database is then sliced horizontally in layers of any desired thickness and displayed to show the variation in reflection amplitudes at a sequence of depths in the ground. This produces images analogous to maps that might be constructed (but never would be, as it would be too time consuming) of all physical and chemical changes in arbitrary excavation levels within a very large standard excavation. The final product is a series of maps of certain layers in the ground, each of which illustrates the spatial distribution of both high- and low-amplitude reflections produced by caskets or other burial goods as well as other natural features (Figure 5). It is always interesting to compare maps of this sort to the location of existing headstones, especially in older cemeteries. In many cases the headstones have been moved over the years due to vandalism, natural processes, or other human-directed elements. The location of the GPR-mapped graves often correlates well with more recent graves, but sometimes there is little correlation with older graves as surface markers have been moved from their original locations (Owsley et al., this volume). It is also common to see distinct burials in portions of historic cemeteries where there are no markers or other documentation of graves at all (Figure 5).

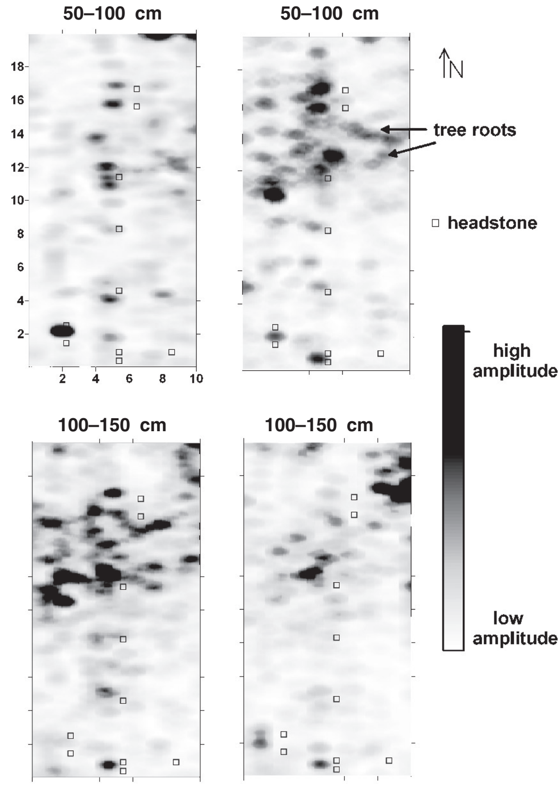

FIGURE 5. Amplitude slice-maps at the Oak Hill Pioneer Cemetery, Lawrence, Kansas. Graves date from the late 1800s. Caskets are identifiable as high amplitude anomalies in varying depth slices. Two tree roots are visible as sinuous reflections in the 50–100 cm depth slice. (Drawing by author.)

Actual depth in the ground for each amplitude time slice is determined by estimating the velocity of the radar energy in the specific soil and sediment types present at each site. This velocity can be highly variable from site to site and sometimes even vary within a GPR grid. It is affected by numerous physical and chemical variables of the ground and by compaction and moisture content. These velocities can be estimated using computer programs that "fit" the geometry of point-source hyperbolas to a known mathematical formula known for radar wave travel in certain media, which is a very accurate way to determine velocity (Conyers and Lucius 1996; Conyers 2004:99). Other, more sophisticated methods can be used if there are open excavations available or the actual depth to caskets is known and where both radar travel time and distance to known objects can be measured in the field. Time slices should always be converted to depth slices for archaeological interpretation, regardless of how velocity is determined.

Conclusion

If soil conditions are conducive to radar penetration and reflections from within the ground are obtained along many closely spaced transects within a grid, a number of grave features can be detected using GPR methods. The two distinct grave features commonly visible are reflection hyperbolas from caskets and vertical shaft truncation planes. Other features common in cemeteries such as large rocks, tree roots, or animal burrows may be confused with caskets, and care must be taken to differentiate them, usually by mapping all reflections spatially. Caskets will always produce spatially distinct reflection anomalies in the size of a human body, whether an adult or infant. Tree roots and burrows can be differentiated from human burials as they will produce elongated and sinuously shaped reflections. Individual rocks will almost always be visible in only one reflection profile and not on the parallel profiles, unless they are very large. The spatial distribution of these materials in the ground can be determined using amplitude slice maps and studied in real depth if the velocity of radar energy in the ground is obtained.

The other distinct grave elements that are visible in GPR data are the vertical planar surfaces of grave shafts that truncate surrounding sediment or soil layers. Often these features are the only clue to the location of graves if bodies were not placed in caskets or if caskets have subsequently collapsed and deteriorated. These types of features are less easily mapped using amplitude analysis and usually must be visually identified in reflection profiles and manually plotted on maps. Truncation surfaces are also only visible in reflection profiles if the undisturbed materials in the ground are stratified. A third, much less common, feature that is sometimes visible in reflection profiles consists of settling features in surface soils that can occur when grave backfill material compacts over time, allowing surface soils to become depressed. These features are sometimes visible in reflection profiles but, by themselves, would not be indicative of grave locations, as there can be other origins such as animal burrow collapse and the disintegration of rotting tree roots.

The use of GPR as a grave-mapping tool can be a precursor to both invasive and noninvasive archaeological studies. Finding human remains that might be excavated for biological research or the analysis of grave goods is one very direct outcome of GPR mapping. Other types of studies not commonly used to date in archaeology would be the incorporation of GPR maps and information with historical records. This could potentially yield important information about changing burial practices over time and differences in ethnicity or economic background of the deceased, their survivors, and the communities in which the burials were located. The efficiency and accuracy of GPR techniques for historic cemetery mapping is just being realized and has the potential to add much to any historical study, whether it involves excavation of remains or noninvasive mapping of the graves alone.

References

Barrett, William, and Theodore Besterman

1968 *The Divining Rod: An Experimental and Psychological Investigation*. University Books, New Hyde Park, NY.

Bevan, Bruce W.

1991 The Search for Graves. *Geophysics* 56(9):1310–1319.

Bevan, Bruce, and Jeffrey Kenyon

1975 Ground-Penetrating Radar for Historical Archaeology. *MASCA Newsletter* 11(2):2–7.

Boddington, A., A. N. Garland, and R. C. Janaway (editors)

1987 *Death, Decay, and Reconstruction: Approaches to Archaeology and Forensic Science*. Manchester University Press, Manchester, England.

Buck, Sabrina C.

2003 Searching for Graves Using Geophysical Technology: Field Tests with Ground-Penetrating Radar, Magnetometry, and Electrical Resistivity. *Journal of Forensic Science* 48(1):1–7.

Conyers, Lawrence B.

2004 *Ground-Penetrating Radar for Archaeology*. AltaMira Press, Walnut Creek, CA.

Conyers, Lawrence B., E. G. Ernenwein, and Leigh-Ann Bedal

2002 Ground-Penetrating Radar (GPR) Mapping as a Method for Planning Excavation Strategies, Petra, Jordan. *Society for American Archaeology E-tiquity* 1 <http://e-tiquity.saa.org/Etiquity/title1.html> May 2002.

Conyers, Lawrence B., and Jeffrey Lucius

1996 Velocity Analysis in Archaeological Ground-Penetrating Radar Studies. *Archaeological Prospection* 3(1): 25–38.

Crissman, James K.

1994 *Death and Dying in Central Appalachia: Changing Attitudes and Practices*. University of Illinois Press, Urbana.

DAVENPORT, G. CLARK
2001 Remote Sensing Applications in Forensic Investigations. *Historical Archaeology* 35(1): 87–100.

DAVIS, J. LES, J. ALAN HEGINBOTTOM, A. PETER ANNAN, S. ROD DANIELS, B. PETER BERDAL, TOM BERGAN, KIRSTY E. DUNCAN, PETER K. LEWIN, JOHN S. OXFORD, NOEL ROBERTS, JOHN J. SKEHEL, AND CHARLES R. SMITH
2000 Ground-Penetrating Radar Surveys to Locate 1918 Spanish Flu Victims in Permafrost. *Journal of Forensic Science* 45(1):68–76.

FARRELL, JAMES J.
1980 *Inventing the American Way of Death, 1830–1920*. Temple University Press, Philadelphia, PA.

GOODMAN, D., Y. NISHIMURA, AND J. D. ROGERS
1995 GPR Time-Slices in Archaeological Prospection. *Archaeological Prospection* 2(2):85–89.

GOODMAN, DEAN
1994 Ground-Penetrating Radar Simulation in Engineering and Archaeology. *Geophysics* 50(2): 224–232.

GOODMAN, JEFFREY
1977 *Psychic Archaeology: Time Machine to the Past*. Berkeley Publishing, New York, NY.

IMAIZUMI, MASATAKA
1974 Locating Buried Bodies. *F.B.I. Law Enforcement Bulletin* 43(8):2–5.

KILLAM, EDWARD W.
1990 *The Detection of Human Remains*. Charles C. Thomas, Springfield, IL.

NOBES, DAVID C.
1999 Geophysical Surveys of Burial Sites: A Case Study of the Oaro Urupa. *Geophysics* 64(2):357–367.

REESE, K. M.
1985 Dowsing for Use in Archaeological Surveys. *Chemical and Engineering News* 63(2):124.

SIMMONS, G., D. W. STRANGWAY, L. BANNISTER, R. BAKER, D. CUBLEY, G. LA TORRACA, AND R. WATTS
1972 The Surface Electrical Properties Experiment. In *Lunar Geophysics: Proceedings of a Conference at the Lunar Science Institute, Houston, Texas, 18–21 October 1971,* Z. Kopal and D. W. Strangway, editors, pp. 258–271. D. Reidel Publishing, Dordrecht, The Netherlands.

SLOAN, CHARLES DAVID
1995 *The Last Great Necessity: Cemeteries in American History*. Johns Hopkins University Press, Baltimore, MD.

STERN, W.
1929 Versuch einer elektrodynamischen Dickenmessung von Gletschereis. *Ger. Beitr. zur Geophysik* 23: 292–333.

VAN LEUSEN, MARTIJN P.
1998 Dowsing and Archaeology. *Archaeological Prospection* 5(3):123–138.

VICKERS, ROGER, LAMBERT DOLPHIN, AND DAVID JOHNSON
1976 Archaeological Investigations at Chaco Canyon Using Subsurface Radar. In *Remote Sensing Experiments in Cultural Resource Studies,* Thomas R. Lyons, editor, pp. 81–101. Reports of the Chaco Center, No. 1. Chaco Center, National Park Service, and University of New Mexico, Albuquerque.

LAWRENCE B. CONYERS
DEPARTMENT OF ANTHROPOLOGY
UNIVERSITY OF DENVER
2000 E. ASBURY ST.
DENVER, CO 80208