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Coupling Ground Penetrating Radar Applications with Continually Changing Decomposing Human Remains

Michelle Lee Miller
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To the Graduate Council:

I am submitting herewith a thesis written by Michelle Lee Miller entitled "Coupling Ground Penetrating Radar Applications with Continually Changing Decomposing Human Remains." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

Murray K. Marks, Major Professor

We have read this thesis and recommend its acceptance:

Gerald F. Schroedl, William M. Bass

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

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Recommend its acceptance:

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William M. Bass

Accepted for the Council:

Dr. Anne Mayhew
Vice Provost and Dean of Graduate Students

(Original signatures are on file in the Graduate Student Services Office.)

Coupling Ground Penetrating Radar Applications with Continually Changing Decomposing Human Targets: An Effort to Enhance Search Strategies Of Buried Human Remains

A Thesis
Presented for the
Master of Arts
Degree

The University of Tennessee, Knoxville

Michelle Lee Miller

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Dedication

This thesis is dedicated to my grandmother, Evelyn Duval, whose strength and courage throughout my life has provided me a highly respectable, positive role model to follow. Through her continued support and influence I have achieved a level of success, academically and personally, which has exceeded all my expectations. Thank you Gram!

Abstract

Locating the clandestine burial of human remains has long perplexed law enforcement officials involved in crime scene investigations, and continues to bewilder all the scientific disciplines that have been incorporated into their search and recovery. Locating concealed human remains can often be compared to the proverbial search for a needle in the haystack. Many notable forensic specialists and law enforcement agencies, in an effort to alleviate some of the bewilderment that commonly accompanies the search for a buried body, suggest that multidisciplinary search efforts are becoming more of a necessity, and less of an option.

Research at the University of Tennessee's Anthropological Research Facility (ARF) in Knoxville supports this theory through a collaborative research effort directed toward the development of more efficient and effective methods in the search for, and detection of, buried human remains. The Department of Anthropology, in conjunction with the University's Department of Biosystems Engineering and Environmental Science, has correlated the use of ground penetrating radar (GPR) with postmortem processes of decomposing human targets. Two and three dimensional imagery programs were utilized to optimize the analysis and interpretation of the data acquired over the past eight months. The processed images were then compared to models of human decompositional stages. The results of this research support and acknowledge that GPR is only capable of enhancing field methods in the search for clandestine burials, and when coupled with target-specific geophysical imagery software, contributes valuable working knowledge in regards to the contents of the burial itself. Hence, such resources can only be seen as beneficial to a search teams' endeavors.

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List of Abbreviations and Symbols

λ	Wavelength
σ	Relative Dielectric Constant
CDP	Common Depth Point
GPR	Ground Penetrating Radar
GSSI	Geophysical Survey Systems, Inc.
nS	Nanosecond
PC	Personal Computer
SIR	Subsurface Interface Radar
TT	Two Way Travel Time

Chapter 1

Introduction and Objectives

The detection and recovery of buried bodies is a concern not just to law enforcement officials, but has long been the focus of anthropological study as well. In fact, searching for a suspected buried body is perhaps one of the most difficult and frustrating tasks facing anthropologists working in a medico-legal context, since the range of places for concealment are as diverse as the environment in which man lives. The ability to detect buried human remains has long stymied law enforcement officials and anthropologists alike, mainly because of the lack of an accurate and efficient means of discovering a potential clandestine burial site. With the high number of buried body investigations conducted each year, it seems only logical that there must be a better method of searching than with a shovel and strong back. Traditionally, unmarked or deliberately concealed burials have been located through a variety of techniques ranging from simple, inexpensive visual inspection to more complex and costly geophysical methods. In a continual effort to further enhance search strategies, the complementary use of several search methods and various disciplinary expertise, is becoming a requirement rather than a choice.

The search for a buried body is a situation which cannot generally be considered an emergency, since the inevitable, death, has already occurred. Simply, it is a search for a buried object whose surface traces may possibly have been completely obliterated over time. Therefore, the additional time taken to properly prepare and deploy an efficient and effective search strategy will, in the long run, be time well spent. Good planning is vital.

The more that is known about the circumstances of the crime and burial, the greater the chances of locating the site.

The search for a body begins when information develops in regards to a missing person, and the possibility that their body may have been concealed by burial. Before the actual search can begin, the search area must be selected. The prediction of where the body may be found is based upon information gathered about the victim, suspect(s), and incidents leading up to the death. Determination of a search site may be the result, or a combination of, a multitude of factors ranging from witness testimony to accidental discovery. Once a site has been evaluated and initial reconnaissance of the area completed, the search strategy is formulated and all available resources are assembled. Finally the actual search and recovery of evidence begins. Search techniques may include non-intrusive foot searches, intrusive ground searches, and/or non-intrusive geophysical techniques, and are chosen after all the advantages and disadvantages are considered in light of the prevailing conditions (Killam 1990).

The success in finding an individual grave depends upon several factors, including: the abundance of surface evidence, the clustering of evidence, the obtrusiveness of the evidence or its probability of detection, the visibility or obstructions to detection, and accessibility. These factors may also influence the choice of search method. Under reasonable conditions, a clandestine burial placed within two years prior to the investigation should manifest surface evidence of its presence (Killam 1990). If recognized, these surface indicators may initiate a direct subsurface search and possible recovery. In the absence of such surface evidence, geophysical search methods may aid in revealing the burial site. Either way, an important fact to be remembered is that any scene involving a buried body should be disturbed as little as possible by search operations, since any evidence contained in the grave is not visible and could be potentially destroyed if extreme caution is not practiced during excavation of the grave.

Buried Human Remains

In 1986, efforts to avoid detection resulted in approximately 10 percent of all homicide victims being concealed by method of burial (Davenport et al. 1988). This percentage has progressively risen since. The number of man-hours devoted to field searches for buried bodies and other physical evidence can in no way be estimated. Searches are time consuming, labor intensive, and can potentially deplete financial resources available to law enforcement agencies, at the local, regional, and even national level.

Techniques for the location of buried human remains have been developed over a long period of time, primarily by archaeologists since they are trained to interpret the facts that surround events for which there is no written record (Bass and Birkby 1978). Since the search for buried human remains in a medico-legal context is not overly common, the search efforts are most often conducted by law enforcement agencies on their own or with the solicited help of volunteer organizations. Most members of the law enforcement community are trained in search techniques, but often their experience does not extend to conducting searches for human remains, particularly those that have been deliberately concealed by burial (France et al. 1997). In the past law enforcement officials have been oblivious to the potential contribution(s) a trained anthropologist may provide to a crime scene. For instance, when a homicide has occurred in a house during the recent past, police will ensure that no clue is overlooked. However, when a homicide occurs months or years before, or when the remains have been concealed, law enforcement tends to believe that little or no information can be obtained from the scene. In fact, rarely is any attempt made to reconstruct the events of the crime or to try and extract remote clues from the scene (Bass and Birkby 1978). Therefore, all too often, all available resources are not utilized, resulting in critical evidence and valuable information being overlooked. The unfortunate reality of this is that the investigator is often unaware of whom to seek for assistance in these types of circumstances. Hence, it is critical to the outcome of cases that involve buried human remains that law enforcement officials are not only aware of, but actually employ, the talents of a forensic anthropologist that has training in archaeological methods. These individuals can most likely be found in the Department of Anthropology at most State or local universities (Bass and Birkby 1978).

There is a general misconception that anything buried beneath the ground surface somehow vanishes into a disordered and amorphous mass of earth and stone. This misconception contradicts the fundamental principles of archaeology, which are based upon the laws of stratigraphy. When a burial takes place, its effect is to cause significant disturbance to the natural strata of the earth in which it is interred. Dr. William M. Bass once said, "One can never dig in the ground and put the dirt back exactly as nature had put it there originally. However, through careful examination, a grave can be located and outlined in most cases" (Bass and Birkby 1978, p. 7). This disturbance is irreversible, and its anomalous nature, in relation to the surrounding undisturbed soil, is the basis for several detection methods that can be utilized.

Locating Buried Human Remains

Generally, unmarked or deliberately concealed burials can be located using a variety of techniques that range from simple, non-intrusive visual inspections to more complex and costly methods which incorporate modern technology. There is a wide range of potential detection techniques using the physical, chemical, or biological effects due to the presence of a body, or due to the disturbance to its environment. More often than not the search for a buried body involves a large area. Hence, the means selected often depends upon the area to be searched, including: type of terrain and soil, climate, time restraints, funding, and available manpower (Owlsey 1995). Various search methods have been suggested and employed over the years. However, no one method or a combination of methods have proven to be optimal under all conditions and circumstances. Regardless, any search should begin with the least intrusive and least potentially damaging methods, where minimal disturbance of the burial and associated artifacts occurs and the maximum data on context is preserved. France et al. (1997) suggest that the most effective search often requires the complementary use of several search methods and many types of disciplinary expertise. Killam (1990) has reviewed the principle techniques used to locate buried human remains thus far, ordering them from the least to the most intrusive, and offering recommendations on their application.

Killam (1990) and Owsley (1995) thoroughly describe the various techniques utilized in the effort to search for the presence of clandestine burials. These methods are intended to cause minimal damage to the search site, since at no time do they involve penetration of the soil. Owsley states, “Visual inspection of the presumed site by trained physical anthropologists, archaeologists, and others is not only the least intrusive technique but the logical first step" (p. 735). Any intrusion into, or disturbance of, a burial site may result in an undesirable loss of evidence and information.

Aerial photography is probably the least intrusive search method available, since the actual search area is never directly contacted (Hunter 1996). The objective of this detection method is to produce photographic imagery which a trained individual can study and recognize the indicators of a sought after target. These indicators may include bare, disturbed soil, or simply a patch of vegetation which presents some spectral anomaly against its surroundings (Hunter 1996). Information gathered from aerial photography can then be of assistance in the comprehensive planning and actual operational efforts.

Changes in vegetation and/or the vigor of plant growth are among the most obvious indicators of a grave. Alterations in the plant community are caused by both the physical action of digging in the ground, and by changes in the soil profile that remain after the grave is complete. Vegetation is usually absent, damaged, or less dense over a recent burial. During the initial excavation of a grave, the soil which is removed will normally be placed adjacent to the hole and on top of any vegetation which may be present, thus damaging the vegetation and intermixing it with the existing topsoil. This entire area is the burial site. As a general rule, it is possible to determine the length, width, and depth of the grave by the size of the damaged area. When the grave is refilled, it will be completely absent of plant growth. With the passage of time, the vegetation will begin to recover and blend in. It may even become lush over the actual grave as a result of the less compact, water retaining soil below that has become rich in the organic materials released from the decomposing body. The sudden presence of plants differing from the naturally occurring vegetation is also indicative of a possible grave (Boyd 1979, Hunter 1996, Killam 1990, Owsley 1995).

The fill of a grave will display a mixing of strata compared to the surrounding earth, and may show differences in color, temperature, pH, and electrical conductivity (Hunter 1996, Owsley 1995). Since the stratigraphy has been disturbed, the mixed fill will never again retain the same consistency as the original soil. However, any color differences that are initially apparent will lessen over time as the surface is exposed to the same weathering conditions (Rodriguez and Bass 1985). These color differences begin to lessen between six months and a year after deposition. There will also be a substantial difference in consistency between the primary undisturbed stratigraphy and the secondary mixed soils. The disturbed soil will be softer as a result of layer mixing and the mechanical actions of digging. The fill will also have an increased organic component, from the commingled plants and ground litter. In fact, the pre-existing soil texture may even determine the depth of the grave (Hunter 1996, Killam 1990).

It is common knowledge that it is not possible to dig a hole and then refill it so that the surface is level. No matter how hard one tries, there is always going to be excess dirt left over due to inflation of the soil with air. If a body is placed in a grave, occupying a significant amount of the space, even more dirt is going to be displaced. Therefore, it is common for a fresh grave to be topped by a mound of dirt. The size of this mound may also be correlated with the depth of the grave, in that the higher the mound, the deeper the grave is likely to be. In most cases, with time, the soil will settle and become compact once again. The amount of settling depends on time, moisture, type of soil, and the depth of the grave. As the fill of the grave becomes more compact, and subsidence occurs, a distinctive depression is produced. This depression, often referred to as a soil compaction site, generally slopes downward and inward toward the center, resulting in the formation of cracks around the periphery and the pulling away of the disturbed soil from the graves' undisturbed margins. In graves less than two feet, if the individual is buried facing upwards, a secondary depression will appear over the abdominal region. This is a result of soil settling into the abdominal cavity as the body decomposes and collapses. As one would expect, the secondary depression is more pronounced in shallow graves, while the primary depression is not as distinct. The mere existence of a secondary depression indicates a shallow burial, while a single depression likely means the body is more than two feet deep (Killam 1990, Owsley 1995).

Other visual indicators involve evidence of insect activity on the surface of the grave, which may be apparent if the burial is recent. Also, different insect species tend to be present at different stages of decay (Rodriguez and Bass 1985, Owsley 1995). Tracks, digging, and tunneling of mammals may also be visible. Any fresh animal digging should be investigated, since Rodriguez and Bass (1985) found that raccoons, opossums and dogs will all dig to unearth shallow burials.

Cadaver dogs are another non-intrusive resource that can often be coupled with a conventional foot search. Dogs are an impressive tool that can be used in a variety of roles if they are properly trained for the specific task they are to undertake (Killam 1990, Owsley 1995). Because of their superior sense of smell, dogs have been used in a variety of forensic contexts. It is estimated that their ability to smell some scents, particularly fatty acids, is as much as a million times more sensitive than that of humans. Scent work and tracking are among the most common uses of canines in search efforts. Tracking dogs are trained to follow a specific scent associated with the object or person they are tracking. They are rarely used in search efforts, since the minimum requirement is a scent article from the individual being sought and a known point of departure. Air-scent dogs, by comparison, are commonly employed by search and rescue teams. Instead of following the scent of a particular individual, they are trained to recognize a generic odor, enabling them to search for generalized airborne scents within the search area (Killam 1990). The gas products produced by a decomposing body, as discussed later, rise through the soil and are carried by prevailing wind currents forming an invisible cone-shaped vapor pattern downwind from the source. These gases are water soluble, so ground moisture and rain only assist the dogs' already natural ability. Even though dogs can be a valuable resource, they have their limitations. First and foremost, dogs are only as reliable as their training allows. Air-scent work especially, requires very strict and specialized training. Also, dogs need regular rest, only being able to work 8 hours at a time. Since they rely so heavily on their noses, they often suffer from "nose fatigue," in which their olfactory sensors are desensitized after continual use (Killam 1990). Other factors that influence the success rate of cadaver dogs include: burial depth, moisture, air temperature, and wind conditions. Given all this, the advantages generally outweigh the disadvantages when it comes to the speed with which a dog can cover a large search area, the ability to replace manpower that could be utilized elsewhere, the fact that they are highly mobile and can search areas that are difficult to search by foot, the fact that their sense of smell is superior enough to enable them to detect bodies concealed from human searches, and that they can re-search an area quickly at a much later date without the problems of mounting another major search effort (Killam 1990).

The following techniques can be classified as being intrusive ground search methods. It should be prefaced that profoundly disruptive search techniques should never be used until less intrusive ones have been exhausted or are impractical considering the totality of search conditions.

Probing is the process of inserting a long pointed metal rod into the ground in a regular search pattern with the intent to detect ground softness associated with a grave site and ultimately determining the outline of the actual grave (Owsley 1995). Never is it to be used to locate the body itself within the grave, since it can cause significant damage. The probing tool is approximately four feet in length with a wooden or metal T-shaped handle on one end. The other end of the rod contains a sharpened groove which collects a soil sample as the rod is inserted into the ground, rotated, then removed. During probing, searchers will attempt to detect differences between disturbed and undisturbed soil. It takes substantial practice to get the "feel" of specific soil conditions (Boyd 1979). The feel of the soil will vary depending upon the depth of the probe and the pressure applied to it. Under all conditions, the probe should sink deeper and easier into disturbed soil. If a soft pattern is discovered, a course probe pattern should be switched to a fine probe pattern, until the outline of the disturbed area is completely defined. The probe should only be inserted deep enough into the ground to confirm a difference in soil texture, since it can potentially damage evidence (Killam 1990).

After a body has been buried and decomposition begins, various gases, such as hydrogen, hydrogen sulfide, hydrogen phosphide, methane, carbon dioxide, and ammonia are released from the body and leach out into the surrounding soils. Gas-sensing probes or combustible vapor detectors can be used to augment a probe search. They can be inserted into the ground to read the presence and levels of decomposition gases, confirming the presence or absence of a body within a suspected grave (Bass and Birkby 1978). This determination can be made without excavation of the site and with no additional damage beyond the pre-existing probe hole.

In situations where all previous methodology has been unsuccessful, which is likely to occur when a grave has been undisturbed for many years, more intrusive search efforts become necessary. Although it is now viewed as a last resort, the use of heavy equipment was once a frequently used method in the search for burials. Since it invariably means the destruction of surface and subsurface evidence, when the decision to use heavy equipment is made, it is likely that all other methods have failed. If this method must be used, it should only be used to search for, but never to actually excavate, a burial. Bass and Birkby (1978) suggest if this resource is employed, that a *non-tooth* bucket be used rather than one with a tooth blade or bucket, which is standard on most backhoes. The reasoning is that a non-tooth bucket enables the operator to make smooth cuts, exposing disturbances in the soil. Tooth blades and buckets do not allow for a smooth excavation. They go on to suggest that a scraper, specifically an elevating scraper, or a pan, is actually a better piece of equipment if properly used, and allows for the maximum amount of information to be obtained. The advantage of the scraper is that it can shave off a few inches of earth at a time, collecting, rather than pushing aside, the overburden and leaving a smooth working surface behind. The disadvantage of this method is the need for at least five to six observers who continually check for indications of previous disturbances to the soil. Using this method, burials can be located by either identifying a clear demarcation between disturbed soil and the surrounding undisturbed soil, or a color change. Changes in soil color may result from topsoil being redeposited at a lower level or wetting patterns. As in a grave, when soil is disturbed and replaced, the compactness of the replaced soil changes. Therefore water seeps deeper into disturbed soil, or into a refilled grave, creating a darker area surrounded by a lighter periphery in which water has not penetrated as deeply (Bass and Birkby 1978). Both William Bass and Walter Birkby have excavated hundreds of burials during their careers as forensic anthropologists, and feel they have perfected this particular technique to locate clandestine burials without disturbing the grave or destroying valuable evidence (1978, p.11). They conclude that if properly used, the heavy equipment is the most economical resource when searching large areas since its use is rapid, it is relatively inexpensive in view of the area searched, and it places the burden of work upon the equipment operator rather than on the investigator. As previously mentioned, the drawbacks are the damage caused to potential evidence, and that if this method fails, there is no going back to less destructive methods.

Geophysical exploration, or remote sensing techniques, are also non-intrusive methods and have proven effective in locating clandestine and unmarked burials. These techniques involve the measurement of signals, either natural or induced. Passive techniques measure natural signals generated by the earth which are inherent physical properties of the ground. Active geophysical techniques measure responses to man-made or induced signals transmitted into the ground (Killam 1990, Owsley 1995). The most commonly used passive geophysical methods are: gravity surveying, magnetic surveying, and electrical self-potential surveying (SP). Active geophysical methods include: electrical resistivity surveying, electromagnetic surveying (EM), metal detectors, seismic refraction, and ground-penetrating radar (GPR). All geophysical techniques are merely aids to grave detection. They are also quite time consuming, but the time and effort spent is negligible compared to test digging. Since geophysical methods do not directly locate bodies, their success is based upon their ability to delineate anomalies, either positive or negative, as potential targets for further study (Davenport et al. 1988, Killam 1990). An anomaly may be the result of disturbed soil from a grave, changes in soil horizons, changes in which a body is progressing as decomposition occurs, or air voids that are created within the head and chest cavities upon cessation of decompositional processes.

Ground-penetrating radar, which involves the transmission of short wavelength, electromagnetic waves into the earth and the recording of the energy reflected back from subsurface materials, has been especially useful in searching for burials (Bevan 1991, Davenport et al. 1992, France et al. 1997). Ground penetrating radar, as all geophysical prospecting, involves the interpretation of data. In fact, 90 percent of the success of GPR is attributed to data interpretation, while the remaining 10 percent is credited to the performance of the technicians in the field. The failure to detect a grave may be due to the instrumentation lacking sufficient sensitivity, or it may be the result of ambiguous data which is not interpreted as an anomaly. Other sources of error are instrument performance and capabilities, operator error, and false positives. False anomalies are geological features, natural or man-made, that mimic a grave site but are not actually the target of interest (Killam 1990). The actual number of searches for buried bodies in which GPR has been applied is small but increasing steadily as we become more aware of its full potential and capabilities.

Decomposition

Under natural conditions, body tissues begin to disintegrate immediately after death. This process, known as decomposition, follows the arrest of the biochemical processes that preserve the integrity of the cellular and sub cellular membranes and organelles. The very earliest phases of decomposition are at the cellular level and are therefore not grossly evident. However, more obvious changes begin to gradually occur. The body cools and rigor mortis makes its appearance. Haemolysis commences and discoloration of the tissues heralds the production of gases. The body bloats, tissues soften, and characteristic odors exude from the body. Destructive processes continue with liquefaction and disintegration until the remains consist of nothing more than the mineralized tissues of bone, and teeth, and cartilage, hair, and nails (Evans 1963, Janaway 1996, Micozzi 1991).

In death, as in life, the decomposing body remains for a time a dynamic system, both internally and in its interactions with the immediate environment. Following death, these interactions are profoundly influenced by the manner of disposition. Numerous physiochemical changes may also occur as a result, ultimately leading to the dissolution of all soft tissues (Gill-King 1997, Torlesse 1973). Accordingly, two parallel processes of decomposition commence: Autolysis, which is self-destruction of cells by enzymatic self-digestion; and putrefaction, decompositional changes produced by the action of bacterial and microorganisms (Micozzi 1991, Torlesse 1973).

Putrefaction is the postmortem destruction of the body's soft tissues by the action of enzymes and endogenous bacteria. Under climatological conditions soft tissue degradation proceeds from within due to the action of enteric micro-organisms, and from without by colonization with soil micro-organisms and decay organisms (Micozzi 1991). As the body's cells reach end-stage autolysis, an almost entirely anaerobic environment is created which favors the rapid growth of the bacterial inhabitants of the large intestine. These organisms reproduce exponentially and operate rapidly upon the host degrading carbohydrates, proteins, and lipids to various acids, gases and other by-products, altering the gross appearance of the body (Janaway 1996). The major changes which can be recognized in the tissues undergoing putrefaction are changes in color, the creation of gases leading to bloating, foul odor, and liquefaction (Perper 1993).

Bacteria are essential to putrefaction and commensal bacteria soon invade the tissues after death (Janaway 1996). The organisms most commonly found are those normally present in the intestinal and respiratory tracts. The marked increase in hydrogen-ion concentration and the rapid loss of oxygen in the tissues after death, favor the growth of anaerobic organisms. Putrefactive changes are primarily dependent upon environmental temperatures and the prior health of the deceased, both of which will be discussed later. Putrefaction is optimal at temperatures ranging between 70-100^{o}F and is retarded when the temperature falls below 50^{o}F or when it exceeds 100^{o}F. Putrefaction does not occur at extreme temperatures (Micozzi 1991).

Stages of Decomposition

The processes that reduce a body to a skeleton through the postmortem destruction of soft tissues are complex. As with all biologic phenomena, there is much variation from one individual to the next, rendering it impossible to assign absolute times to any one stage. While postmortem decomposition is recognized as a continual process, it is useful to divide the characteristic sequences into discrete stages. These stages are in a temporal sequence, but because of variations in environmental conditions and body habitus, it is not possible to assign an absolute "time since death" to any one of these stages (Micozzi 1991). This systematic approach to the degree of decomposition, as depicted in Table 1.1, is useful for descriptive and comparative purposes in regards to this study.

Variables Affecting Rates of Decomposition

Postmortem events can be regarded as interplay between the opposing agencies of preservation and destruction. The intrinsic physical characteristics of the skeleton are the preserving agencies in this context, set against the destructive chemical and physical factors and biological agents within the depositional environment. It is also apparent that the decay of soft and hard tissues, flesh and bone, is profoundly influenced by the period

Table 1.1~ Decomposition Staging Scale (Clark et al. 1997).

Category	Stage	Changes
Putrid	I	Early putrid odor
		Lividity fixed
		Rigor waning
		Tissues tacky
	II	Green discoloration of abdomen
		Hemolysis
		Intense livor
		No rigor
		Early skin slippage
		Drying of nose, lips, and fingers
	III	Tissue gas on X-rays
		Prominent hemolysis
		Tissues soft and slick
		Skin slips easily
Bloating	IV	Early body swelling
		Discoloration of head
		No discoloration of trunk
		Gas in heart
		Marbling
	V	Moderate swelling
		Discoloration of head and trunk
	VI	Maximal body swelling
Destruction	VII	Release of gases
		Exhausted putrefied soft tissues
		Total destruction of blood
	VIII	Partially skeletonized
		Adipocere
		Mummification
Skeleton	IX	Skeleton with ligaments
	X	Skeleton with no sft tissues

between death and burial. As the complex series of relationships between the pre-burial treatment and the post-burial decay become clearer, so does our ability to interpret the overall burial scene (Boddington et al. a & b 1987).

Recent research and experience have documented how variable the rate of decomposition can be. Taphonomic factors include, but are not restricted to, climatological, geological, biological, and cultural aspects. For most of these factors, only general information about the effects is known (Henderson 1987). It is important to realize however, that no single factor determines the rate of destruction or preservation of human remains.

It is known that physiochemical changes following death are greatly influenced by climatological and meteorological factors which include: ambient temperature, humidity, amount of rainfall, and other related phenomena (Sledzik, 1998). In turn, the ambient temperature may be related to altitude, latitude, burial depth, moisture levels, and air movement. All bodies progress through essentially the same stages of decomposition, but temperature is the most important variable influencing the time spent at each stage and the overall velocity of the process. Van't Hoff's rule, or the "rule of ten," is the principle at work here, stating that the velocity of chemical reactions increases two or more times with each 10^{o}C rise in temperature (Bass 1997, Gill-King 1997). Putrefaction however, does not occur at extreme temperatures. Freezing inhibits putrefaction and although warm temperatures enhance it, intense heat produces heat fixation of tissues and inactivates autolytic enzymes with a resultant delay in the onset and course of decomposition (Micozzi 1991).

Mann et al. (1990) examined the effects of environmental, natural, and biological factors on the rate of decomposition in the eastern United States. In this study, ambient temperature proved to have the greatest effect on the decay rate of the human body. Humidity and aridity were also found to be very influential on decomposition rates. Both of these factors are also highly correlated with carrion insect, or maggot activity (Bass 1997 and Henderson 1987).

The physical state of the body at the time of death has been found to have a profound bearing upon its subsequent form and rate of decomposition. Trauma to the body promotes entomology by providing portals of entry for bacteria, and the associated blood provides an excellent medium for bacterial growth. Individuals suffering from infectious diseases or obesity prior to death tend to putrefy more rapidly since they both furnish beneficial conditions for bacterial growth (Mant 1987). In contrast, the presence of certain poisons in the body, such as arsenic, zinc, cocaine and lead, have been shown to retard decompositional processes, destroying putrefactive bacteria and preserving the tissues (Watkins 1983).

Depth of interment is another influential factor that plays an integral part in decay rates. Bodies buried at depths of one to two feet can skeletonize in a few months to a year. However, bodies buried at four feet or more may take several years to completely decompose (Mann et al. 1990). The restriction of air in deeper burials, particularly in clay soils, will retard decomposition, but never totally prevent it. Also, individuals buried at shallow depths may be affected by seasonal fluctuations of temperature, whereas below a certain depth, temperatures remains constantly cool, acting as a refrigerator (Mant 1987). Soil texture and consistency is an additional factor for consideration in regards to buried remains. Decomposition may be accelerated in porous, light soils, while dense, clay-like soils may actively retard it. In addition, well drained dry soil may be conducive to mummification rather than adipocere formation (Mant 1987). Finally, the presence of clothing or any other material covering or surrounding an individual, can serve to protect the body from its environment, retaining body heat and thus accelerating the decay process (Bass 1997, Mann et al. 1990). In rare instances clothing has retarded decomposition to some degree by resulting in protection against the surrounding environment and by absorbing and retaining moisture, therefore aiding in adipocere formation (Mant 1987). These variables and their overall effect on decompositional processes are listed in Table 1.2.

Two types of postmortem changes, mummification and adipocere, may substantially counter the process of tissue destruction by decomposition. Mummification results from drying of tissue under conditions of high environmental temperature, low humidity, and good ventilation (Mant 1987). Once mummification fully develops, the body may remain preserved as a shell for an extensive period of time. The forensic importance of mummification lies primarily in the preservation of tissues, which aids in

Table 1.2~ Variables Affecting Decay Rate of the Human Body (Sledzik 1998).

Variable	Effect on decay
Temperature	5
Access by insects	5
Depth of burial	5
Carnivores/rodents	4
Trauma	4
Humidity/aridity	4
Rainfall	3
Body size and weight	3
Clothing	2
Surface body is placed on	1
Soil pH	unknown

*Adapted from Mann, Bass, and Meadows (1990)
1 = least influential
2 = most influential

personal identification and the recognition of injuries. Saponification, or adipocere formation, commonly known as grave wax, develops under conditions of high humidity, moisture, and high environmental temperatures. The chemical process underlying adipocere consists of hydration and dehydrogenation of body fats with the release of fatty acids which, being acidic, inhibit putrefactive bacteria. This process imparts a grayish-white color and soft, greasy, clay-like, plastic consistency to the soft tissues of the body (Mant 1987, Perper 1993). Adipocere formation tends to be more common in females due to the greater content of body fat (Micozzi 1991).

Decomposition of Buried Human Remains

Even with all of the knowledge that exists in regards to decompositional processes, very little pertains to buried human remains. This lack of information results in gross estimations, most often based on minimal experience or previous casework. However, on the basis of the examinations of one previous study, a roughly defined model of the decompositional processes of buried human remains has been identified. Rodriguez and Bass (1985) set out to bridge this gap in knowledge and provide more reliable criteria for the decomposition of buried human remains.

By burying six human cadavers at various depths, at different times of the year, Rodriguez and Bass (1985) were able to extract a working knowledge regarding human decomposition as it pertains to buried remains. Problems of variability in burial environment present major dangers in making generalizations regarding decay to specific cases. Buried bodies are contained in a much less predictable decay environment in which a whole host of factors will affect the rate and nature of the interaction between the body and the environment. It is known that buried human remains are affected by the environment which surrounds them. Human burials exist in an environment in which a complex interaction occurs between a wide range of variables, and each individual burial exists within its own niche within that environment (Janaway 1996). Once interred, remains are subjected to a number of soil processes or pedoturbation, which may influence the deposition and placement of the remains. However, bodies that ultimately end up in a subsurface clandestine grave decompose in a manner that is similar to a body in the open air, but at a slower rate. Rodriguez and Bass (1985) determined that clandestine burials frequently show signs of very moist decomposition, and more importantly that decompositional rates of buried individuals are directly dependent upon the environmental conditions of the soil and above-ground temperature.

The reduced rate of decomposition of a buried corpse, which proceeds in general at a rate of eight times slower than above ground, can be attributed to two major factors. First is the limitation of carrion insect and carnivore activity. The burial of a body either limits or completely prevents access to the corpse by carrion insects and animals; thus breakdown of the tissues is primarily the result of autolysis and bacterial putrefaction. The degree of access is directly related to burial depth and soil compactness (Rodriguez 1997). Studies and numerous field observations have shown that carrion depredation is primarily restricted to burial depths of a foot or less (Rodriguez and Bass, 1985).

The second influential factor responsible for reduced decompositional rates in buried bodies is the soil environment. Soil provides an effective barrier to solar radiation, and therefore both temperatures and temperature fluctuation decreases with soil depth. As temperature decreases with depth so does the rate of decomposition by cooling the body (Janaway 1996). At depths of less than one foot, one can expect temperatures to be close to those above ground, and to fluctuate daily (Rodriguez and Bass 1985). Thermal stabilization in soil generally occurs at depths greater than two feet, with no significant temperature fluctuation other than by season. Deep burials of four feet or greater, by maintenance of cool temperatures and inhibition of depredation, provide an extremely reduced rate of decomposition. An individual buried at such depths will remain virtually intact, with minimal tissue loss for a period of at least one year (Rodriguez 1997).

Three other aspects of the soil environment affecting decompositional rate are moisture content, the presence of soil organisms, both plant and animal, and soil pH levels (Henderson 1987, Janaway 1996, Rodriguez 1997, Vass et al. 1992). The presence of ground water, or clay type soils which retain moisture, produces an environment conducive for adipocere formation. Wet soil environments are associated with deep burials. At shallow depths, a buried body is subjected to temperatures which approximate those above ground and undergoes increased degradation by plants and soil organisms. Plant roots grow towards a decaying corpse, seeking the rich organic nutrients produced by decomposition, and can be very destructive in nature. Many skeletal remains recovered from shallow burials exhibit obvious root damage (Henderson 1987, Rodriguez 1997). Even though a buried body will decompose more slowly than one found on the surface, acidic soils, soils high in moisture content, and plant growth will actually accelerate decomposition (Rodriguez 1997, Rodriguez and Bass 1985).

Studies at the University of Tennessee-Knoxville have shown that bodies buried at one to two feet may skeletonize within a year, while bodies buried at three to four feet may take as long as seven years to reach complete skeletonization (Mann et al. 1990, Micozzi 1991, Rodriguez and Bass 1985). It was found that the greater the depth of the burial, the greater the preservation of the body will be. In addition, buried bodies generally show slow decomposition due to soil environment, and limited access by carrion insects and carnivores (Rodriguez and Bass, 1985).

Just as the environment influences the decomposition of a buried body, the decomposing body in turn affects its surrounding environment. The burial of a human corpse affects the soil, soil fauna, and vegetation in many ways. The mere act of digging a hole then replacing the soil produces visible surface effects and causes mixing of natural occurring strata. This mixing breaks the uniform soil into an aggregation of varying sized lumps. This disturbed soil then shows a change in drainage and moisture retention properties compared to the nearby undisturbed soils. The presence of a buried body, which is impermeable to water, affects the vertical drainage pattern in the soil, producing a moisture anomaly above the body. This moisture deficiency in turn reduces the thermal capacity of the area. Therefore, the soil above the buried body cools and heats faster than undisturbed soil (Torlesse 1973).

The decomposing body itself provides a source of liquids, gases, and bacteria that contribute in the alteration of the surrounding environment. Vass et al. (1992) reported a distinct pattern of change in the composition of volatile fatty acids in soil during soft tissue decomposition, directly correlating decompositional stages and the production of volatile fatty acids. This study also found that there are acidic shifts in the pH of the soil below and around the cadaver as it progresses through decomposition. It was recorded that pH variations around a corpse increased from 7 initially, to 8.2 in an active decay stage, then decreased to 7.3 when the corpse was nearly skeletonized (Vass et al. 1992).

It is evident from the above discussion that a wide range of potential detection techniques exists through the use of physical, chemical, and/or biological effects of a decomposing human cadaver, or due to the disturbance to its environment.

Applications of Ground Penetrating Radar

Since the first ground penetrating radar (GPR) survey in 1929, its applications have expanded at an incredible pace (Miller 1996). GPR system manufacturers estimate there are thousands of systems around the world being applied to a variety of problems from forensics and archaeology, to geology, glaciology, environmental, engineering, mining, and many others (Miller 1996).

The first ground penetrating radar survey, reported in 1929, was to determine the depth of a glacier (Miller 1996). The technology was then lost until the 1950's when planes crashing into the Greenland ice cap reawakened interest in the subject. Most of today's GPR systems are short impulse time domain systems used in simple imaging mode to map subsurface events such as the occurrence of the water table (Miller 1996). While there are many possible applications of GPR, I will discuss some of the generic applications, and those with anthropological and forensic relevance.

Ground penetrating radar has been used to find a wide variety of objects buried by human beings. In the 1970's there was a shift to human-induced environmental problems. GPR was then recognized as an effective method in detecting utility lines, landfill debris, deposits of contaminated fluids, highway voids, and unexploded ordnance (Miller 1996). In 1978, the Soil Conservation Service, using GPR, began extensive soil mapping of the United States. GPR has proven to be an effective method in estimating depths of soil horizons, charting water tables, and studying changes in soil properties that affect both crop and forest productivity (Doolittle and Collins 1995).

Applications of GPR have grown more diverse with the continual design and development of enhanced technology. GPR has been successfully used in archaeological surveys. The excavation of an archaeological site is usually a long and labor-intensive process. Often the only way to know whether artifacts are present is to do a great deal of exploratory digging, which adds greatly to the time and expense. Ground penetrating radar has proven to be an invaluable resource that offers a solution to this archaeological quandary. In only a short period of time, an entire site can be profiled and the data interpreted. The results can be read immediately in the field to pinpoint anomalous zones for excavating, or to directly locate buried structures and artifacts. The result of using GPR is a great savings in time and finances (Vaughn 1986). Some of the successful archaeological applications of GPR have been imaging the location of adobe walls, floors, pits, and artifacts at prehistoric sites in the American Southwest (Sternberg and McGill 1995), the detection of eroded burial mounds in Japan (Imai et al. 1987), and the successful location of human burials at multiple American archaeological sites (Bevan 1991, Mellett 1996).

Ground penetrating radar has been moderately successful in locating unmarked burials, in both the archaeological and forensic context. Vaughn (1986) began searching for, and was occasionally successful in locating, graves at a 16th century Basque whaling station in Canada. Davis et al. (2000) demonstrate how GPR can be used as an effective tool in the planning stages of excavation. By interpreting GPR images, Davis and his colleagues were able to save time and finances through optimal mapping of grave depth and location during the excavation of 1918 Spanish flu victims found embedded in permafrost in Norway. Bevan (1991) found graves at nine locations in the United States with varying quality of results. Mellett (1992) was able to demonstrate the capabilities of GPR in finding graves at four different types of sites in the eastern United States: historical cemeteries up to 200 years old; plots for the indigent poor; a clandestine burial that occurred in 1982; and a Native American burial site from circa AD 800. Mellett (1992) discussed the first forensic case in which GPR was utilized. GPR was recently used in a missing person case in which the discovery of the body led to a murder indictment (Nobes 2000). GPR is also one of the techniques being applied in Southeast Asia to search for Vietnam War era isolated burials, buried ordnance, and incident-related artifacts from aircraft crashes (Miller 1996). Finally, France and her colleagues in Colorado continue to conduct research with a variety of methods, but have stated that GPR surveys offer the investigator the most useful tool to delineate possible graves (France et al. 1997).

Technology Overview

Geophysics has been defined as a science based on the application of physical principles to the study of the earth (Davenport et al., 1992). Applied geophysics, or exploration geophysics, is concerned with anomalies in the earth and is traditionally linked with the practical business of locating economic resources such as minerals or energy. In recent years, applied geophysics has been routinely used in civil engineering projects to detect subsurface features before the construction of large buildings, dams, tunnels, and nuclear power facilities (Doolittle and Collins 1995). It is exploration geophysics, or geophysical prospecting, which lends itself to forensic applications.

All geophysical techniques are based on contrasting properties, either physical, biological, or chemical, in the earth's materials. The fundamental limitation of these techniques is that there may be an insufficient contrast between the target of interest, a buried body, and the surrounding formation. Though each geophysical method has special capabilities and limitations, the universal rule is that no contrast means no detection. The contrast between the target and its medium may be one of acoustical velocity, electrical conductivity, material density, magnetic susceptibility, water content, or chemical composition (Davenport et al. 1988, Killam 1990).

As previously mentioned, all geophysical methods involve the measurement of signals, induced or natural. All other detected, unwanted signals are "noise." Noise is always detrimental to geophysical surveying, as it can mask the sought-after signal (Killam 1990). Noise can be natural or cultural, and to some degree can be minimized during data manipulation, which can in turn result in the loss of real data signals as well.

Ground Penetrating Radar

Humans make efficient use only of the first few meters of the Earth's surface. In fact, anthropologists and engineers seem to be of the few that penetrate these depths, whether it is for construction proposes or to excavate an area in search for answers to the past. It seems obvious that these two disciplines would collaborate their knowledge and skills when applicable.

Ground-penetrating radar, also known as subsurface interface radar (SIR), is perhaps the newest of the geophysical prospecting techniques utilized in the discovery of clandestine burials (Killam 1990, Miller 1996). GPR has rapidly become a highly sufficient geophysical research method; its applications are extending to an increasing number of scientific disciplines. GPR is an electromagnetic sounding method, which uses radio frequencies to provide a continuous profile of the earths' subsurface. It is relatively rapid to implement, which in turn reduces fieldwork costs, and can be used to measure the subsurface from a few centimeters to several meters (Killam 1990).

GPR Basics

The basic principle in ground penetrating radar is simple. Ground penetrating radar is a broadband, impulse radar system that is specifically designed to penetrate earthen materials (Doolitttle 1987). Subsurface images are formed when short electromagnetic pulses, which are influenced by the dielectric contrasts (interface) of different subsurface media and features, are emitted from the radar antenna. The pulses from the transmitting antenna travel at speeds proportional to the characteristics of the material through which is passes, similar to sonar. When the pulse reaches an electrical interface, the pulse speed changes and some of the energy is reflected back to the receiving antenna, while the rest proceeds forward. The amount of energy that reflects back to the antenna is directly proportional to the electromagnetic change in the boundary, and the travel time of the reflected pulse is proportional to the depth of the interface (Doolittle 1987). The sharper the contrast between the dielectric properties of the media, the stronger the reflection. The portion of the wave that progresses will be diffused over a larger area, which will reduce its energy per unit surface area (The Finnish Geotechnical Society 1992). A receiving unit inside the radar antenna detects the reflected signals and the time difference between transmission and detection is recorded in nanoseconds (nS). A continuous scan of the electrical interfaces within the medium is then displayed on an output screen as the antenna is simultaneously pulled across the surface. It should also be noted that the electromagnetic wave will be reflected and/or penetrate through each interface as it travels upwards again.

The ability of the earth to propagate radio waves depends upon several factors, including soil conductivity, soil density and porosity, water content, temperature, the frequency of the electromagnetic wave, and the amount of salt in the ground solution (The Finnish Geotechnical Society 1992). The speed of wave travel is a terrain property expressed as the material's relative dielectric constant (σ). The attenuation of the electromagnetic wave in a medium is directly dependent upon the σ of the material. The σ is a measure of how well that material stores an electrical charge. Radio waves travel fastest in air which has a σ of one, and slowest in sea water which has a σ of 81. As listed in Table 1.3, other materials have dielectric constants that range somewhere in between these two extremes. Since the dielectric constant of sea water is 81, the primary factor affecting the average σ of a soil profile is moisture content (The Finnish Geotechnical Society 1992).

There are two separate methods of determining the average σ of soil: common depth point (CDP) and two way travel time (TT). The CDP method requires the use of

Table 1.3~ Approximate dielectric constant (σ) of various applicable materials.

Material	Approximate Dielectric Constant
Air	1
Average soil	12
Bone	13
Cartilage	48
Clay	10
Concrete	7
Granite	8
Metal	2
Muscle	56
Rock	7
Sand, dry	5
Sand, saturated	30
Silt, saturated	10
Skin	38
Water	81

two antennas being operated on a relatively flat surface. One antenna is used as the transmitter and the second is used as the receiver. The two antennas are then pulled away from a common point in equal distance increments. This method allows the velocity of the wave moving through the soil to be calculated by triangulation. When using this method, the antenna separation is set to zero (Ulrikson 1982).

The TT method of calculating average σ requires that the depth of an object or reflector within the soil be known. As the antenna passes over the known reflector, the TT is recorded by the receiver in nanoseconds (nS). Using the known depth to the reflector and the TT value, an average σ for the soil can be calculated using equation 1.1.

$$\sigma = \frac{(nS/m)^2}{43.56}$$

where: σ = overall relative dielectric constant of medium
nS = two way travel time of radar wave in nanoseconds
m = distance in meters

Overall accuracy and maximum probing depth of GPR are determined by the relative σ of the geologic material over which the unit is being operated, the transparency of the soil, and by the frequency of the antenna being used. Mediums with high conductive properties, such as wet clay, are least transparent and may provide a poor image when surveyed, whereas mediums with lower conductive properties, such as coarse-grained sands, are extremely transparent and provide much sharper images (Doolittle 1987).

Maximum probing depth of the antenna is a function of the frequency or wavelength (λ) generated by the antenna. Antennas that transmit high frequencies (500 to

100 MHz) are capable of resolving very distinct electrical charges within a medium; however, these high frequency models are not able to probe very deep within the medium. Antennas that transmit at lower frequencies (100 to 300 MHz) lack the resolution of the higher frequency models, but possess the ability to penetrate deeper depths. The typical usable depth penetration of a radar system operating at 200 MHz is one to four meters. It has been estimated that in wet sand, radar is capable of penetrating 75 feet, but only 5 feet in wet clay, and less than one foot in seawater. This limited penetration ability is generally not a handicap to most forensic applications.

Overall, the resolution ability of GPR makes it a powerful resource in a forensic setting. Not only can it identify the depth of an object to within a few inches, it can locate its horizontal location with the same degree of accuracy. Radar can also locate air voids beneath the surface and disturbed soils, such as areas that have been excavated and refilled. Other factors that govern the ability of radar to detect targets are the shape of the target itself and its orientation with respect to the antenna. The radar signal can be adjusted to help resolve an underground anomaly. Changes can also be made in the pulse time, frequency, antenna orientation, and polarization of the radar signal.

A principle advantage of GPR techniques in searching for buried human remains, as with several other geophysical methods, is that it is non-destructive to the subsurface crime scene. GPR can be used as the primary resource of search, or as a way of refining and corroborating the results of other non-destructive methods. Basically, any man-made alteration in the ground will change the physical parameters of the soil, rendering it detectable by radar.

Radar Profile

GPR data is presented as a radargram. This radar image is composed of three primary parts. The first reflection of a radar image is a result of the radar wave traveling through the air to the receiver. The second reflection in the radar profile is caused by the surface of the medium. Finally, the third and subsequent reflections in the radar profile are a result of electrical boundaries within the medium.

The TT and intensity of a signal are analyzed by the instrumentation. Multiple scans are taken consecutively to create a continuous image of the σ profile. This allows digitized information to be viewed on a monitor and written to disk. Once the radar images are analyzed by the instrumentation, they can be viewed in two different formats: wiggle or line scan. A radar image in wiggle format consists of lines or curves that are representative of each energy pulse; the higher the amplitude of the reflection, the larger the curve. Line scan format assigns a color to each electrical change in the medium. The color scale of a GPR image ranges from positive to negative (Figure 1.1). The more a color representing a reflection intensity deviates from zero, the stronger the reflection or change in σ. Colors or reflections that are situated close to zero represent weak reflections or small changes. These scans are displayed close together to form a continuous representation of the electrical boundaries in the medium.

Instrumentation Settings

A GPR unit is configured on: antenna model number, horizontal filters, vertical filters, range gain, trace position, range, and display parameters. Descriptions of these settings and other radar parameters are presented in SIR System-10A Training Notes (GSSI 1992) and SIR System-20A User's Manual (GSSI 1993). Several preset

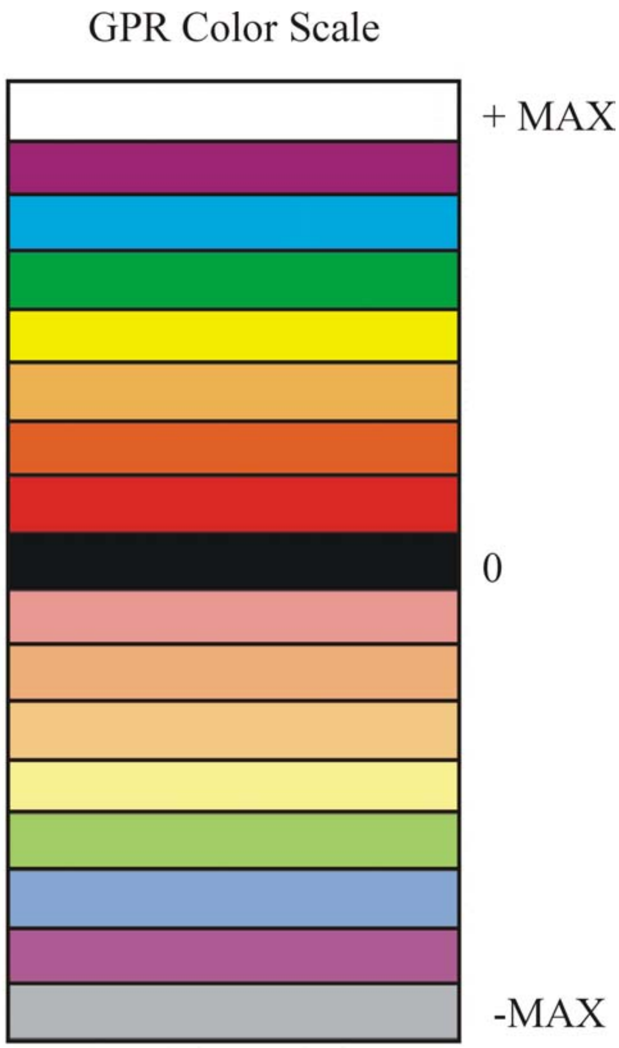


Figure 1.1~ Color scale used to compare reflection intensity of GPR images.

parameters are loaded by entering the antenna model number. Range selection is based on the length of time returning waves are sampled; if a range of 100ns is selected, the returning radar wave is sampled for 100ns after the pulse is emitted. This allows the GPR operator to view depths of interest. Range gain configures the amount of amplification applied to certain depths within the medium. These range gain settings are manually controlled by the operator and allow relative features to be targeted in the subsurface. Filter settings remove unwanted noise from radar images. High pass filters pass high frequencies within a certain range while removing low frequency noise, and low pass filters pass low frequencies within a certain range while removing high frequency noise. These settings are site-specific and can be adjusted with varying field conditions.

Radar Wave Penetration and Resolution

Penetration depth of the radar wave is limited by: electrical conductivity of the medium, number and strength of the electrical interfaces, and the angle at which the radar waves travel from the antenna to the earth. Of the limiting variables, conductivity of the medium is the primary factor that affects the penetration of the radar image (GSSI 1992, GSSI 1993). A medium with high conductivity (e.g., wet clay) diminishes radar waves more readily than a medium with low conductivity (e.g., dry sand). A medium with several sharp electrical interfaces reflects more of a radar wave's energy than a medium with fewer interfaces.

Radar waves enter the medium in a cone-shaped formation. As the penetration depth of the radar wave increases, the cone becomes larger. GPR data is collected from a smaller cone, called the First Fresnal Zone (FFZ), which is within the previously mentioned cone. As the cone becomes too large, the radar signal becomes noncontinuous, and a portion of the signal cannot reflect from the FFZ to the antenna. If the radar wave enters the profile at an angle, the cone will attenuate at shallower depths than a radar wave entering the profile vertically (Finnish Geotechnical Society 1992).

Resolution and penetration depths of the radar image are affected by the wavelength (λ) of the radar signal, which is a function of the antenna. The effects of these two variables can be reduced with proper antenna selection. Antenna selection is based upon the desired surveying depths. Antennas that transmit high frequencies resolve more distinct electrical properties of the medium, even though penetration depths are limited. Antennas that transmit lower frequencies, increase penetration depth, but have reduced resolution (GSSI 1992, GSSI 1993).

Objectives and Justification for Research

For years the search for clandestine burials has stymied both anthropologists and law enforcement personnel, primarily because of the lack of an accurate means of detection. Ground penetrating radar, which has been used for years by geologists and engineers to map the subsurface of the earth, is a resource that could enhance search efforts of clandestine burials. GPR has already proven to be successful in the delineation of graves in both mortuary and archaeological contexts. However, the aim of this research is to combine GPR imaging with anthropological models of the decomposition of buried human remains. With this collaboration in mind, the progressive changes that result from human decomposition can be viewed and recorded using GPR imagery. This study intends to reveal that GPR is the best known available geophysical resource to detect the metamorphosis that is taking place within established grave plots during the postmortem interval (PMI). The findings of this research are twofold: first to demonstrate the need and potential success of a collaborative disciplinary approach when searching for buried human remains; and second, to aid anthropologists, forensic scientists, and law enforcement personnel in future efforts to search for and locate buried human remains.

Chapter 2

Materials and Methodology

The research for this project was carried out at the University of Tennessee (UT) Anthropological Research Facility (ARF) in Knoxville, TN. The facility was established in 1971 by William M. Bass, a professor of anthropology, in order to observe the decay processes of human cadavers, and further develop knowledge of human decomposition. Studies performed at ARF have supplied much of the existing scientific knowledge base as it pertains to human decomposition, and continues to assist academic, medical, and law enforcement personnel in their applicable endeavors.

ARF is approximately a one acre section of land, managed by the Department of Anthropology at The University of Tennessee, and is located to the east of The University of Tennessee Medical Center. The tightly secured facility is enclosed by a wooden privacy fence and a chain-link fence topped with razor wire. The site has a heavy forested canopy with dense undergrowth and tree roots extending throughout the subsurface. Various artifacts are co-mingled within the soil, left both from previous anthropological experiments and from when the land was used as a dump ground for the University hospital. Foliage in the southwest corner of the facility was manicured and/or cut down and removed in order to create sufficient space for the research plots to be installed and properly utilized. Clearing of this area was carried out in the fall and winter of 2000-2001, while growth was stunted and the foliage was dormant. The vegetation in this region of the facility was continually manicured for the duration of the project.

Research Plot Design and Layout

To accurately and fairly assess the suitability of GPR technology to the search and discovery of buried human remains, a real life situation needed to be manufactured under controlled circumstances. Specifically for this research, six grave plots, each containing decomposing human remains, were established at the ARF where repetitive and controlled testing could be orchestrated (Figure 2.1). The graves are each 6ft x 8ft in dimension, covered by a 4in thick concrete pad, and all but one contain the remains of one donated individual. The remaining plot contains two individuals. The bodies encased in these plots were buried at various stages of decomposition, ranging from two days after death to complete skeletonization. Each plot includes two variables, one being different depths, the second being various anomalous features that are frequently found in relation to clandestine burials (i.e., metal, plastic, stones, and wood).

Figure 2.1~ Orientation of primary research plots.

Test Plot l~

***Variables*:** This grave plot is two feet deep. A commercial-grade plastic tarp is wrapped around the lower half of the individual. A 6ft x 8ft, 4in thick, concrete pad covers the entire graphically represented plot (Figure 2.2).

***The Grave*:** The grave was hand dug with a rounded spade to be a consistent two feet deep along the grave floor. In order for the grave to be 2ft deep at all four corners and along the floor, the horizontal leveling of the grave below the ground surface has a slight western downward slope. The grave walls flare outward. The base dimensions are: 2ft 8in at the head, 2ft 6in at the feet, and 6ft 6in on both sides. Dimensions of the grave opening at ground level are 3ft 4in at the head and feet, and 8ft in length.

The Body*:* The individual was buried May 14, 2001. The body is that of a male (11-01), in advanced decomposition, with dried skin still present and covering the entire body, except for the skull, face, and neck, which are completely skeletonized. The individual was placed in the test pit orientated east to west with the head at the eastern aspect. The body is positioned face up with the head turned 90 degrees, facing north.

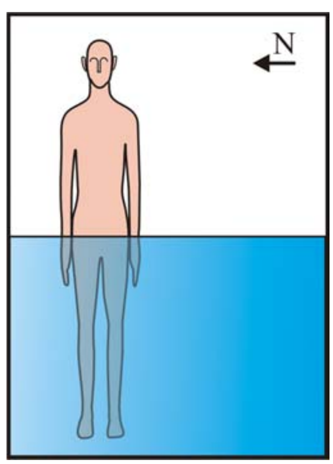


Figure 2.2~ Positioning of body in plot 1 and placement of plastic tarp.

The right arm is fully extended along the right side of the body. The upper half of the left arm is positioned alongside the body; however it is bent 90 degrees at the elbow and lying across the mid-section of the body. The left wrist is also bent 90 degrees with the fingers pointing towards the feet (west) and the palmar surface pointing south. The legs are spread slightly, with the left leg fully extended and the foot slightly rotated laterally with the toes pointing south. The heel of the left foot is flush with the floor of the grave, and the dorsal surface faces upward. The right leg is rotated medially, slightly flexed at the hip and knee. The right foot is medially rotated with the medial aspect flat on the floor of the grave, toes pointing southward. Figure 2.3 displays the orientation of the body in the grave, as well as the condition of the remains.

***Miscellaneous*:** Two metal identification tags are buried with the body and are attached to the individual using plastic zip ties. One is wrapped around the right leg just above the ankle, with the tag positioned on the medial aspect of the leg. The other is located on the left wrist.

Figure 2.3~ Exact orientation and condition of body in grave plot 1.

Test Plot 2~

Variables: This grave plot is 4ft deep and has a 2in layer of pea gravel over the lower half of the plot (Figure 2.4). A 6ft x 8ft, 4in thick, concrete pad covers the entire graphically represented plot.

***The Grave**:* The grave was primarily dug using a backhoe. When the grave was approximately 4ft deep, use of the backhoe was discontinued. The superior and posterior walls of the grave and the base were manicured using a rounded spade. The lateral walls were left smooth from the backhoe, and the corners were squared with a flat-nosed shovel, creating a more standardized shape. Several large and small tree roots were present and were removed with a chainsaw and/or pair of pruning sheers. The floor of the grave was carefully leveled at a depth of 4ft, but a drastic downward slope on the surface caused the western half of the grave to be only 3ft 6in deep. The walls slope laterally towards ground level. The grave base dimensions are 1ft 7in at the head, 2ft 2in at the feet, and 7ft 6in on both sides. The dimensions at ground level are 3ft at the head and feet, and 8ft in length.

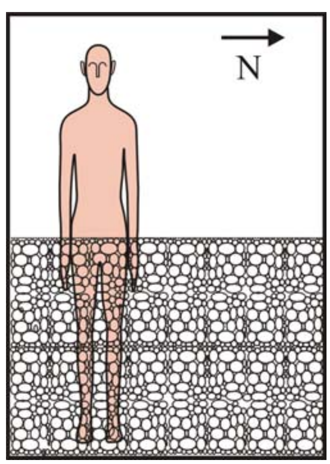


Figure 2.4~ Positioning of body in plot 2 and placement of pea gravel.

***The Body**:* The individual was buried May 15, 2001. The body is a male (00-11), in advanced decomposition, with dried skin still present and covering the trunk (not including the hips), arms, and feet. Cotton pants, saturated in putrefactive elements, are covering both legs and the pelvic region. Cotton brief-style underwear are also present. The tissue of the feet are dried and atrophied; however, the skin is still present. The innominates and the rest of the pelvic region are completely skeletonized. The chest is covered in dried skin; however, the bones of the shoulder girdle are completely visible. The skull is completely skeletonized. The body is placed in the test pit orientated east to west with the head at the eastern aspect of the grave. The body is arranged in anatomical position with the arms at its sides, palms facing up. Since the cranio-cervical muscles are completely absent leaving the entire region skeletonized, the skull is detached from the body. However, it has been placed appropriately and is laying on its right side facing north. Both legs are fully extended with the right foot plantar flexed and slightly rotated laterally. The right heel is in contact with the ground and the toes are pointing up and slightly to the north. The left foot is medially rotated and the medial aspect is in full contact with the floor of the grave, toes pointing north. Figure 2.5 displays the orientation of the body in the grave as well as the condition of the remains.

Miscellaneous: A metal identification tag is attached to the body with a plastic zip tie that is wrapped around the right leg just above the ankle. The ID tag is positioned on the lateral aspect of the leg beneath the pant leg. A second ID tag is located on the right wrist and is situated anterio-laterally.

Figure 2.5~ Exact orientation and condition of body in grave plot 2.

Test Plot 3~

Variables: The grave plot is 6ft deep and has a uniform grid layer of rebar over the lower half of the plot (Figure 2.6). A 6ft x 8ft, 4in thick, concrete pad covers the entire graphically represented plot.

The Grave*:* The grave was dug primarily with the use of a backhoe. Use of the heavy equipment was suspended when the base of the grave reached approximately 6ft. The lateral walls of the grave were left smooth. Both rounded and flat-nosed shovels were used to square out and level the floor and manicure the corners. Several tree roots embedded within and projecting from the grave walls were removed with a chainsaw and pruning sheers.

Due to heavy rainfall, the lateral walls of the grave collapsed after the body was placed within, but before measurements of the body's orientation within the grave could

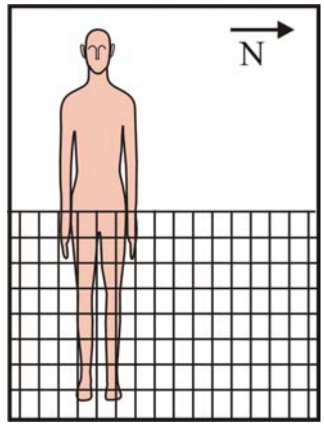


Figure 2.6~ Positioning of body in plot 3 and arrangement of rebar.

be taken. Therefore, the grave was again excavated. This time, shovels had to be used in order to spare any damage to the body. The excess rain and clay soil created a mud consistency that prohibited manicuring the floor and walls as in the other five plots. Therefore, the grave floor maintained a very uneven contour, being the deepest (6ft) at the center beneath the body. The anterior and posterior ends of the grave were more shallow at 5ft 6in. The grave walls were extremely rough due to the collapse, sloping laterally towards ground level. The base dimensions being: 2ft 1in at the head, 2ft 8in at the feet, and 6ft 6in in length on both sides. The dimensions at ground level are: 4ft at the head, 3ft 3in at the feet, and 8ft in length.

The Body: The individual was buried May 18, 2001. The body is a male (25-00), in advanced decomposition. The majority of muscle mass has deteriorated. However, dried skin is present, covering the entire body, with the exception of the skull. The face is completely skeletonized with the mandible detached and positioned against the throat of the individual. Mandibular dentures are present and are situated on the grave floor to the right of the skull. The body is placed within the plot orientated east to west with the head at the eastern aspect of the grave. The body is lying on its back with the arms crossing over the pelvic region, hands stacked over the pubic region. The skull is in anatomical position, facing up. Both legs are fully extended, with the right slightly rotated laterally. The right heel is flush with the ground, toes pointing anterio-laterally. The left leg is also laterally rotated, with the lateral aspect of the foot flush with the grave floor, toes pointing south. Figure 2.7 displays the orientation of the body in the grave as well as the conditions of the remains.

Miscellaneous: One metal identification tag is attached to the body with a plastic zip tie, wrapped around the left leg just above the ankle. The ID tag is positioned on the lateral aspect of the leg.

Figure 2.7~ Exact orientation and condition of body in grave plot 3.

Test Plot 4~

Variables: The grave plot is 1ft deep and the concrete pad of cement covering the entire plot ranges in thickness from 1in at the southern aspect to 8in at the northern aspect (Figure 2.8).

The Grave: The grave was dug using a standard rounded spade, while a flat-nosed shovel was used to square the corners and level the floor. The floor of the grave plot is fairly level, sloping downward toward the northern aspect, but consistently 1ft in depth throughout. The grave walls were given a uniform smooth texture, using a flat-nosed shovel. The walls are fairly vertical, exhibiting little to no lateral sloping. The base, as well as the ground surface dimensions are: 2ft 8in at the head, 2ft 6in at the feet, and 7ft 10in long on both sides.

***The Body**:* The individual was buried May 11, 2001. The body is a female (14-01), in the advanced stages of decomposition. Although decomposition is advanced, a large majority of muscle mass and skin is present, with a few exceptions. The right side of the face, the upper right arm and both quad regions of the legs are skeletonized. The abdominal region has passed bloat stage and therefore has liquefied and collapsed. The

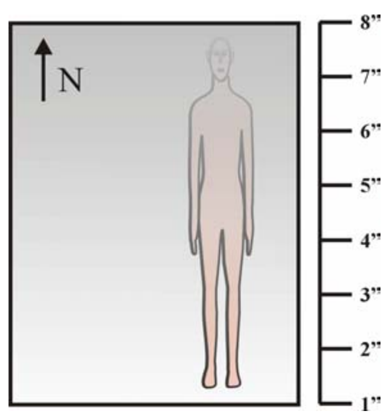


Figure 2.8~ Positioning of body in plot 4 and depth scale of cement pad.

body is placed within the grave plot orientated north to south, with the head at the northern aspect of the grave. The body is positioned on its back, with the head turned 45 degrees to the east. The left arm is raised above the head, bent 90 degrees at the elbow so that the forearm runs parallel to the northern aspect of the grave above the head. The right arm is along the side of the body, fully extended, palm down. The right leg is fully extended with the foot in plantar flexion. The left leg is bent 45 degrees, with the lateral aspect against the floor of the grave. The left ankle, in correct anatomical position, is thus situated so that the plantar surface faces the right calf. Figure 2.9 shows the orientation of the body in the grave, as well as the condition of the remains.

Figure 2.9~ Exact orientation and condition of body in grave plot 4.

Miscellaneous: Two metal identification tags are buried with the body and are attached with plastic zip ties. One is wrapped around the right leg just above the ankle, with the tag positioned on the lateral aspect of the leg. The second is situated around the right mid-forearm.

Test Plot 5~

Variables: The grave plot is 1ft 6in deep, containing human remains and construction debris (e.g., metal, plastic, and wood), arranged to roughly represent the dimensions of a human cadaver. The northern half of the grave was leveled with dirt, before the entire plot was covered by concrete (Figure 2.10). The northern half of the plot is topped with a 4in thick, concrete pad, while the southern half is entombed completely in concrete, with no soil buffer.

The Grave: The majority of the grave was dug using a standard round shovel, while the floor and walls were manicured using a flat-nosed shovel. The floor of the grave is consistently 1ft deep, however, several large rocks are present and emerging through the leveled floor. The walls are fairly vertical, exhibiting little or no lateral

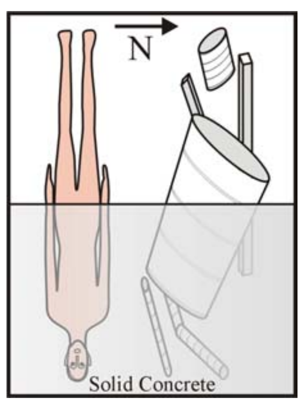


Figure 2.10~ Positioning of the body and mock-up in plot 5, exhibiting solid concrete on the lower half. Debris positioning and dimensions are not to scale.

sloping. The base, as well as the ground surface dimensions, are: 5ft 4in at the head, 5ft 7in at the feet, and 7ft 3in on both sides.

***The Body*:** The individual and mock-up counterpart were buried June 7, 200l. The body is a male (24-0l), buried two days after death, hence, exhibiting no sign of decomposition. All skin and muscle mass are intact. The body is placed within the grave plot orientated east to west, with the head at the eastern aspect of the grave. The body is in anatomical position, lying on its stomach. The face of the individual is flush with the base of the grave, and both arms are positioned alongside the body with both hands slightly clasped. The right leg is fully extended with the foot in plantar flexion, resulting in the dorsal aspect being flush with the base of the grave. The left leg is slightly bent and laterally rotated. The left foot is also in plantar flexion, with the medial aspect flush with the grave floor, toes pointing to the southeast.

The mock-up is positioned to the north of the individual, lying in the opposite direction of the cadaver, and is arranged in anatomical position. This mock-up consists of a metal paint can representing the head, a five gallon plastic bucket in place of the entire trunk region, sections of 2in x 4in wood studs for arms, and metal cylindrical casings for legs. Leather gloves have been strategically placed to represent hands, while sections of 2in x 4in wood studs are placed to represent the feet. Figure 2.11 depicts the arrangement of both the individual and the mock-up.

Miscellaneous: Two metal identification tags, attached with plastic zip ties, are buried with the body. One is wrapped around the left leg just above the ankle. The second is wrapped around the middle section of the left upper arm, and is positioned on the lateral aspect.

Figure 2.11~ Exact orientation and condition of body and mock-up in grave plot 5.

Test Plot 6~

Variables: The grave is 1ft 2in deep and contains two individuals: one is fully fleshed, and the other nearly completely skeletonized. After the grave was filled with dirt, only the southern half of the plot was covered by a 6ft x 4ft, 4in thick concrete pad. The northern half of the plot remains with only its soil covering (Figure 2.12).

The Grave: The grave was hand dug using a standard rounded spade. The grave floor, having a northern slope, is 1ft 2in deep at the northern perimeter and 1ft 3in deep at the eastern perimeter. The grave walls are uneven, with the eastern wall exhibiting a large surface depression, and the northwest corner requiring reconstruction due to collapse. The walls are fairly vertical, with no lateral sloping. The base, as well as the ground surface dimensions are: 5ft 6in at the northern perimeter, 6ft 5ft at the southern perimeter, and 8ft 1in long on the eastern and western perimeters.

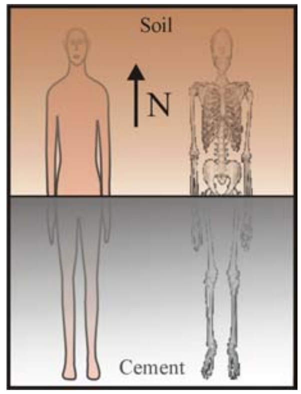


Figure 2.12~ Positioning of bodies in plot 6, with ordering of concrete and soil coverings.

The Bodies: The two individuals were buried May 10, 200l. The fleshed individual (15-0l) is that of an obese female in the initial stages of decomposition. Heavy maggot activity is present in the chest region. The body is placed within the grave plot orientated north to south with the head at the northern aspect. The individual is in anatomical position on its back, with both arms at its side. The left arm, fully extended with palmar surface up, is positioned next to the body, while the right arm, also fully extended, is medially rotated so that the palmar surface of the hand is flush with the grave floor. Both legs are fully extended, slightly parted, due to body size, with toes pointing upward.

The skeletonized individual (33-00) is also orientated in the grave north to south, with the skull at the northern aspect of the grave. The remains are positioned face down. The skull is situated on its right side facing west. The thoracic region of the remains are covered with a short sleeve, cotton t-shirt. Most of the ribs appear to be absent, likely due to carnivorous activity. The right arm is slightly bent at the elbow, with the palmar surface of the hand facing upward. The lateral aspect of the right hand is in contact with the eastern edge of the grave. The left arm is completely separated from the body with the scapula and clavicle attached by mummified skin. The arm, fully extended with the dorsal surface of the hand visible, has been placed appropriately in relation to the body. The majority of the pelvic region and both legs are concealed by cotton pants. The left leg is bent slightly at the knee, with the medial aspect of the knee flush with the grave floor. The right leg is fully extended, with the foot being absent due to carnivore activity. Figure 2.13 displays the orientation and condition of both bodies in the grave, and their relation to one another.

Miscellaneous: A metal identification tag is attached to the fleshed body with a plastic zip tie that is wrapped around the left wrist. A second ID tag is lying on the upper left thigh of the fleshed individual. Although the zip tie is present with the ID tag, it has not been used to attach the tag to the body. The skeletonized individual has one ID tag

Figure 2.13~ Exact orientation and condition of bodies in grave plot 6.

attached to the left arm with a plastic zip tie at the distal end of the humerus, just above the elbow. A second tag is attached with a plastic zip tie to the right wrist. Figure 2.14 depicts all six research plots and their variables.

After each grave was dug and manicured, its contents were placed and meticulous notes, measurements, and photographs were taken of the positioning and orientation of each individual within its environment. The graves were then filled with the soil initially removed during the excavation of each individual trench. As each grave was refilled, the soil was occasionally packed using a shovel in an attempt to restore some of its original compactness.

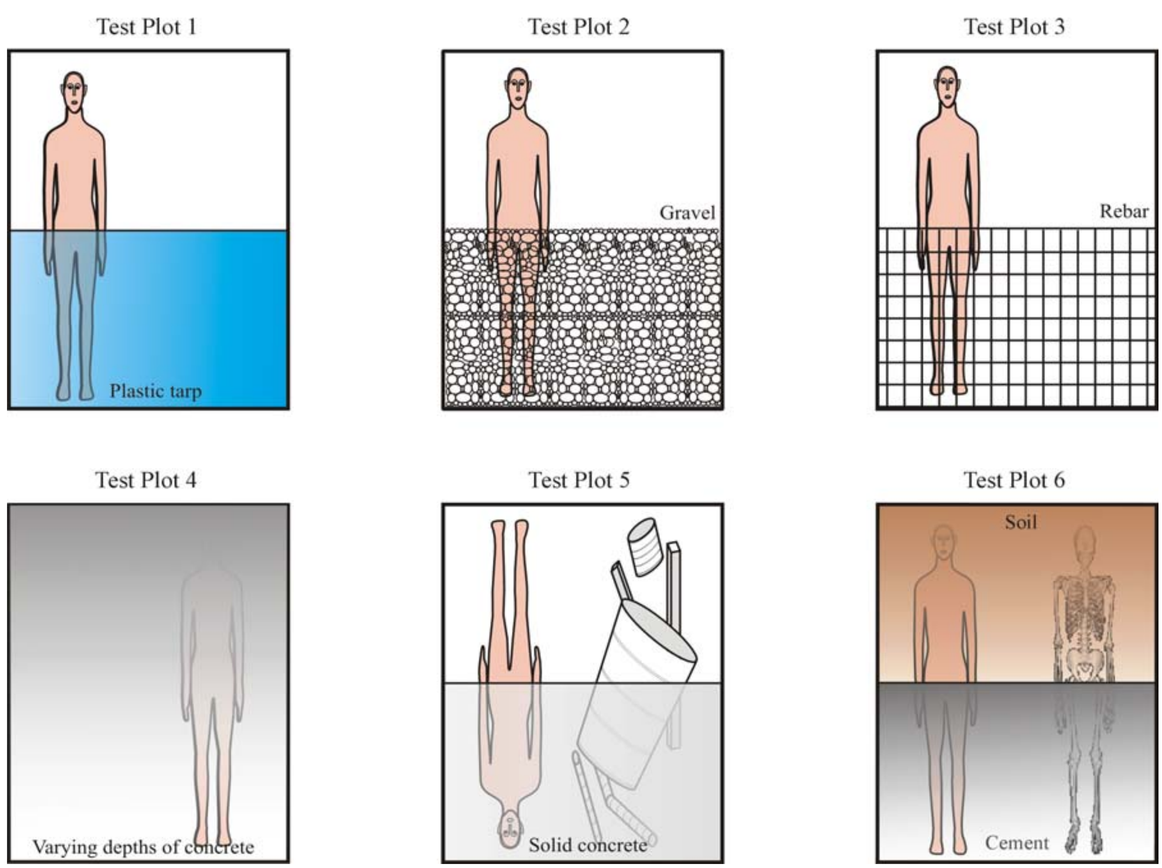


Figure 2.14~ All 6 research grave plots.

Once all six graves were refilled, 6ft x 8ft square wooden cement frames were built using 2in x 4in builders studs and 2in contractor grade nails. The frames were then evenly situated and leveled over each grave. In plots 1, 2, 3, and 4, where only one individual is entombed, the frame was positioned so that the grave beneath it resided on either the left or right half of the frame (Figure 2.15). Since plots 5 and 6 contained two subjects, and the actual grave was twice as wide, the frame was merely centered over the entire opening (Figure 2.16).

Figure 2.15~ Positioning of cement frame over grave with one body.

Figure 2.16~ Positioning of cement frame over grave with two subjects.

Upon proper placement of the cement frames, the ground surface within the frame was leveled; first by hand, using excess soil from the original excavation, then with the aid of a straight edge made with a 2in x 4in wooden stud (Figure 2.17).

When the earth within the cement frames was perfectly leveled using the available soil, bagged play sand was evenly distributed over the surface to fill in any large voids left in the soil. The same leveling device used previously was then utilized to ensure the most level surface possible within each individual frame (Figure 2.18).

Figure 2.17~ Stages of leveling within the cement frame.

Figure 2.18~ Final leveling stage within the cement frame.

Once all six graves were framed and the interior surface leveled, pea gravel and rebar was then added to plots 2 and 3 (Figure 2.19 & Figure 2.20), respectively.

On June 8, 2001, with assistance from my colleagues, the forms were filled with 4inches of concrete (with the exception of plot 4, which has a varying depth). A wheelbarrow, shovels, and four strong backs were utilized to fill each form. As the concrete began to cure, a 2in x 2in wooden stud was used to screed each plot, resulting in a leveled surface with a semi-smooth texture (Figure 2.21).

Figure 2.19~ Plot 2, leveled, with pea gravel distributed over eastern aspect of grave.

Figure 2.20~ Plot 3, leveled, with rebar distributed over eastern aspect of grave.

Figure 2.21~ Pouring and leveling concrete pads.

GPR Equipment Summary

The detection of buried objects gained significant interest in the United States in the late 1990's. The desire to remediate the thousands of sites worldwide has become an increasing concern and the application of radar to this problem has received renewed attention. Past research methods using GPR are known to be time-consuming, require multiple operators, and are limited by environmental conditions. Special Technologies Laboratory (STL), operated by Bechtal Nevada, and the University of California, Santa Barbara (UCSB) is investigating advanced GPR hardware, signal processing, and synthetic-aperture imaging with the development of an innovative system. The goal is to design and fabricate a lightweight, battery-operated unit that does not require surface contact, can be operated by a novice user, and can achieve improved resolution (Koppenjan et al. 2000). Geophysical Survey Systems, Inc. (GSSI) is also attempting to create a GPR system that overcomes challenges of the past. The SIR-20 is the most recent addition and is the first in a new generation of GPR data acquisition systems, revolutionizing GPR systems on many fronts.

Synthetic-Aperture GPR (GPR-X)

The GPR-X is a highly portable, self-contained GPR system that weighs only 22 pounds, and consists of four subassemblies: the computer, radar, antenna, and power supply (Figure 2.22).

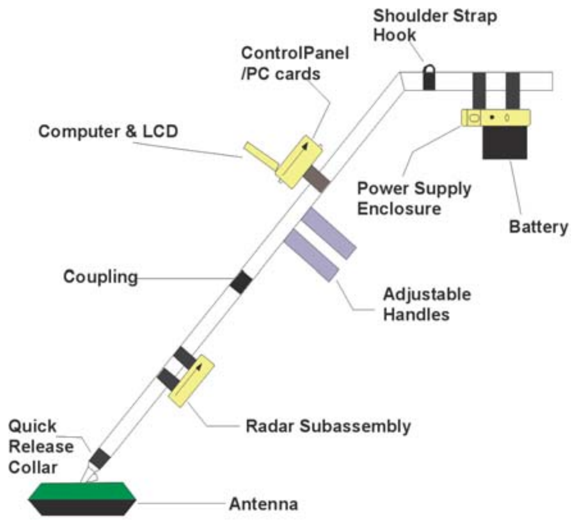


Figure 2.22~ GPR-X (Koppenjan *et al.* 2000)

The GPR-X unit acquires, processes, and displays data in real-time at 30 sweeps per second using a frequency-modulated, continuous-wave (FM-CW) radar that operates over a frequency range of 200-700 MHz. It has the capability to detect targets to depths of 5 meters with a range resolution of 20 centimeters. One person can operate the unit, observing the display as the antenna is swept across the target. It can be rapidly assembled and disassembled, and has few operator controls beyond its power switch, display contrast dial, and image marker control. For basic field operation, minimal operator training (i.e., less than one hour) is required for a skilled novice (Koppenjan *et al.* 2000).

The computer subassembly contains the signal processing and display hardware. It houses a PC 104 bus-based computer, which controls the digital-signal processing (DSP) board, driving data acquisition, signal processing, and depth profile display, all of which are performed in parallel thus increasing overall speed. It also includes a liquid crystal display (LCD) that is a low-power 640 x 480 resolution screen that is a supertwisted pneumatic type with transflective backing so it can be viewed in direct sunlight (Koppenjan et al. 2000). The system computer has two PC card sockets for flash memory cards, which emulate removable mass storage. Thus, stored data are easily transferred for post-processing to any PCMCIA-equipped computer. Power is supplied by one rechargeable camcorder battery.

The designers modeled the GPR-X as a synthetic-aperture multiple-frequency system operating in reflection mode. During image processing sequences of 128 coherent backward-propagating procedures form a composite image. The image becomes an overlay of 128 holographic images, each for every coherent frequency step. Koppenjan et al. (2000) stated that when using this method, diffraction is fully compensated in both range and cross-range directions thereby improving the overall quality of the image.

Impulse GPR (GSSI SIR-20)

The commercial Subsurface Interface Radar System-20 (SIR-20) mainframe, designed by Geophysical Survey Systems, Inc. (GSSI), is a portable, self-contained GPR that weighs 221bs. (Figure 2.23 a, b).

(a) **(b)**

Figure 2.23~ Impulse GPR (a)SIRveyor SIR-20 GPR System Unit and (b) GSSI Model 5103 400-MHz antenna (GSSI, 2002).

The SIR-20 collects data at the extremely fast rate of 800 scans per second, several times faster than any other available GPR system. The system is unique when compared to previous GSSI models in that it provides integrated data collection and post-processing which is displayed and stored, in real-time, on a ruggedized detachable laptop computer running Windows 2000. This real-time feature is important for several reasons. Other 'fast' systems cannot manage the data display or storage when they are collecting data at top speed. Therefore, the operator must stop and wait for data storage to catch up with the data in memory, then resume the survey only to wait again each time the buffer is full. System setup and data collection are accomplished by running a subroutine of GSSI's Radan-NT (RAdar Data ANalyzer) post-processing software (GSSI 2002). With data acquisition and processing software both housed 0n the laptop, the user is able to easily maneuver between data collection and data processing. Both modes use a common protocol and a common set of program function icons (filters, 3-D file setup, display parameters, etc). Although the SIR-20 has become the backbone of road and bridge scan systems, it is obviously not limited to transportation applications since several other industries are benefiting from it as well. For any application where previous SIR systems have operated, its field-ruggedness, versatility, and on-site processing capability make SlRveyor (SIR-20) a worthy, state-of the-art detection instrument.

The system unit operates with any GSSI antenna and can handle up to 2 antenna inputs simultaneously. Considering the soil conditions of the site and the depths to be penetrated, the GSSI Model 5103 (400) MHz antenna was chosen to be most applicable to this particular study (Figure 2.23 a, b). The 400 MHz antenna is marketed for moderately shallow investigations and is suited for utility detection, underground storage tank location, void identification, or any other ground disturbance in the range of 0.5 to about 3.5 meters in depth. In addition, the unit is capable of automated system setups, and can store an unlimited number of system setup files for different environments, survey conditions, and/or antenna deployment configurations (GSSI 2002). Typically, two persons conduct the survey, one a trained operator that monitors and controls the laptop, while the second pulls the antenna. However, this system can be operated by one individual.

Impulse radar works through the system unit generating repeated triggers, which are transformed by the antenna electronics into a transmission bipolar pulse. Its shape and center frequency is controlled by the size of the antenna and the electrical properties of the subsurface being investigated. Returning reflections off dielectric contrasts are stacked to form a composite image. External data storage is optional with any standard PC peripheral using the PC parallel port, USB port, or Ethernet port (GSSI 2002).

GPR Data Collection Summary

Before GPR surveys can be obtained in the field, a combination of environmental and field conditions must occur. GPR surveys cannot be conducted under harsh environmental conditions. If the ambient temperature falls below 0^{o}C the electronic equipment will not function properly. This is also true in cases of extreme heat. Rain is also known to present problems with the operation of GPR equipment. In addition, surface conditions may present challenges when conducting GPR surveys. Rough surfaces in particular cause irregular antenna movement along transects, potentially generating false signals in the GPR radargram. The smooth surface of the concrete pads above each grave plot eliminates this particular problem.

It is strongly recommended that a grid be established that encompasses the entire area to be surveyed. A grid has three primary functions: as a guide for determining survey lines; as a means for precise determination of the location of anything within the surveyed area; and as a convenient reference system by which to produce an accurate map. It is recommended when setting up this grid system that the project area limits are defined within a rectangle and that a one meter buffer outside the four sides of the project area is cleared to allow for the antenna sled to be stopped just outside of, rather than within, the project boundary. A test pit, or calibration area, just outside the project area is also necessary for the successful interpretation of the GPR results.

As a rule, GPR survey results are reproducible, given similarity of site conditions. One can return to a site where utility lines, rebar, or debris exists and generate almost identical scans over the same grid lines. However, with buried bodies the targets will change over time, and it is important to know what those changes might look like when GPR scans are run to locate the bodies. Some type of workable model needs to be developed in which progressive changes of a decomposing human body can be recognized in GPR imagery, thus providing the investigator and GPR operator a template by which to guide their efforts and compare their findings.

Calibration Data Collection

The primary goals in collecting calibration data sets in this project were to identify the reflective characteristics of the targeted subsurface, and to obtain the optimal antenna settings for the research plots. Calibration data sets for this project were collected at two different sites; the Anthropological Research Facility (ARF) and inside the Biosystems Engineering and Environmental Sciences (BEES) laboratory.

A 6’x 8’ grid (Figure 2.24) was mapped out on the floor of the BEES lab, resembling the concrete research plots at the ARF, in order for the calibration scans to replicate those of the actual research plots. The same grid was constructed over an empty grave at the ARF, known to be two foot in depth. Both the Sir-20 unit, with the 400 MHz antenna, and the GPR-X unit were used to collect the calibration data sets. With the known depths of a particular target, a suitable σ for the soil could be calculated using equation 1.1. Once the σ was calculated at both sites, depths of the interfaces that lie within each grave could be properly interpreted in the lab using the acquired radar images.

Main Research Plot(s) Data Collection

A grid system of 27 transects was designed to guide the antenna over each grave plot. This grid was developed so that each transect would slightly overlap the next. Perpendicular transects allow for better evaluation of the shape and size of the target, as

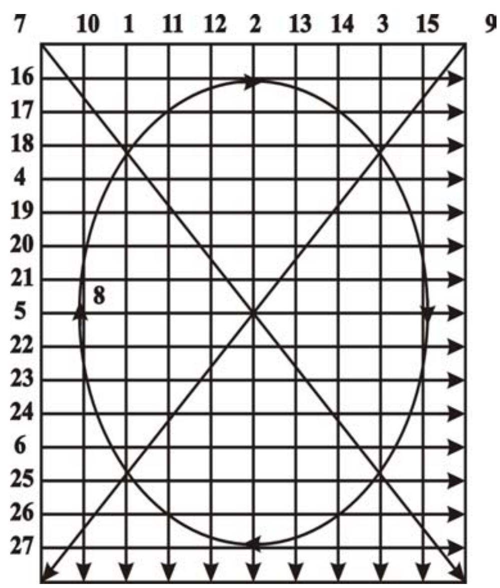


Figure 2.24~ Orientation of transect lines 1-27 used in GPR research surveys.

well as aiding in narrowing the area of disturbed to a size that might contain the target and be worth excavating. Therefore, vertical and horizontal transects were implemented, in addition to two horizontal and one circular transects. Figure 2.24 illustrates the design of the grid system that was used in both the calibration and the research plot surveys.

Transects 1-8 were those obtained during the first data set. Transect 9 was added during the second and third data collection set, and transects 10-27 were incorporated into the acquisition of the forth through the ninth data set. The additional 17 transects were introduced for the purpose of overlapping the scans to ensure that no one part of the survey area was left unaccounted for. This overlap later proved to be beneficial when normalizing the data for 3D imaging programs. This grid system was then measured and permanently applied to each of the six research plots using spray paint (Figure2.25). Since the number of each plot is inscribed into the cement in the lower, right-hand corner dictating the orientation and direction of the scans, exact replication of every scan was made possible.

Figure 2.25~ Grid system applied to each research plot.

Approximately every four weeks over an eight month span, data were collected for each research plot using the GPR-X system. Each transect was sampled twice with the same unit: once in full-screen mode and once in half-screen mode. The SIRveyor SIR-20 was only used once to obtain data from the research plots. Since a full-screen/half-screen mode option is not available with this system, only 162 scans (27 transects x 6 plots) were collected. The acquired data was then taken to the BEES lab where it could be analyzed with various imaging software programs and interpreted more accurately.

Data Analysis Hardware and Software

Once in the lab, the raw GPR-X data files, which are stored on a 64 MB flashdisk memory card, were downloaded to a laptop computer and transferred to a server drive. The SIR-20 data files were downloaded directly from the system unit to the server drive using RADAN for Windows NT software. From the server the data were then capable of being accessed by any desktop workstation within the defined network. All raw data files were individually transformed from algorithms (binary format) into text files (ASCII format) using *Translator*, a software program designed to aid in the conversion and simplify the analysis of GPR data. Each text file was then opened using *Transform Version 3.3* (Fortner Research, LLC) where it could be configured, normalized, interpolated, and displayed as two-dimensional color-enhanced images.

The transformed data files were then imported into *Adobe Photoshop Version 5.0* so that each image could be formatted and flattened for further processing. This Windows compatible software package enabled the radar image files to be converted and handled by most other Windows-based software packages. As each image was processed, it was saved as a bitmap file. From here the images were imported into *Corel Presentations Version 9*, a standard graphics package, where the 2D images could be chronologically arranged for comparison purposes.

These two-dimensional images were further processed into amplitude slice-maps using *T3D Version 1.1.3* (Fortner Research, LLC), a three-dimensional visualization software package. These slice-maps are the result of a series of images that illustrate the three-dimensional location of anomalies within the research plots from the computer analysis of several stacked two-dimensional profiles. Using *T3D*, dimensions of these images were magnified to represent the actual grave dimension, and volumes of patterns within the image were calculated in units of voxels. As with the 2-D images above, these slice maps were then imported into *Corel Draw Version 9* for final annotation, and so that they could be systematically arranged, compared, and correlated with the decompositional patterns of the buried human remains.

Chapter 3

Results

Calibration Data Results

The calibration data using the GPR-X system was obtained on August 17, 2001, while the calibration data using the SIRveyor SIR-20 system with the 400 MHz antenna was obtained on January 8, 2002. The primary goals of acquiring these data sets were to:

(1) Identify reflective characteristics of the soil layers at the ARF

(2) Determine optimal antenna settings for applicable soil types

By comparing the known depths of buried objects with the radar images from the calibration survey, a suitable σ was calculated using equation 1.1. Once the σ was calculated, accurate depths within the obtained GPR images could later be determined in the lab. Figure 3.1 and 3.2 are examples of calibrations scans obtained with the two different GPR systems, used to help determine penetration depth.

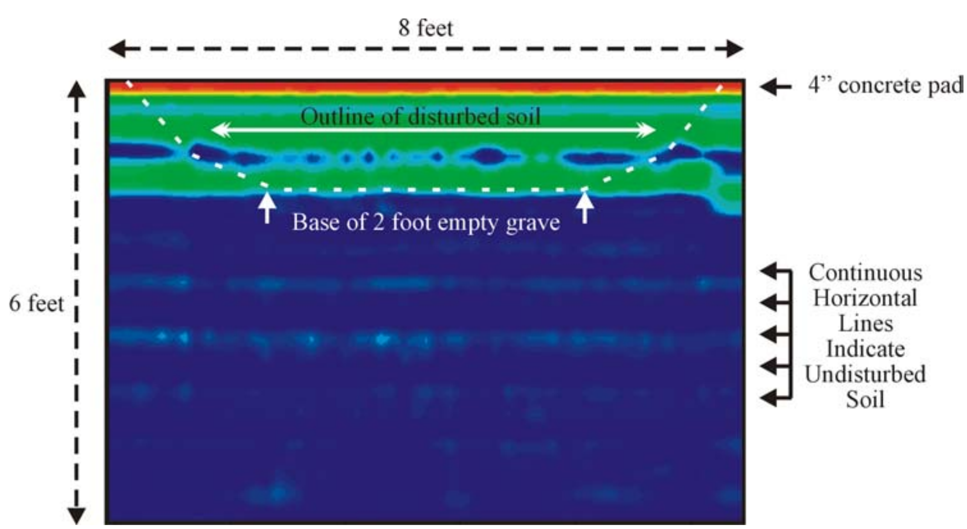


Figure 3.1~ GPR-X calibration data scan displaying an empty grave.

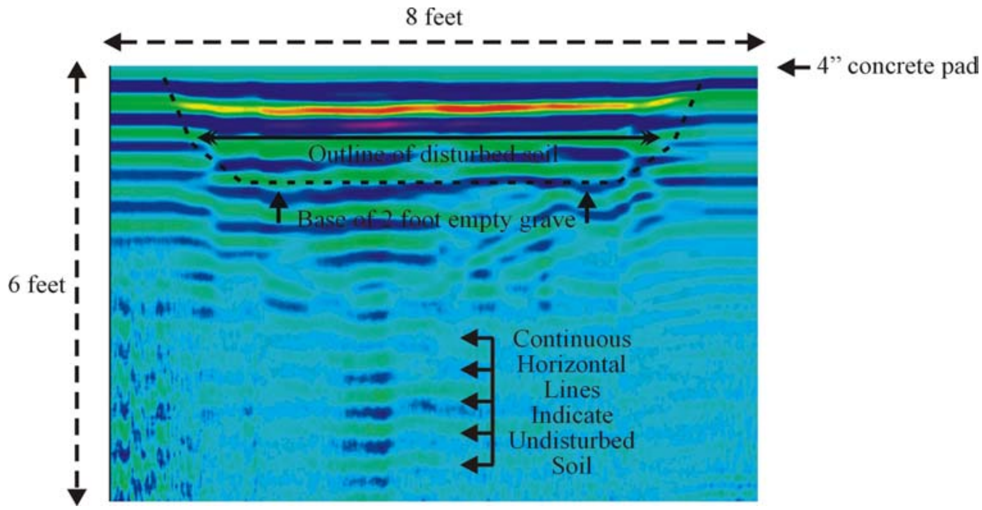


Figure 3.2~ SIRveyor SIR-20 calibration data scan displaying an empty grave.

Main Research Plot(s) Results

It is important to preface that a total of 2256 scans were acquired throughout the eight month period of this research. Since the illustration of all these images is of no value, not to mention practicality, to the final outcome of this document, a random representative sample has been chosen from each data set.

Data Set One

Data set one was obtained at ARF on August 14, 2001, with the GPR-X system. Eight scans were obtained from each of the six plots in both half and full-screen modes: three horizontal, three vertical, a diagonal, from the upper left corner to the lower right, and one circular scan (Figure 3.3). A total of 96 scans were collected.

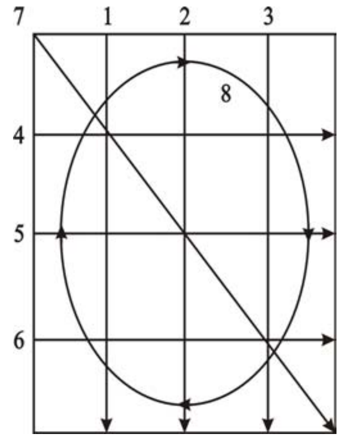


Figure 3.3~ Configuration of scans obtained from each plot in data set one.

The interpolated images in Figure 3.4 and 3.5 are a representative sample of all scans obtained for data set one. The images within these figures are identical in content and configuration with one exception; the half-screen mode (Figure 3.5) is merely a magnified (x2) version of the full-screen mode (Figure 3.4). The rainbow color scheme, in which the images are displayed, is the default color scheme applied when data is initially processed using *Transform, Version 3.3*. Other available color schemes are presented later.

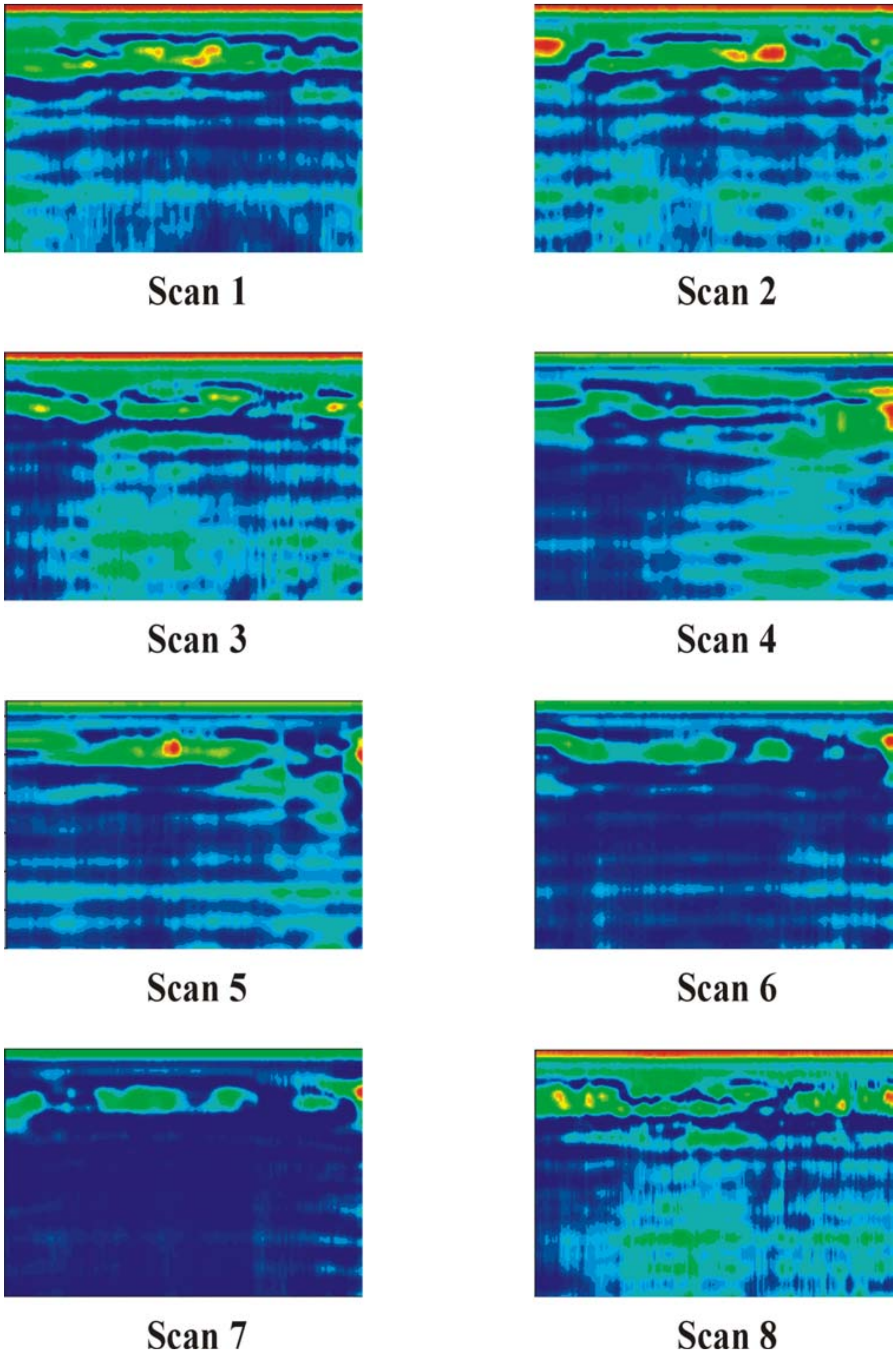


Figure 3.4~ Interpolated GPR-X scans of plot 1 in full-screen mode, displayed in rainbow color scheme, showing the 8 transects of the selected plot.

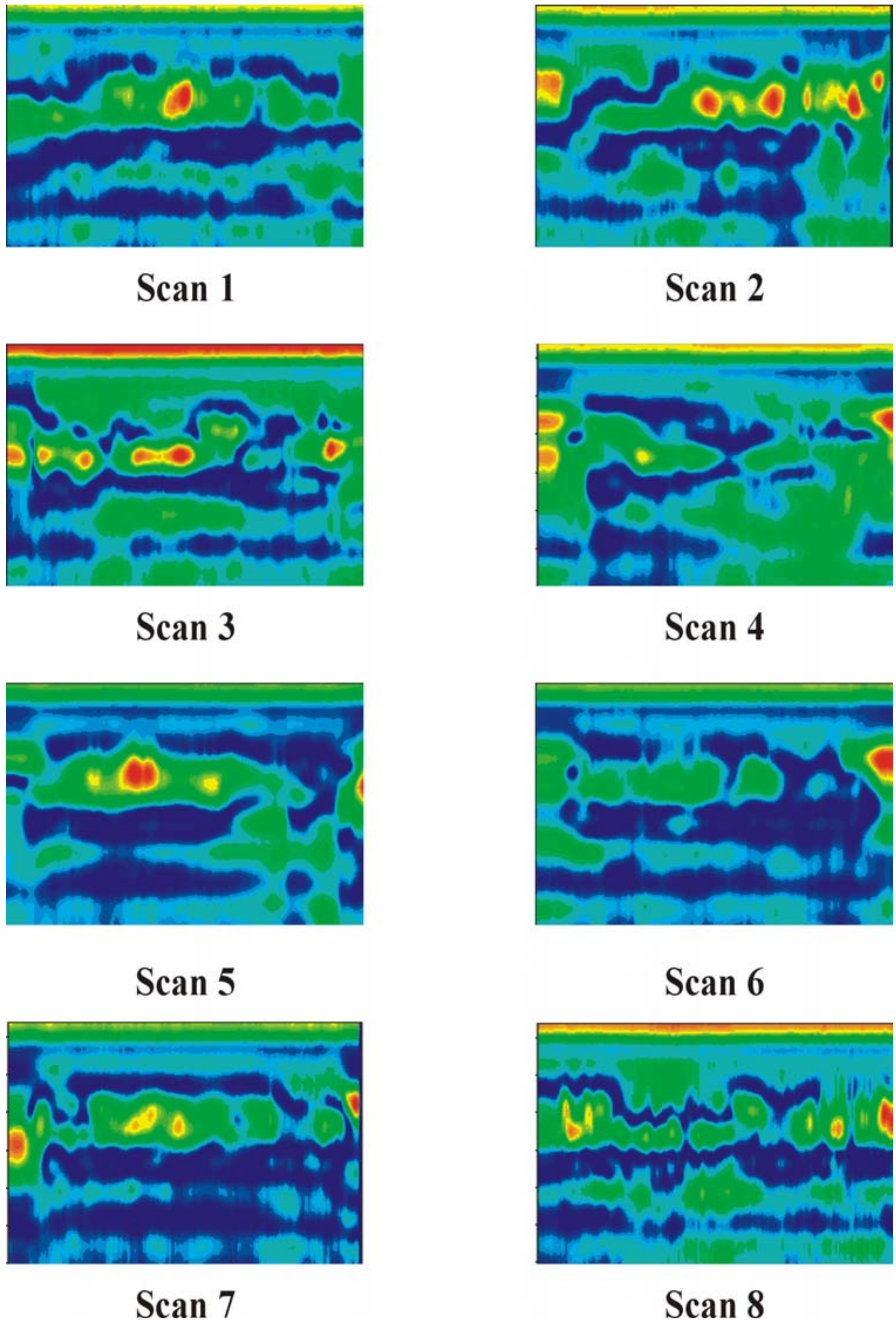


Figure 3.5~ Interpolated GPR-X scans of plot 1 in half-screen mode, displayed in rainbow color scheme, showing the 8 transect of the selected plot.

Data Set Two

Data set two was obtained at ARF on September 15, 2001, with the GPR-X system. Nine scans were obtained from each of the six plots in both half and full-screen modes: three horizontal, three vertical, two diagonal, and one circular scan (Figure 3.6). A total of 108 scans were collected.

The surface plots in Figure 3.7 are a representative sample of all data acquired for data set two. The above images are all transects taken through the midline of the buried body and are displayed in a planer, mirrored fashion. The upper right-side of the surface plots, demarcated by red and yellow apices, portrays the head and torso regions of the individual. The images clearly indicate a disturbance of the subsurface, as well as the presence of a very large concealed object, in this case, a body.

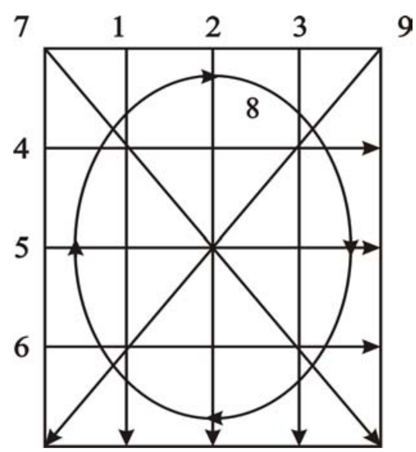


Figure 3.6~ Configuration of scans obtained from each plot in data set two.

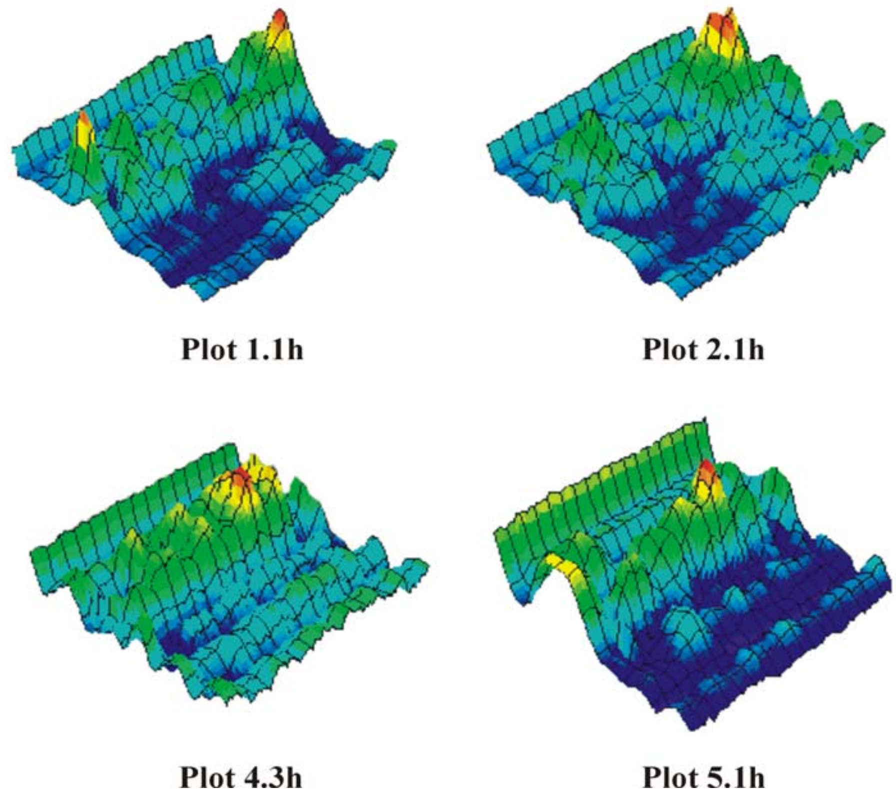


Figure 3.7~ Surface plots of GPR-X scans, depicting the presence of a buried object.

Data Set Three

Data set three was obtained at ARF on October 24, 2001, with the GPR-X system. Nine scans were obtained from each of the six plots in both half and full-screen modes: three horizontal, three vertical, two diagonal, and one circular scan (Figure3.6). A total of 108 scans were collected.

The histogram in Figure 3.8 is representative of all transects taken for data set three. As seen above, the histogram is not of substantial value as far as being a reliable indicator of disturbances to, or contents concealed within, the subsurface. It merely depicts the range of dielectrical constants that are encountered within a particular scan, and the incidence rate of each.

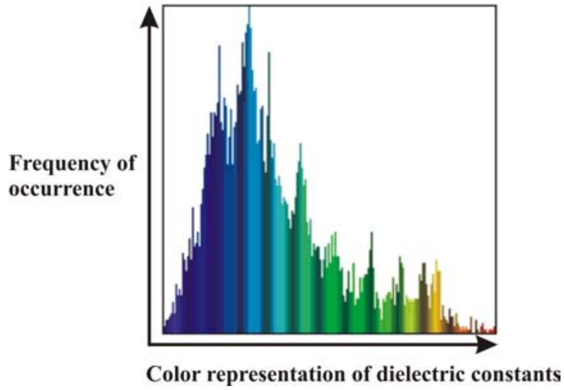


Figure 3.8~ Histogram of GPR-X scan, showing the frequency of the dielectric constants present within the test plots.

Data Set Four

Data set four was obtained at ARF on November 19, 2001, with the GPR-X system. Twenty-seven scans were obtained from each of the six plots in both half and full-screen modes: fifteen horizontal, nine vertical, two diagonal, and one circular scan (Figure 2.10). A total of 324 scans were collected.

The interpolated images in Figure 3.9 are a representative sample of those obtained for data set four. The eight images are of the same radar profile, taken through the midline of the body entombed in plot five. The individual is situated so that the head and torso regions are on the left side of the scan, while the legs and feet are on the right. Various color schemes, as depicted above, are often used by the interpreter to better illustrate an image, making its final analysis more thorough. Since each color scheme exhibits differing viewpoints, it is beneficial to utilize as many as possible when interpreting GPR imagery.

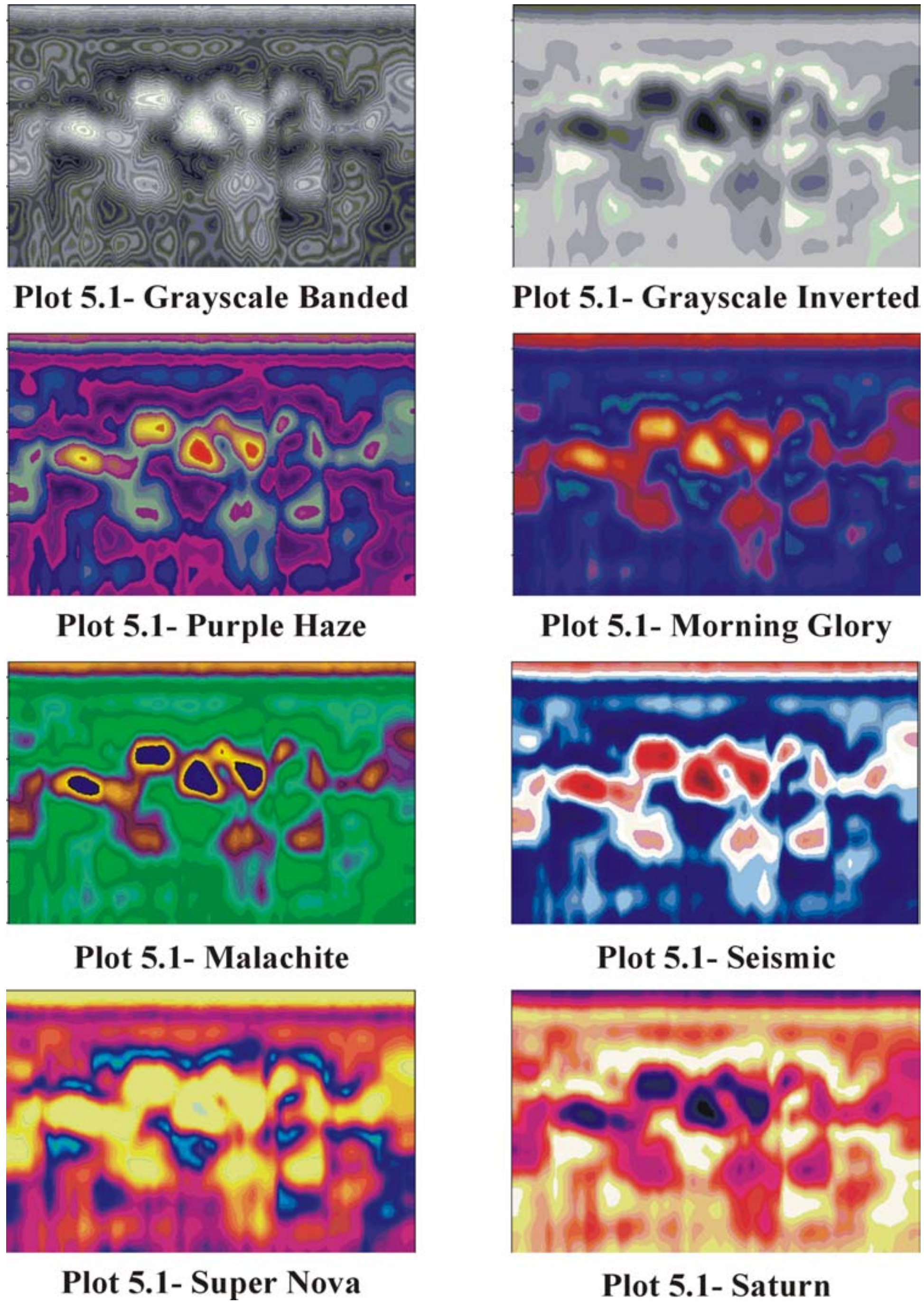


Figure 3.9~ Interpolated GPR-X scans, displayed in various color schemes, showing how different colors express different features within the grave plots.

Data Set Five

Data set five was obtained at ARF on December 18, 2001, with the GPR-X system. Twenty-seven scans were obtained from each of the six plots in both half and full-screen modes: fifteen horizontal, nine vertical, two diagonal, and one circular scan (Figure 2.10). A total of 324 scans were collected.

The contour plot images in Figure 3.10 are a representative sample of all transects data in data set five. The images situated on the left side of the figure are identical to their adjacent counterparts, with the exception of the color scheme in which they are displayed. The first scan, 5.4, if read from left to right, passes through the lower half of the five gallon bucket (meant to resemble the abdomen) of the mock-up individual and through the thoracic region of the cadaver. The second scan, 5.5, passes through the upper half of the bucket (meant to resemble the chest) of the mock-up, then through the lower abdominal region of the adjacent human.

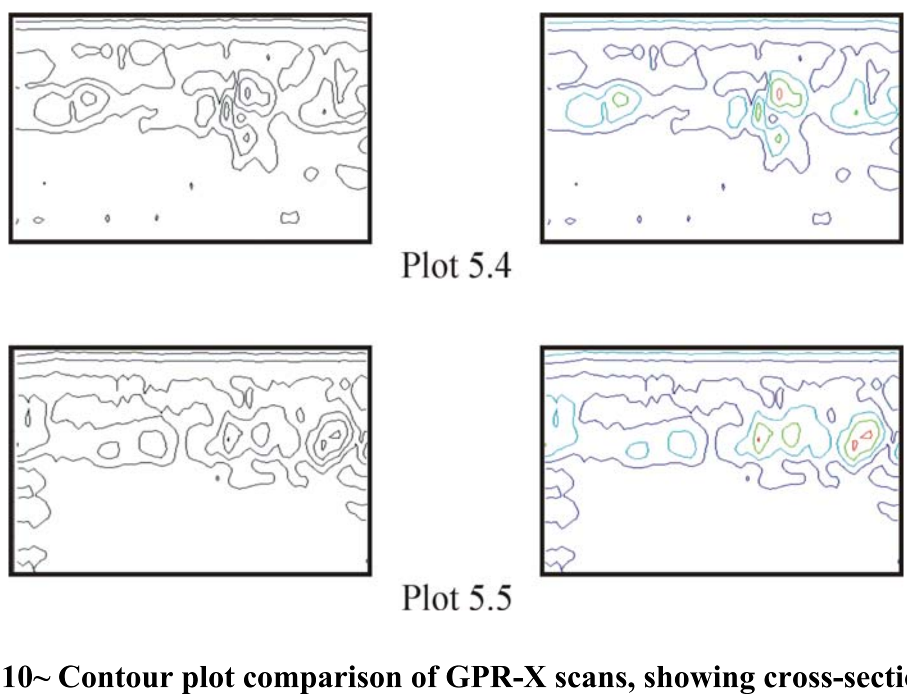


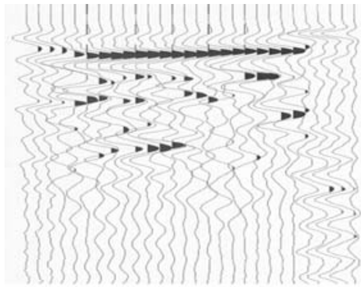
Figure 3.10~ Contour plot comparison of GPR-X scans, showing cross-sectional views of the test plots.

As seen above, contour maps, displayed in black and white, are informative only in the sense that they simply depict the silhouette of disturbances and buried objects. However, when color is incorporated into the image, the realm of differentiation between varying dielectric constants is introduced.

Data Set Six

Data set six was obtained at ARF on January 10, 2002, using the SIRveyor SIR-20 unit with the GSSI Model 5103 400-MHz antenna. Twenty-seven scans were obtained from each of the six plots: fifteen horizontal, nine vertical, two diagonal, and one circular scan (Figure 2.10). A total of 162 scans were collected.

The line and wiggle scans in Figure 3.11 are a representative sample of all those acquired for data set six. The line scan is the real-time image generated on the display monitor as the antenna is pulled across the surface above the target. Since these scans are produced immediately and have not been manipulated, they often contain "noise" and/or "interferences," and lack corrected depth and horizontal scales, making them difficult to interpret. Wiggle scans are two-dimensional vertical profiles of the sequentially ordered reflection traces. When printed out, these profiles display the individual traces and their corresponding amplitudes. Wiggle scan profile can be exaggerated vertically and/or horizontally to emphasize certain aspects of a target. Various color schemes can also be incorporated so that each interface is represented by a different color, aiding in enhanced interpretation.


Wiggle Scan of Plot 1-4

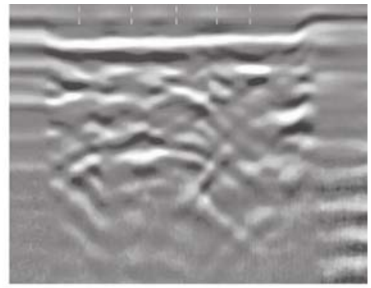

Line Scan of Plot 1-4

Figure 3.11~ Wiggle and line scan comparison of SIR-20 images, showing raw data images.

Data Set Seven

Data set seven was obtained at ARF on January 31, 2002, using the GPR-X system. Twenty-seven scans were obtained from each of the six plots in both half and full-screen modes: fifteen horizontal, nine vertical, two diagonal, and one circular scan (Figure 2.10). A total of 324 scans were collected.

The 3-dimensional images in figure 3.12 are a representative sample of all those obtained for data set seven. These images were generated in *T3D Version 1.1.3* (Fortner research, LLC) by consecutively stacking adjacent two-dimensional images of each plot. These images can be produced using all acquired vertical or horizontal scans, depending on the needs of the interpreter and what extractable information is desired. Since the mere stacking of 2D images produces another 2D image, the dimensions of the Z plane for each 2D image was magnified by ten, thus creating a 3D cube. Appropriate color schemes were then chosen to best depict the contrast of interfaces occurring within each image.

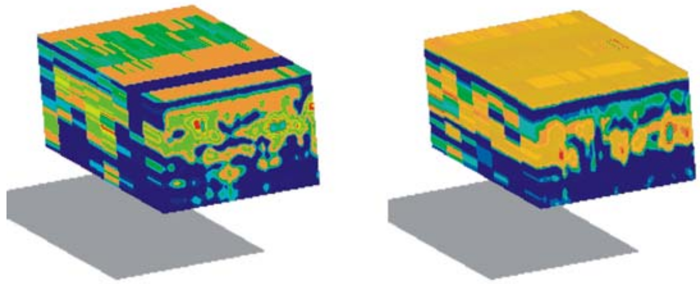


Figure 3.12~ 3-Dimensional imagery of GPR-X scans, showing the entire scanned area of the test plots.

Data Set Eight

Data set eight was obtained at ARF on February 22, 2002, using the GPR-X system. Twenty-seven scans were obtained from each of the six plots in both half and full-screen modes: fifteen horizontal, nine vertical, two diagonal, and one circular scan (Figure 2.10). A total of 324 scans were collected.

The 3-dimensional slice-maps in figure 3.13 represent all the images collected in data set eight. Using *T3D,* these slice maps were extracted from entire 3D images as those pictured in figure 3.12. The program enables one to select any locale, in any of the three orientation planes of the complete image, to be displayed, while making all others transparent. Slice-maps help illustrate the three-dimensional location of reflection anomalies derived from the computer analysis of two-dimensional profiles.

As can be ascertained from the figure provided, the buried individual in plot four is situated in the right side of the image. The first slice (top) exhibits a transect through the legs of the individual, the second (middle) passes through the hip region, and the third slice depicts a cross-section of the upper thoracic region. In plot five, the body is

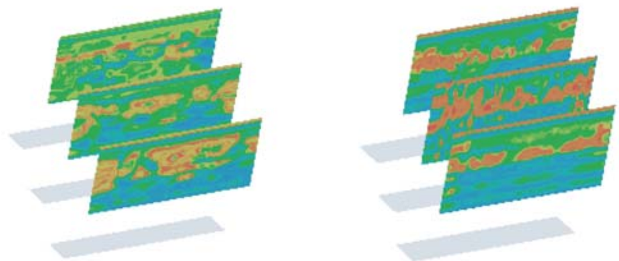


Figure 3.13~ 3-Dimensional slice-maps of GPR-X scans, showing three horizontal views of the selected plots.

positioned within the left side of the image, with the first slice through the thoracic region, the second through the lower abdominal area, and the third through the legs of the individual.

Data Set Nine

Data set nine was obtained at ARF on March 14, 2002, using the GPR-X system. Twenty-seven scans were obtained from each of the six plots in both half and full-screen modes: fifteen horizontal, nine vertical, two diagonal, and one circular scan (Figure 2.10). A total of 324 scans were collected.

The 3-dimensional images in figure 3.14 are a representative sample of the data collected in set nine. These 3D cutout and reverse cutout images are also extracted from the entire 3D image initially generated and viewed in figure 3.12. The ability to select volumes, making them transparent within the image, is another option available when processing GPR data with *T3D*. The manipulation of color schemes and the range within each palette of colors proves to be very helpful when generating cutout views of these images. In the above figure, the reverse cutout in plot 5 better illustrates the presence, or better yet, the absence of a large continuous object, surrounded by disturbed soil. The lime green color represents the immediate soil in which the body is encased. The cutout image on the right, depicting all of the contents of grave plot 5, is much more convoluted, making it difficult to accurately interpret. Whether a cutout or the inverse is used, is dictated by the properties of the object being sought, and is determined on a case by case basis.

Figure 3.15 depicts one 2-dimensional image of the transect through the midline of the body in test plot one. The plot scan overlay exhibits the accuracy of the GPR-X in detecting the approximate size and shape of subsurface features.

Figure 3.16 is an example of a 3-dimensional sliced image that is constructed from the 2-dimensional, stacked horizontal images obtained from plot 5, pictured above. The three slices of the 3-dimensional image were chosen to represent the three critical cross-section of the body as seen through data collected with the GPR-X. This image also depicts the capabilities of the GPR-X in collecting representative data.

Figure 3.17a is a graphic representation of plot 5, and the slices taken to create the 3-dimensional plot scan comparison shown in Figure 3.17b.

The plot scan comparison in Figure 3.17b, an accurate 3-dimensional depiction of data collected over the term of this project, shows how the body decomposes within the grave over time.

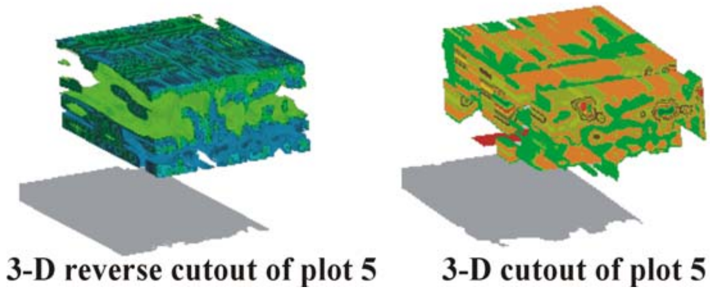


Figure 3.14~ 3-Dimensional cutout imagery of GPR-X scans, showing the position of the body entombed in plot 5.

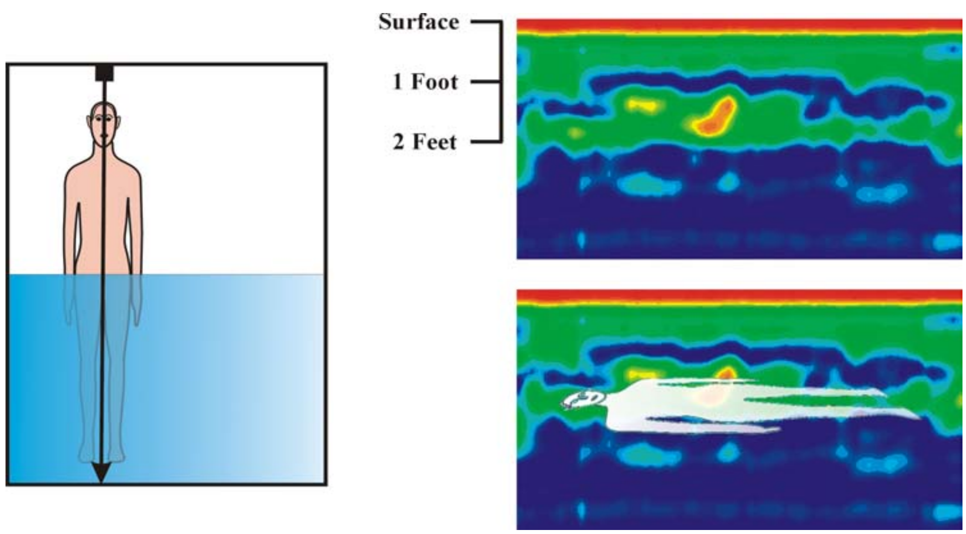


Figure 3.15~ 2-Dimensional plot scan overlay of plot 1.

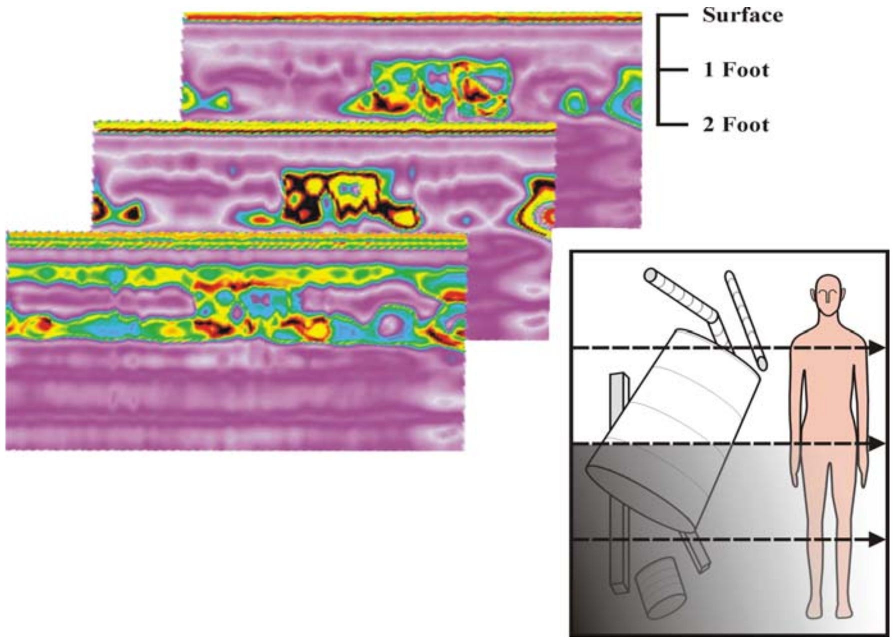


Figure 3.16~ 3-Dimensional comparison of plot 5.

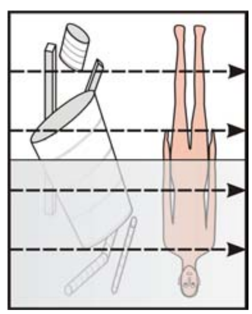


Figure 3.17~ 3-D Imagery (a)Depiction of 4 horizontal scans of plot 5 for 3-D comparison.

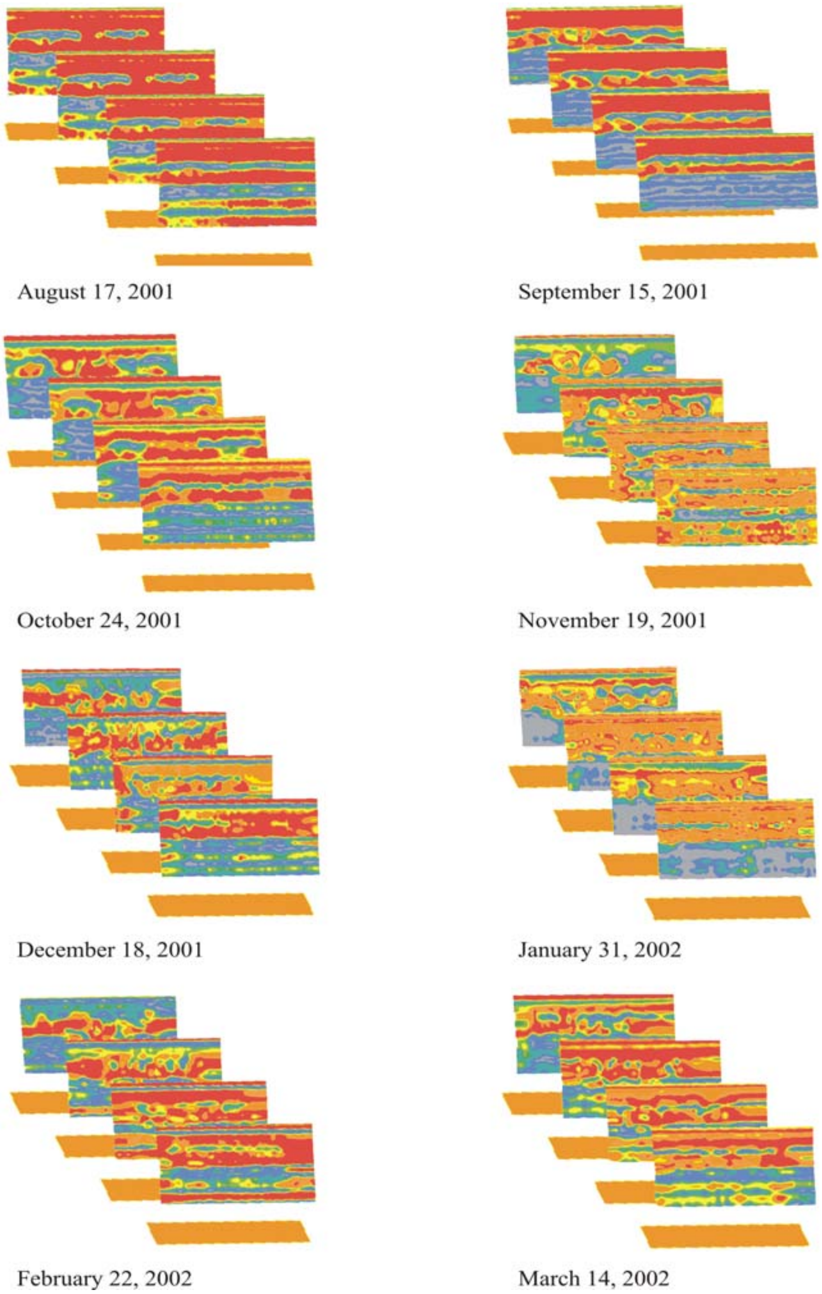


Figure 3.17 cont~ (b) 3-Dimensional plot scan comparison.

Chapter 4

Discussion

Advance processing and interpretation of the raw data is the most time consuming phase of any geophysical survey requiring the most expertise, both in familiarity with the applicable field conditions, and image analysis. First and foremost, it is imperative that the individual responsible for the analysis and subsequent interpretation of the data be aware of the aims and objectives of the investigation, hence, the importance of the required specificity and accuracy. Since most representative sites can be selected from the radar profiles, the profiles should be subjected to preliminary interpretation in the field, therefore facilitating the ability to conclude if further data collection is necessary.

The primary goal of the interpretation is to identify anomalies or specific targets within a radar profile, determining if they provide relevance to the investigation. The first step in the analysis of the radar profile is to identify the origin of the reflection(s). This involves being able to ascertain whether the indicated interfaces represent actual targets, or are interferences consisting of random noise or regular repeating reflections independent of the target. If found to be applicable, the data can then be converted to algorithms, and subjected to mathematical operations such as horizontal and vertical filtering, amplification, and comparison. Importing the data into commercial graphics programs allows the interpreter to examine and process the data interactively. The data can be displayed in a variety of forms, including: generated images, interpolated images, contour plots, surface plots, wiggle scans, line graphs, 3D images, and histograms, depending on the needs of the interpreter and the information sought. Each of these forms can be further enhanced using various color schemes to display a different perspective of the data.

Calibration Data

Calibration processes for this project consisted of dragging the GPR-X unit and SIR-20 400 MHz antenna over an empty grave of known depth. The GPR-X image depicted the disturbed soil of the grave as a specific target, while the SIR-20 image exhibited the delineation of the grave outline. From the known depth of the base of the disturbance, a σ was calculated for the soil using equation 1.1. Once a σ was calculated and applied to the data collected from the six research plots, it was then possible to determine the approximate depths of specific targets beneath the surface in the acquired radar images.

Main Research Plot(s) Image Interpretation

Test Plot 1~

The variables used in this research plot proved to very valuable in that they provided a great deal of information. The fact that GPR surveys are generally least effective in soils which are high in water content, along the primarily wet clay subsurface at ARF, resulted in a substantial decrease in the searchable depth and resolution, overall for this survey. The two foot depth at which this body was buried allowed for both GPR units to capture the changes that occurred within the burial plot over the eight month period. By examining all of the images acquired, especially those generated into 3-dimensional profiles, I was able to identify and track the metamorphosis transpiring within the grave and its immediate environment over the stated period.

Test Plot 2~

The burial trench of this plot was 4ft deep, which severely hindered the ability of either GPR unit to obtain sufficient data. The resolution in most, if not all, of the images was extremely poor, making it difficult to recognize the definition of the grave shaft and the body encased within. With this lack of interpretable data, it was impossible to identify whether any changes were taking place as the body progressed through decomposition.

Test Plot 3~

At 6ft below the ground surface, a body buried in a clay environment is not likely to exhibit many indications of decomposition over an eight month time span. Even if the body had made any detectable transformations, neither the GPR-X nor the SIR-20 units could have penetrated such depths to facilitate interpretation of these changes from the generated images. Therefore, no valuable data was obtained from this research plot.

Test Plot 4~

Since the base of the burial trench in this plot was only one foot in depth, it is fair to say that less than a half a foot of soil covered the majority of the decomposing remains. Since most clandestine burials have proven to be this shallow, the interpretation of the data from this plot was of extreme value and importance. It is also imperative to mention that the individual within this plot had only progressed through the initial stages of decomposition at the time of burial. Since GPR travels through a continuous medium without any difficulty, the varying depth of concrete that was situated over the burial plot did not benefit or hinder the collected results. Examination of all images generated over the research period, using the 2-D and 3-D comparison plots, enabled me to easily distinguish the decompositional stages through which this individual passed.

Test Plot 5~

Overall, the data collected and resulting images generated from this research plot, proved to be the most informative of the entire study. The configuration of the variables in plot 5 allowed visual comparison of continual changes through which the individual progressed, while its adjacent inanimate counterpart made only subtle changes. Given that the body lay in a one foot grave, decompositional changes were easily visible within the radar profiles. The subtle changes to the mock-up that were detected in the images were most likely the result of soil settling into the air voids of the one and five gallon buckets. These air voids in the calvarium and thoracic regions of the cadaver never changed over time. Three-dimensional comparison imagery proved to be the most informative and reliable media when examining these decompositional changes. The advantage this plot had over the other five is that the individual concealed within it had only recently expired, therefore no signs of decomposition had commenced before the body was entombed.

Test Plot 6~

Even though this plot had the potential to produce significant results, the data had to be disregarded in the final analysis since collection procedures were not consistent as they had been in the other five plots. Since two different individuals obtained data for this project, it was of the utmost importance that strict procedures were followed. Unfortunately, there was a lack of communication in regards to the layout of plot 6, and therefore the collection patterns expressed several inconsistencies, leading to its discard.

Recommendations

One of the substantial benefits of using GPR is the ability of the system to collect large amounts of continuous, nonintrusive subsurface data effectively and efficiently. This capability allows tremendous amounts of data to be gathered in relatively short periods of time, thus reducing costs to investigators. However, there are several recommendations that can be made to further ease its utilization in future research projects and surveys, including: environmental conditions, survey techniques, and data processing and interpretation.

Over the span of this project, certain environmental factors were encountered that resulted in compromised data results. Extreme heat and cold conditions had the potential to prevent the GPR equipment from functioning properly. If ambient temperatures are not suitable, it is not worth the time nor the effort to attempt data acquisition. I found that it is sensible to avoid harsh conditions all together. Electrical storms and heavy rain which saturates the ground, and can affect data, should be avoided at all costs. If possible, the GPR unit should be protected from any adverse environmental conditions.

As stated previously, grid systems are highly recommended to enable repetitive data to be collected over a period of time. However, transect line configurations can be a very timely process. Therefore, if the technology is available, the implementation of Global Positioning Systems (GPS) methodologies would be beneficial in saving time, as well as having the capabilities of being correlated with the GPR scans using geophysical based computer programs.

Since data analysis and interpretation is the most time consuming portion of a GPR survey, the interpreter should be familiar with the various software programs utilized in data processing. The mere working knowledge of such programs, in itself will save time and frustration in the lab. It is also important that the interpreter is aware of the aims and objectives of any investigation. As reviewed in the previous chapter, several techniques can be used to present GPR data. How it is presented is determined by what information is being sought.

Chapter 5

Summary and Conclusions

Over the past eight months, ground penetrating radar profiles were acquired from six simulated and controlled clandestine burials. Two and three dimensional imagery programs were utilized to optimize the analysis and interpretation of the data collected during this period of research. The processed images were then compared to models of human decompositional stages. The primary objective was to support the theory of the need for a collaborative disciplinary approach when searching for buried human remains. The results of this project have produced positive evidence to support such collaborative search efforts.

Having evaluated both the raw data and the radargrams, several interesting interpretations and observations in regards to the use of GPR in the detection of decomposing buried human remains have been made. The radar signature of the burial trench has proven to be a function of the fundamental differences (dielectric constant, velocity, and homogeneity) between the infill of the grave and the in-situ soils. As seen in the aforementioned radar profiles, undisturbed soil is characterized by laterally continuous reflection events, whereas in situations of disturbed soil, there is a lack of such lateral continuity. Over the eight month period in which data was collected, the signatures of the burial trenches showed very subtle changes. These changes were most likely a result of physical and chemical changes to the burial trench due to the decomposing body. However, the contents of the graves showed substantial continual changes over time, indicating the metamorphosis that was occurring within. At the end of the eight month research period, it was still possible to differentiate the peripheral margins of the burial trench, its decomposing contents, and the undisturbed soil that encompassed the burial sites.

As with any scientific instrument, GPR is not without limitations. The impulses cannot determine the differences between randomly buried static objects and decomposing human remains. Fortunately, the significant difference here is that decomposing bodies transform over time, producing air voids and other substantial changes within the burial trench, whereas randomly buried objects do not exhibit such conversions. By utilizing two different GPR systems I have been able to make additional observations and determinations beyond my initial considerations. For instance, impulse radar (the GSSI SIRveyor SIR-20 system) produces images that depict even the most subtle of disturbances to the ground surface and subsurface, such as those created as a result of the digging and infilling of a grave. Synthetic-aperture GPR (the GPR-X system), on the other hand, produces images that are more target specific, such as a body or associated paraphernalia that is concealed within such a disturbance. This finding demonstrates that depending upon the sought after target, be it a buried body or the burial trench that may possibly house a body, the type of GPR system utilized can provide an added choice in search technique. In cases involving clandestine burials, the most optimal choice would be to incorporate both systems. If one method fails, the second may be successful and/or the findings of one system might be used to further substantiate those of the other. This would enhance search efforts twofold: first it would allow investigators twice the opportunity to discover a potential burial site, and second, if a suspected grave is detected with a commercial impulse system, the GPR-X could be used to determine if the suspected grave contains a buried object. In cases where the GPR-X system has detected a buried object that could potentially be a body, an impulse radar system could then be utilized to determine if the area around the target displays the disturbance signatures of a grave.

This research was successful in that it provided a venue to determine that GPR is capable of producing images which conclusively exhibit the progressive decompositional changes of a buried human body. These conclusions support the value of incorporating collaborative search efforts in the future. By allowing geophysical surveys, such as ground penetrating radar to be conducted during the search for a clandestine burial and utilizing the resulting data analysis, a limited amount of excavation may be necessary thus creating substantial savings in time, finances, and level of effort. Using a combination of search techniques has, and always will be, better than relying on any single method. Therefore, to enhance search methods for buried human remains, use of ground penetrating radar should be routinely considered as an alternative method for obtaining viable data, the value of which greatly outweighs the resource commitment associated with the effort.

During the past couple decades, forensic anthropology has progressed from a peripheral academic activity to a formally recognized subdiscipline of physical anthropology. This progression has created opportunity for forensic anthropologists to apply their full knowledge of human biological variability to a much wider range of medico-legal problems than just those related to the identification and interpretation of the human skeleton. These opportunities create the potential for scientists and other professionals from diverse backgrounds and experience to work together with common goals offering an ideal juncture for transfer of technology. Iscan (2001, page 4), in his editorial *Global Forensic Anthropology in the 21st Century*, states, "Anthropologists need to collaborate with other scientists to identify areas so that new knowledge is gained." If the concept of forensic anthropology can be expanded beyond its traditional and self-imposed boundaries of skeletal identification, many of these scholars have the knowledge and skill sets available, at least potentially, for application to medico-legal issues. As Clyde Snow said, "Although skeletal identification will undoubtedly continue to provide the major part of the caseload of forensic anthropologists, these experts should be willing to come out of their bone closets and serve the criminal justice system to their fullest as *human biologists*" (1982, p.129).

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