Rediscovering the Dead: Practical Applications of Remote Sensing in Historic Cemeteries

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REDISCOVERING THE DEAD
Practical Applications of Remote Sensing in Historic Cemeteries

A Thesis
Presented to
The Faculty of the Department of Anthropology
The College of William and Mary in Virginia

In Partial Fulfillment
Of the Requirements for the Degree of
Master of Arts

by
Michael Strutt
1991
APPROVAL SHEET

This thesis is submitted in partial fulfillment of
the requirements for the degree of

Master of Arts

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When I look back at all the people who have lent assistance to this thesis, I realize that the list is a long one. But perhaps that is to be expected in interdisciplinary research. First, I would like to thank the William and Mary members of my thesis committee who waded through several drafts and provided valuable insights as well as necessary logistical changes. These professors are Dr. Norman Barka, Dr. Theodore Reinhart, and Dr. Virginia Kerns. Dr. Stephen Potter of the National Park Service - also on my committee - allowed free access to equipment and sites, and the ability to spend work time on this research. Dr. William F. Hanna of the U. S. Geological Survey - also on the committee - lent considerable time and expertise to this work. Without his unfailing willingness to help in all kinds of weather, and his patience teach me these techniques, this thesis would never have become a reality. To Bill I owe a debt of gratitude I can never repay, and to him go my sincerest and most heartfelt thanks.

C.E. (Pete) Petrone of the National Geographic Society gave freely of his own time and experience in the spirit of learning, to him also goes many thanks. National Park Service volunteer excavators John Imlay, Bill Lindquist, Rich Richardson, Diane Chote, and George Washington University graduate student intern Laura Pilette, gave their
time to help with much of the archeological field work at Manassas - thanks guys.

The Executive Director, and Director of Archeology of the Corporation For Jefferson's Poplar Forest, Lynn Beebe, and Bill Kelso, allowed me time to finally get this thesis "over the hump."

Finally, my fellow graduate student and amour Jacqueline Hernigle gave me undying support and countless hours both in the field and editing, at the expense of her own research. Her devotion to this work is as great as my own. There is no way to verbally express my gratitude to her.
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ABSTRACT

This paper illustrates the ability of two remote sensing technologies to locate unmarked burials in historic cemeteries. The two technologies employed are ground-penetrating radar and the proton magnetometer. The discussion includes the field methods necessary to carry out a successful survey. Optimum survey conditions and soil types are addressed, interjecting some problems that may be encountered using either technique. The research presented in this paper illustrates that both radar and the magnetometer can locate unmarked graves in less than the "best" soil conditions.

Finally a methodology of soil coring to locate the actual grave material, and subsequent archeological trenching to uncover part of a graveshaft is defined.

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REDISCOVERING THE DEAD

Practical Applications of Remote Sensing In Historic Cemeteries
Over the last 20 years remote sensing has played an increasing role in archeological surveying. The National Park Service alone has published at least 12 handbooks on the use of remote sensing in archeology. When one thinks of remote sensing, aerial photographs and infra-red images come to mind. Aerial photos were the first modern methods of remotely locating sites (Parrington 1983:106). Today, remote sensing has blossomed into a field in its own right, ranging from satellite imaging of sites to locating individual artifacts. Some of these methods stem from instruments developed for astronomical and general public use. Many of the other methods of remote sensing have been borrowed from geophysics.

A survey of the literature shows that there has been some lag time between the invention of remote sensing instruments and their adaptation for archeological purposes. The lag time has been mostly due to the lack of sensitivity in the original devices, but also archeologists are
unfamiliar with the capabilities of newly introduced instruments. An example is the magnetometer. The first magnetometer was invented in 1874 (Parasnis 1972:3); however, the first archeological application was not until 1957 (Weymouth 1976:192). Turning radar waves from the sky to the ground did not happen until 1974, when the National Park Service used ground-penetrating radar at Chaco Canyon (Vickers et al. 1976:86; Weymouth 1986a:376). Radar had been in aerial use since World War II. These last two methods of remote sensing are the focus of this study.

Remote Sensing of Historic Burials

This thesis will discuss ground-penetrating radar (GPR) and the proton precession magnetometer, illustrating their ability to locate unmarked graves in two historic cemeteries. The field testing was designed to answer several questions concerning the efficiency of these two methods in archeological contexts. The first question is how well radar and the magnetometer locate unmarked graves in two cemeteries with very different soil types. The second question is how closely the anomalies located by each method correspond to each other. The third question concerns the economical efficiency of the two methods, considering the cost differences, success, and ease of use.
Finally, a technique for rapidly and non-invasively identifying the detected anomalies was conducted to determine if the remote sensing procedures actually located any unmarked graves. This anomaly testing methodology consisted of soil coring with a one inch-diameter coring tool at six inch-intervals in areas suspected to contain grave shafts. The coring tool can be used to a depth of three feet, in one foot sections. In that depth, either natural stratigraphy or a single layer of disturbed soil, indicating an unmarked grave, should be seen. At one of the sites, the topsoil was removed from over several of the anomalies located by remote sensing and coring for visual verification. This last step was only possible at one cemetery. The descendants of those buried in the second cemetery do not want the soil above the graveshafts disturbed.

The cemeteries studied are on National Park Service property in the Washington D.C. area. The first is the Ball Family Cemetery at Manassas National Battlefield Park, Manassas, Virginia. The second is the Marshall Family Cemetery at Marshall Hall in Piscataway Park, Maryland. These two sites have very different soil types. The Manassas soil is Piedmont silty clay. Manassas sits in a Triassic basin within sight of the Blue Ridge Mountains (Ries and Somers 1917:17). The soil at Marshall Hall is
Coastal Plain sand and unconsolidated gravels (Hershberger and Compy 1948:189).

The motivation for attempting this study is to develop a procedure for locating historic burials other than by using standard archeological methods. Excavating is, of course, the only absolute method of locating archeological features. However, remote sensing as suggested here, will show that archeologists can narrow the scope of their investigations, and with less time and expense locate unmarked graves. This research is timely because in the rapidly developing areas of the country, large cemeteries are being moved and small ones accidentally destroyed. Many small family cemeteries from the eighteenth and nineteenth centuries have local traditions insisting that unmarked burials lie there. This is the case for both cemeteries discussed in this thesis. The procedures presented here demonstrate a way to identify unmarked graves that may go unnoticed in a cemetery removal.

The remainder of Chapter I discusses research done on historic cemeteries for paleopathological or osteological purposes. Chapter II is a brief look at the history of the two cemeteries studied for this thesis. Chapter III is a general remote sensing discussion with a more in-depth look at ground-penetrating radar and the proton magnetometer. Chapter IV is a review of remote sensing surveys at other
cemeteries and the success of the applied techniques. The fifth chapter reviews in detail the field methodology used to survey the cemeteries for this research. The sixth and final chapter is an analysis of the information presented in Chapter V and an effort to answer the questions stated in Chapter I.

CEMETERY RESEARCH

The exhumation or exposing of human remains allows archeologists an opportunity to study a part of the past not available to any other discipline. Many people outside the field question the necessity of studying remains of the dead, especially ones we know from historic documents. Even within anthropology, and its subfield of archeology, there has been some discussion on the value of examining human remains. In 1976 there was a conference held at Oxford University to discuss the relationship of archeology to anthropology and the areas of mutual interest (Spriggs 1977). One of the papers in Sprigg's book deals with burials as an area that both the anthropologist and the archeologist can learn from (Chapman 1977). Chapman argued that residence patterns, trade networks, religious beliefs, status, economic rank and burial practices are cultural phenomena that can all be discerned by studying graves. The
fact that an archeologist felt compelled to write such a paper illustrates the desire of practitioners to impart the information they feel is valuable to other students of culture. It also shows that, in Britain anyway, even anthropologists needed to be convinced that archeological investigation of burials can teach us about past cultures.

Since the 1960s, the study of human remains, osteology, has become a science in its own right (Buikstra and Cook 1980). Discussions about osteology can be found in a number of introductory texts to anthropology and archeology (Hester, Heizer, Graham 1975; Joukowsky 1980; Nelson and Jurmain 1982). These general text books offer a brief look at what the field of osteology investigates.

The basic information that studying human remains imparts to osteologists are sex, age at death, stature, basic health, and race. This information gained from several individuals in a cemetery usually allows the investigator to make some conclusions about the general population represented in the burial ground. Based on percentages of males to females and their ages at death, a mortality rate for both sexes and the group as a whole can be ascertained.

Researchers use much of this scientific data to glean more anthropological information from cemeteries as Rathbun suggests:
Scientific analysis of human remains can help document the structure of the group, reflect subsistence activities, illustrate cultural change processes through demography and pathology, and record the interaction of cultural and biological factors of human development (Rathbun 1989:1).

The fundamental group that an osteologist studies is the population, which is usually done through analyzing a sample of individuals. A single individual never provides enough data to make any kind of statement about the larger group. In fact, five is the smallest group that can be treated as statistically valid (Rathbun 1989:6).

The general health of a population is studied through the human remains in an area of research called paleopathology. Paleopathologists analyze the bones for evidence of disease pathogens. Direct evidence of some pathogens does not manifest itself on bones; however, growth arrest lines, or "Harris Lines" may appear as a result of a disease. Physical stress from famine conditions and malnutrition can be represented on the bones as Harris Lines as well. Comparisons of Harris Lines between the different sexes of a population has led some scholars to theorize differential treatment of males and females at different ages. If one gender shows less growth stunting there is a real possibility that those individuals were healthier for some cultural reason, possibly the status of that particular sex (Lane and Sublette 1972).
In addition to the Harris Lines, the stature of individuals has been used to determine the relative social status of individuals. It is generally assumed that the taller and less stressed skeletons are the remains of higher status individuals. It is also presumed that skeletons having evidence of stress and physical labor are the working class of the population. The stature also ties in with the general health of individuals and the group. Those people whose bones indicate inadequate diet, physical stress, and short stature are classified as the lower socio-economic classes of the society.

Beyond the general information gained from skeletal remains, several very specific investigative techniques are used by osteologists. Two of the most advanced of these is the analysis of trace elements and radiocarbon isotopes from the bones (Buikstra and Cook 1980). The elements and isotopes indicate the type of diet and the intake of various nutrients of the deceased. This information again can lead to conclusions about the status of individuals within a population.

Another example of a very specific analytical technique was recently published in the *Journal of Archaeological Science*. The article discusses erosion of the auditory bones, the ossicles, and its relation to leprosy (Bruintjes 1990). The author studied bones of individuals from a leper
cemetery in Chichester, England. He contends that the auditory bones are typically neglected in osteological studies. The fact that a majority of the auditory bones showed an erosion of the incus led him to conclude that leprosy caused the deformation. He also stresses that future studies of human remains should include a more detailed analysis of the auditory bones.

Many anthropological questions can be answered simply by studying the relationship and contexts of burials. Probably the most common anthropological method is demography (Lane and Sublett 1972; Buikstra 1981). The osteologist who attempts to determine something as complex as the total size of a group, the residence pattern, and the mortality rate must take into account the sample size, amount of bone preservation, and the archeological sampling techniques. Demographic studies are usually carried out on prehistoric populations because historic cemeteries generally have interment registers or at the very least headstones. In cases where the cemetery does not have any documentation of its own, board of health records may be used.

One of the more recent popular anthropological goals of cemetery studies is ethnicity and acculturation, particularly with reference to blacks in the American colonial period (Parrington and Wideman 1986; Parrington
1987). A number of supposed "African survivals" were noted by excavators at the First African Baptist Church cemetery, operated between 1824 to 1842, in Philadelphia (Parrington and Wideman 1986:55). Among the survivals were artifacts buried with the person in the coffin, such as a shoe on top of the coffin, and atypical positions of the deceased within the coffin.

Artifacts found within the coffins were dishes and coins. The dishes could have had a myriad of functions. Dishes with deceased have been noted in graves of white people as well (Fremmer 1973). It is possible that this was a borrowed tradition from whites or possibly one that whites had borrowed from blacks. Coins within the coffin have been interpreted as payment for carrying the dead to the afterworld, or to keep the dead from haunting the living. Coins within graves are well documented occurrences in the Greek civilization, as they represented payment for ferrying the dead over the River Styx into the hereafter (Parrington and Wideman 1986:61). Whatever the reason for the artifacts, it is certain that they represent acculturation to some degree.

Placing a shoe on top of the coffin has been interpreted as a symbol of power, as a good luck charm, or to stumble the dead so they cannot haunt the living (Parrington and Wideman 1986:61). These interpretations are based on folk beliefs and traditions known from ethnographic
evidence. As with the plates and coins, shoes within the context of a black person's grave is explained in several ways, yet always seen as a holdover of African customs.

The all-black congregation at the Philadelphia church took part in an organized western Christian religion. One important aspect of this religion can be seen in the burial practices. Placing the body in an east-west alignment has always been an integral part of an honorable Christian burial. Any difference in the position of the person within the coffin has been interpreted in various ways, not the least of which is simple slouching of the body during transit to the graveyard. Excavators found one body in a semi-prone position at the Philadelphia cemetery. Other researchers apparently have explained the same type of positioning as persons with supernatural power. Folklore suggests that the prone position indicates a murder victim and the position is to keep him from bothering the living. As one can see there are a number of suggested reasons for each of the so-called African survivals uncovered in cemeteries. Whatever the real reasons are, it is reasonably certain that the various burial practices indicate the process of acculturation in action.

Fraser Neiman (1980) in his discussion of the graves discovered at the Clifts Plantation theorizes that there are African burial custom survivals there. Thirteen graves were
discovered, four white and nine black. Three black males were interred in clothes and all the rest were in coffins and shrouds. The use of coffin and shroud was apparently the European burial custom of the early seventeenth century in Virginia. Neiman also mentions that the general nutrition of the group was poor. A high incidence of tooth decay for the group indicated a lack of meat in their diet. Since none of the people met violent deaths and the average age was 32, malaria and dysentery were blamed as the causes of their demise.

A case of attempting to answer more historical oriented questions through the use of osteological techniques is presented for the remains excavated at the Santa Barbara Presidio Chapel (Costello and Walker 1987). In this paper the authors state that the main goal of analyzing the remains of three persons was to identify them as to their sex, age and most importantly their racial affinity. There were four races known to be represented at the Presidio Chapel. Certain races of people have been shown to statistically manifest a known range of measurements in specific bones. Knowing first the sex and age of the person and accounting for those variables, measurements falling within particular ranges categorize the individual to a race. This analysis was performed on the bones from the Presidio. With that information the researchers could
assign a name to the person with the aid of the Presidio documents. A bonus of this project was the identification of burial practices among the upper-class Spanish inhabitants of the area. One of the graves contained a female who was interred with several pieces of jewelry and fine clothing.

Mortuary practices and the artifacts associated with them have been studied and class status has been ascribed to certain artifacts. However, a recent study of a pauper cemetery in Uxbridge, Massachusetts, has demonstrated that coffin hardware normally associated with high status can also be found with the destitute poor (Bell 1990). The main contention of this paper is that most archeological studies of cemeteries assume certain hierarchies of status and do not take into consideration broad popular cultural phenomena, such as the beautification of death which occurred in the late nineteenth century. This cultural practice is displayed by the burials in the Uxbridge paupers cemetery. The town council saw fit to bury the indigent in a Christian manner with a few of the effects, but certainly not to the extent of their own cemetery, which according to the author was a "veritable statuary garden" (Bell 1990:72). The poor received coffins with a few of the hardware items that were easily available at the time. The archeologically recovered hinges and handles were mass produced and
inexpensive. Therefore, Bell concludes that future studies of cemeteries should not look upon these types of items as indicators of high status, but that other factors concerning the presence of coffin hardware must be considered.

Many studies have been conducted on cemeteries or on human remains to answer basic historical questions. A skull reported to be Mozart's was recently analyzed by a French pathologist to determine if indeed the skull belonged to the great composer (Bahn 1991). Similar historical considerations are reported by Logan and Tuck (1990). They unearthed a Basque cemetery in Canada that has yielded clues concerning the type of clothing worn by sixteenth-century whalers who plied their trade along the Canadian coast.

A summary of reports on excavations at historic cemeteries compiled by Robert W. Mann of the Department of Anthropology, Smithsonian Institution, reveals some insight into the questions paleopathologists and physical anthropologists are asking about human remains (Mann 1990). Of the 53 reports listed, 39 discussed goals, and of those only 10 were interested in merely identifying the deceased. A majority of the other reports were interested in the health of the group studied. Many others discussed anthropological questions such as burial practices, status, and occupational stress exhibited in the bones. Several reports stated goals of determining diseases and/or the
status of individuals. Only three of the reports were interested in just the basics of age, sex, and race determinations. The high quality of reports, including those done on limited time and budgets, is due to an increased awareness among archeologists and osteologists of the value of their respective endeavors and a willingness to work together. The field of anthropology and its subdiscipline of archeology, in conjunction with the osteologist and paleopathologist, have come a long way in the 15 years since Chapman defended the archeological perspective on human remains.
CHAPTER II

THE FAMILY CEMETERY HISTORIES

History of The Ball Family Cemetery

The Ball Family Cemetery sits on land with a rich history reaching back to Colonial Virginia. Originally part of the Carter family's vast landholdings, the property passed through several generations of Virginia elite (see figure 1), to eventually be bloodied during the Civil War. It was these events that led the Federal Government to purchase the land for Manassas National Battlefield Park in 1985.

Robert "King" Carter served as a land agent in the colony of Virginia from 1703 to 1712, and again from 1722 to 1728 (Parker and Hernigle 1990:9). In that capacity, he managed to acquire a large amount of acreage in the colony. In 1724, one of the parcels King Carter patented was a piece of property called the Lower Bull Run Tract. The patent was given to his son Robert Carter II. His tract included 6,030 acres of land in Virginia's Piedmont.

Robert Carter II died in 1732, leaving behind one son and one daughter. Robert Carter III inherited 40,000 acres
from his father. Within several months he inherited another 30,000 acres from his grandfather King Carter. However, when his father and grandfather died, Robert Carter III was still a minor. His inheritance was held in trust by his three uncles, John, Charles, and Landon Carter. For two years after his majority Robert Carter III lived in London, while his stepfather John Lewis managed his property.

When he returned from London in 1751, Robert Carter III was a wealthy young man. Known as "Councillor" Carter, he controlled 70,000 acres and over 100 slaves. He managed 16 plantations averaging 1,000 acres, 23 slaves, and 15 dependencies (Parker and Hernigle 1990:11). The rest of his land was in tenancy. This method of land use applied to the Lower Bull Run Tract. Tenancy divided the land into small parcels which were then leased for varying periods of time. The terms of the lease were rigid and required that within three years the tenants build:

...A good dwelling house twenty feet by sixteen feet and a house thirty two feet by twenty feet as good as the common tobacco houses, and plant fifty apple trees and fifty peach trees and the same enclose with a lawful fence... (Prince William County Deed Book Q:447).

Along with his landholdings Councillor Carter managed interests in the Baltimore Iron Works, textile manufacture, grain mills, bakeries, and salt production. The goods produced by Carter's various operations were used to furnish
the plantations, but were also sent to the local market for commercial profit (Parker and Hernigle 1990:11).

Councillor Carter also found the time to father 17 children by his wife Frances Anne Tasker. From their marriage in 1754, until her death in 1787, they had 13 daughters and four sons. Only 10 of those 17 children lived to their majority.

By 1793, Councillor Carter was aging and the management of his large estate had probably become taxing to him. He retired to Baltimore that year and began arranging for his 10 children to take over management of his lands. He divided his landholdings and other ventures into 10 equal parts. Then in 1798, each of his children chose their shares, and paid their father a yearly rent. However, the children did not become legal owners of each share until Councillor died in 1804.

The Lower Bull Run Tract was then divided between several of the Councillor's children. However, George Carter the only surviving son held 1,000 acres of the tract, including the acreage this study is concerned with. George leased out the property while he lived at Oatlands in Loudon County. George's sister Elizabeth Landon Carter moved onto the property in May of 1799. She brought with her Spencer Ball, her husband of 11 years. Spencer Ball had been a Justice of the Peace in Westmoreland and Prince William
Counties. As such, he had occasionally managed legal matters for the Carter family.

Although part of the acreage was in a lease agreement through George, Spencer and Elizabeth Ball established a home. By 1802, the Ball plantation had become known as "Pohoke" (Davis 1802:52). However, Spencer did not actually purchase the land until 1811. In that year, Spencer Ball acquired the 762 acres that had become his home (Prince William County Deed Book 4 Role 9:387). He apparently did well financially and, in 1820, completed a new house for his family. The new house is believed to have had several damaging fires, and this twist of fate may have caused Spencer to rename his plantation "Portici." The name apparently came from an Italian village at the base of Mount Vesuvius, which also experienced the ravages of several fires. As for Pohoke, it simply was incorporated into the new Portici plantation.

The year 1831 is an important one for this study. Spencer Ball died in that year, and his is the earliest marked interment in the Ball Family Cemetery today. Spencer left all his land and possessions, except six slaves, to his wife, Elizabeth Landon Carter Ball. The six slaves went to his surviving children, one each (Prince William County Court Records, Will Book M. N. R:21).
In 1842, Elizabeth Ball died and was buried beside her husband Spencer. At her death, Elizabeth had only one surviving son, Alfred Ball. He inherited the entire 762 acre Portici plantation. Elizabeth's slaves were then divided between Alfred and his four sisters.

Alfred Ball was apparently a good business man, for he increased the size of his plantation to 1,022 acres by 1849. He also managed several thousand acres in the surrounding counties of Fairfax, Loudon, and Fauquier. Portici was in Prince William County.

Alfred married Sarah Caroline Carter and the couple settled in at Portici. However, Sarah and Alfred did not have any children when Alfred died in 1853. Consequently, the plantation was divided into parcels between Sarah and Alfred's four sisters. Sarah received the house, 350 acres, and the family cemetery, which at this time contained at least four interments: Spencer Ball, Elizabeth Ball, their child Francis Ball, and Alfred Ball. After Alfred's death, Sarah apparently sold her portion of the land to Alfred's oldest sister, Frances Tasker Ball Lewis, and moved away. Sarah died in 1875 and was buried beside her husband. Hers is the latest marked interment in the cemetery today.

Frances Tasker Ball Lewis' eldest son was Frank Lewis, and the next person to live at Portici. Frank Lewis had made his fortune as a mule train driver in the California
gold fields. When he returned from California, he married Frances "Fannie" Adeline Stuart. Frank Lewis bought Portici from his mother in 1855, and he soon moved in with his wife Fannie. Frank turned himself to the task of piecing back together the land of Portici. He did so by purchasing all the land his aunts had inherited from Alfred Ball. By 1859, Frank must have attained his goal for he owned 769 acres that made up Portici.

The year 1861 was pivotal for the house and land of Portici plantation. On or about July 21, Frank and Fannie Lewis were forced to abandon their home. The Confederate Army had notified the Lewises of the imminent Battle of First Manassas, and the fact that their house was in danger. Fannie therefore moved her family to her father's home of "Snow Hill."

Portici commanded high ground which allowed views of the battle and the town of Manassas; consequently, Confederate General Joseph E. Johnston set up his headquarters in the house. Johnston was the commanding General of the Armies of the Shenandoah and Potomac. During both the First and Second Battles of Manassas, troops from both armies were either positioned near or camped on Portici's land. Sometime after March 1863, the house of Portici was burned to the ground.
Frank and Frances Lewis moved back to Portici after the Civil War to begin rebuilding their lives and home. Unfortunately, the next house, Portici II, suffered the fate of the first, and burned. The hardship of losing slave labor and his home to fire probably forced Frank Lewis to sell portions of his land. By 1896, Frank had sold 396 acres of Portici (Parker and Hernigle 1990:26). Three years later Frances died, leaving Frank with one daughter and two sons at home to farm the remaining acreage.

Frank Lewis died in 1913, and bequeathed his home with 75 acres to son Robert Lee Lewis. Sixty more acres went to Frank's grandchildren by his deceased daughters, 110 acres went to eldest daughter Fannie Tasker Lewis, and the rest was split between son Warner Lewis and daughter Rosa Lewis.

Robert Lee Lewis bought back 50 acres that had gone to his sister's children, and also some of his brother Warner's inheritance. Robert Lee managed to bring back together 178 acres of Portici. At his death in 1938, Lewis left 168 acres to his son Robert Lee Lewis Jr., and 10 acres to daughter Janice. Robert Lee Lewis Jr. bought back the 10 acres given to Janice, thereby keeping his father's farm intact. However, in 1950, bad health forced Robert Lewis II to sell his home and property to William Wheeler. This was the first time in 226 years that the land of Portici was not owned by the family. William Wheeler owned the property for
26 years before selling it to the National Park Foundation in 1976.

Recognizing the long history and events of the Civil War which took place on this land, the National Park Foundation held the property until the National Park Service could secure funds to buy the tract. That occurred in 1985, when the National Park Service added the land of Portici, Pohoke, and the Ball Family Cemetery to Manassas National Battlefield Park.

The Cemetery

The Ball Family Cemetery is enclosed by a fieldstone wall approximately 40 feet by 30 feet, and three feet high. The cemetery sits on a small ridge approximately one quarter of a mile west of the site of Portici and 100 feet west of the site of Pohoke. There are five marked interments, all members of the Ball Family, none of the Carters or Lewises. The five people in order of burial are: Spencer Ball - 1832, Francis Waring Ball - 1835, Elizabeth Landon Carter Ball - 1842, Alfred Ball - 1853, and Sarah Ball - 1875.

The graves are marked with both headstones and footstones of white quartzite. The headstones face away from the footstones. They have been turned around so that visitors to the cemetery can read the stones without going
inside the walls. This work was done by the National Park Service to minimize traffic inside the cemetery. The five stones are lined up on an axis running west-northwest and east-southeast.

In addition to the five engraved markers, there are unmarked sandstone fieldstones intermittently placed inside the walls (Figure 3). The fieldstones may mark other interments. A large Hackberry Tree in the northeast corner of the cemetery has encompassed one of these fieldstones. Another tree sits in the northeast quadrant of the walled-in area, very near Francis Waring Ball's headstone. The roots from this tree have grown into the disturbed soil of the graveshaft. A tree stump sits at the very northeast corner inside the walls. One final physical aspect of the cemetery is the presence of groundhog burrows throughout the area. The burrows have undoubtedly extended into the graveshafts in many cases.

According to local tradition, there are more interments in the cemetery than the five marked with engraved headstones. The last Lewis to own the property knew of no other burials however, and his memory stretches to about 1900 (Conner 1981:141). The other possible interments may be marked by the fieldstones previously mentioned, or the markers may be missing. The other interments could be family members or slaves owned by the Ball family.
Research on the family documents shows that two children of Elizabeth and Spencer Ball died while they were living on the property. A daughter named Elizabeth died in 1801 and a son named Churchill died in 1802 (Ball Family Bible). At that time the Balls were living at Pohoke, which is near the cemetery. One of their other children, Francis was buried in the cemetery in 1835. It is possible that Elizabeth and Churchill are also buried there. Spencer and Elizabeth may have wanted their deceased children close to the house of Pohoke.

A later document states that the remains of 16 Civil War soldiers were buried in the Ball Family Cemetery in this century. According to a letter dated February 1936, a local farmer had previously unearthed the bones of the soldiers and reburied them himself (Hanson 1936:2). The letter states that this event occurred early in this century, probably sometime well before the letter date of 1936.

The History of Marshall Hall

What we see today as the Marshall Hall property started as a small land patent by Thomas Marshall I in 1727 (Hughes and Hughes 1985:1). The patent was named "Mistake". He did so because the 66 acre parcel of land had been missed by other land patents on either side of the tract. This was a
common occurrence in the 18th century. Surveying techniques were not highly sophisticated and parcel boundaries often ran ambiguous lines. More evidence of this is that the Marshall Family (see figure 2) was to later add another nine and three-quarter acres to this original patent, for fear that their home, "Marshall Hall", did not sit fully on their property. That acreage was patented as "Addition to Mistake" (Hughes and Hughes 1985:1).

Thomas Marshall's original patent was a humble start for what eventually became a large and prosperous Maryland Tidewater plantation. Thomas was the second son in his family, thereby making his inheritance from his father rather small in comparison to his older brother. In December of 1726, at age 32, Thomas Marshall married the widow Elizabeth Stoddert (Hughes and Hughes 1985:11). In so doing he gained control of Elizabeth's land inherited from her first marriage. Elizabeth's first husband was James Stoddert, a land surveyor in Prince Georges County, Maryland. It was through this acquisition of land and the patent of Mistake that Thomas Marshall began building his estate.

Thomas Marshall I eventually amassed over 1,300 acres in Prince Georges and Charles County, Maryland. The majority of his land was in Prince Georges County, but a boundary shift in 1748, put much of his property, including
the house, in Charles County (Hughes and Hughes 1985:12). Thomas also purchased land in Fairfax County, Virginia, across the Potomac River from his home.

Thomas Marshall I is credited as the man who built the manor house called Marshall Hall. However, records are unclear as to exactly when the manor was built. It probably was constructed sometime between the patent date of 1727, and Marshall's death in 1759. Marshall is also the first person buried in the family cemetery.

In 1768, Thomas Hanson Marshall II patented the other nine and three quarter acres as "Addition To Mistake." He probably realized that his house and father's grave were not sitting on Marshall property. The problem was rectified by the additional patent, but it is unclear exactly how the second Thomas Marshall found out about the discrepancy. New boundary surveys may have discovered the problem. As the only son of Thomas I and Elizabeth, Thomas Hanson Marshall II inherited his father's entire estate.

Thomas Marshall II continued expanding the family landholdings. Some evidence of this is found in negotiations with George Washington concerning the Fairfax County land originally bought by Thomas Marshall I. Washington wanted to buy the land that bordered his property on Dogue Creek. Thomas Marshall II would not sell, but was interested in a trade if Washington could secure land
adjoining Marshall Hall in Maryland. For various reasons the trade never took place. Finally in 1779, during the Revolution, Marshall sold the Dogue Creek property to Lund Washington, who was acting on George Washington's behalf (Hughes and Hughes 1985:12).

Thomas Marshall II married Rebeckah Dent and they had six children, three boys and three girls. Two of the boys died as children and all of the girls died in their early twenties. Only the oldest son survived to maturity. Thomas Marshall III was born in 1757, and lived in Prince Georges County till his father's death in 1801. At that time, the third Thomas Marshall inherited the family property.

Thomas Marshall III became a doctor and remained a bachelor until the age of 38. In 1795, he married 17-year-old Anne Clagett. Dr. Marshall had four children by his wife Anne. Two died, leaving two sons named Thomas Hanson Marshall IV, and Richard Henry Marshall. Dr. Marshall died in 1829, and at the age of 33 Thomas Hanson Marshall IV inherited Marshall Hall. At the time he was already married to Eleanor Ann Hardesty, and had seven children. Their oldest son was Thomas Marshall V born in 1826. Thomas Hanson IV died in 1843 intestate. In 1846, his wife Ann and three surviving children petitioned the courts to divide the estate of Thomas Hanson Marshall IV (Hughes and Hughes 1985:12). The family apparently asked for the division so
that they could sell parts of the land. There was no dispute among the family members. As a matter of fact, the three children were still minors in 1846. The oldest son received 377 acres including the manor house. The other children and their mother each received approximately equal value of the estate.

In 1850, Thomas Marshall V sold his tract and the mansion house to William Page. This was the first time someone other than a Marshall lived in the house since it had been built. William Page defaulted on his loan for the property, and the land was auctioned off in 1851. The buyer was John Augustine Washington, the great-grandnephew of George Washington. He was also the last Washington to own and live at Mount Vernon. Washington owned the Marshall land for eight years before selling it to Seaton W. Norris of Missouri in 1859. Norris, however, owned the property for only four years before selling the house and land to Henrietta Lyles Marshall, second wife of Thomas Marshall V, who had originally sold the property out of the Marshall family in 1850.

In 1863, Thomas Marshall V was a partner in the merchant firm of Blalock, Marshall, and Company. This firm owned an office in Alexandria near the docks. When the Civil War came business declined, and by 1865 the company had lost its offices in Alexandria. However, Thomas
Marshall V appears to have paid his debts by 1867, the year he sold Marshall Hall the final time. Historians have yet to determine why the family estate was sold again. This time the property left the Marshall family forever. The only portion of the land they retained is the one half acre family burial plot. Later deeds to the property note this small exception to the sale of the land.

From 1867 to 1884, the land was in private hands. However, 1884 marked a new era for Marshall Hall. Various corporations bought the house and land for profit motivations. Sightseeing excursions and an amusement park were just two uses of the property. Finally in 1975, the Federal Government purchased the property as part of the proposed George Washington Memorial Parkway. The envisioned Parkway never took shape on the Maryland side of the Potomac River. Nonetheless, the National Park Service did establish Piscataway Park to preserve the beauty of the Maryland shoreline. Marshall Hall is the southern terminus of that Park.

The Marshall Hall mansion was burned by arsonists in 1981. The National Park Service has since put up a fence around the brick skeleton of the once elegant manor house. Today, this ghost from the past sits as a quiet reminder of a piece of history that has come and gone on Maryland's Potomac shore.
The Marshall Family Cemetery

The Marshall Family cemetery sits approximately 100 yards east of the house remains. A white picket fence surrounds 18 inscribed stones that lie flat on the ground. A large deciduous tree sits in the southeast corner outside the fence. According to National Park Service publications, there is at least one more, circa 1866, burial that is not marked (Long 1983:101). Also, there is a disagreement in this document concerning the number of graves seen in this century. Long (1983:31) states that there are 24 graves, while McGarry (1983:72) states that there are 18. Eighteen is the number of graves noted in a recording of the cemetery conducted in 1923, therefore, the figure of 24 must be wrong. The last marked burial in the cemetery dates to 1852. By that time, the Marshall family had sold the manor house and most of the land, but still retained the cemetery, so it is not inconceivable that a burial was made in 1866.
CHAPTER III

REMOTE SENSING

During the past 20 years, archeologists have become increasingly familiar with, and reliant upon, a group of technologically sophisticated surveying techniques, collectively known as remote sensing. In archeology, remote sensing is defined as; locating sites or features through the acquisition, processing, and interpretation of photographs or patterns of electromagnetic and magnetostatic energy. These energies detect subsurface contrasts between the physical properties of objects and of the soils they are buried in. These physical properties include magnetic susceptibility, remanent magnetization, density, elasticity, and electrical conductivity. In the special case of subsurface voids, such as caves, tunnels, or space inside coffins, it is the contrast between subsurface air and surrounding soil or rock that is sensed. The purpose of this thesis is to discuss two such remote sensing techniques in light of their potential value to archeological surveying.
The two remote sensing methods discussed in this study, ground-penetrating radar and the proton magnetometer, permit the detection of objects, archeological features, or soil variations through the use of electromagnetic or magnetostatic energy (William Hanna, personal communication 1989). Remote sensing methods are commonly termed "passive" if no stimulus is required to detect the contrasts in physical properties of soil and objects, or "active" if some stimulus is required. For example, magnetometry is passive because no man-made stimulus is required to sense the physical property of magnetism. On the other hand, GPR is active because electromagnetic radiation is required as a stimulus to detect the physical properties of permittivity, permeability, and electrical conductivity. In this case, these physical properties are seen as depth to reflector and velocity of material above the reflector.

The magnetic method used here involves measuring the total magnetic field of the earth at a particular place and time. Radar involves sending a signal into the ground which is then reflected or refracted back and received by the instrument. Other active methods employed in archeology include seismic sounding and electromagnetic techniques; including the use of a metal detector and a conductivity meter. Other passive methods used in archeology include; the self-potential method, which senses electrochemical
effects of hidden objects or soil, and gravimetry, which senses the density or massiveness of objects or soil (William Hanna, personal communication 1989). It should be noted that the GPR or magnetic method alone will only provide partial information; used together they provide complementary information. No one remote sensing method is perfectly suited for all situations in archeology.

The following section discusses some of the remote sensing techniques that have been used for archeological purposes. Several examples of each technique will be presented and related to the detection of historic burials. Authors who conducted pioneering work and some more up-to-date research will be outlined also. This is not to be considered an exhaustive discussion of each technique or the major contributors; that large of an undertaking is outside the scope of this thesis.

Under the heading of active methods, the most widely used technique is the resistivity meter. The usefulness of this instrument to archeology has been proven in many archeological contexts (Bevan 1985; Ellwood 1990; Ralph 1969; Shapiro 1984; Weymouth and Huggins 1985; Weymouth 1986a, 1986b). In practice this instrument measures the electrical resistivity of the soil. Features are delineated because of the electrical contrast between the feature and surrounding matrix. Four probes are inserted into the
ground in line using a predetermined spacing. The outer two probes transmit an electric current and the inner two measure the resistivity over the distance. Resistivity, and conversely conductivity, are greatly influenced by soil moisture content. The more water there is in the soil the less resistance there is, as water is a very good conductor. Consequently, attempting to conduct a resistivity survey shortly after a rain, particularly in poorly drained soils, is not a good idea. Conversely, soil that is entirely dried out is not a good medium for resistivity surveys either. The other factors influencing resistivity are the type of soils present and topography. Clay soils hold more water than loams or sand. If there is quite a bit of relief to a site, that factor must be considered when interpreting the data. Topographically lower areas tend to hold more moisture. The ideal conditions for resistivity surveying are a flat area moderately moist and a homogenous soil with features containing a soil other than the background matrix.

A survey is performed over a gridded area with the spacing of the grid lines chosen to maximize the capability of the instrument in defining the features sought. Wall remains and large features will be more readily apparent in the data. Small pits or ditches are harder to define and will require a tighter grid spacing.
A group of remote sensing practitioners emerged from the Museum Applied Science Center for Archeology (MASCA) at the University of Pennsylvania in the 1960s. This group conducted numerous surveys with different instruments all over the world. One of their more successful surveys was at Ile-aux-Noix, Canada. There the MASCA teams located portions of historic Fort Lennox (Ralph 1964). The resistivity meter was found to be better than a magnetometer at defining the outlines of buildings. They tested two types of magnetometers at the site; a proton precession model and a rubidium vapor model. The rubidium magnetometer is nearly 100 times more sensitive than a proton magnetometer (Ralph 1964).

Also in Canada, the MASCA group located graves at Fort Louisbourg, Nova Scotia. There the resistivity meter was not as precise as a magnetometer in locating graves. Ralph attributed the problem to the closeness of bedrock at the site. This last study points out the very important need for field researchers to understand the soils and underlying geology of a site before undertaking a survey.

Gary Shapiro of the University of Florida conducted a resistivity survey on the site of sixteenth-century Puerto Real in Haiti (Shapiro 1984). The moist clays at that site provided a low background resistivity. Potentially, low background resistance is helpful when searching for
buildings which are highly electrically resistive. Shapiro discovered that the technique worked very well at the site, locating two buildings, one already known and the other previously unknown. The anomalies were so well defined that it allowed test excavations as small two meters square to follow lengthy features.

John Weymouth of the University of Nebraska in cooperation with the National Park Service conducted resistivity surveys on a number of historic Indian village sites in Nebraska (Weymouth and Huggins 1985; Weymouth 1986a, 1986b). There, the resistivity meter was helpful in locating individual earth lodge circles, as well as possible livestock pens. The various features within the village were defined by the survey as a result of activities in the past. Refuse middens were located because those areas are deep with organic debris.

In Northeast Texas two historic cemeteries were studied with a Williams resistivity meter (Ellwood 1990). The first was a known cemetery with marked graves. That site was examined to test if the meter could locate burials in known locations. If the results of that test were positive the technique would be tried on a cemetery with unmarked graves. Not surprisingly, several graves were correctly interpreted at the first site, so the second cemetery was studied. As it turned out the researchers located six unmarked burials.
As can be seen from this section, the electrical resistivity technique is a valuable archeological reconnaissance tool. However, it must be clearly understood that this instrument may not work on all sites. The variables mentioned above must be considered before undertaking any field work. The examples listed above were all highly successful field campaigns. There may be just as many instances where resistivity did not work on a site. It is always possible that one of the other remote sensing techniques may work better than resistivity at any given site.

Under the heading of active methods is a technique that works on the same principle as resistivity, but measures the converse, electrical conductivity. A conductivity meter (or simply EM) measures how conducive the ground is to an electric current. Archeological features can be located with the electrical conductivity meter because of the electrical contrast between the feature and the surrounding soil. The meter is a simple instrument that is carried by a single person. It consists of two coils mounted horizontally on a pole at a preset distance. The pole is held parallel to the ground and moved over the site at a walking pace while measurements are taken. The prearranged distance for measurements is decided upon weighing several factors. The size and shape of the features sought, much
like the resistivity and magnetic techniques, requires planning ahead.

The EM does not appear to be as popular a prospecting device as either magnetics or resistivity, but several articles do appear in the literature. Bruce Bevan has conducted a number of EM surveys on historic sites. At Fort de Chartres, Illinois, Bevan used the EM to discover the location of a backfilled fortification ditch in front of the fort (Bevan 1983). The feature was discernible because of chemical reactions in the soil directly below the infill. Chemical reactions can occur at interfaces such as this one when water seeps through non-compacted material. The actual fill material was stone and less electrically conducive than the surrounding soil. Bevan also used a conductivity meter at the Plains - Sothoron Family Cemetery. He states that the measurements derived from one transect run with the conductivity meter did not add anything to the magnetic information. Mostly the instrument was employed as a backup to the magnetic data. However, that in itself illustrates the usefulness of the instrument.

The French have been very instrumental in the development of the conductivity meter. A group from the Center of Geophysical Research in Garchy, France, headed by A. Tabbaugh, have developed a conductivity meter coupled to an optically-pumped magnetometer (Tabbaugh, Boussuet, and
Becker 1988). This combination of instruments allows the measurement of two different aspects of the soil and provides complimentary information. The instrument has the capability to make rapid measurements, which is quite an advantage over the resistivity meter in that respect. The results obtained from the tests suggest that the greatest contribution was the ability to detect the magnetic susceptibility of the soil. The features they hoped to precisely locate are a group of ditches marking a Neolithic Ring in Bavaria. This feature is quite a bit larger than a historic grave, yet the creation and filling of it are fairly similar. The authors stated however, that the advantages of the instrument were not fully realized in this experiment. Apparently the resistivity is very low in the region and the magnetic susceptibility is high. Bevan has also pointed out other advantages of the EM method. It is much faster than resistivity, it can be used in brushy areas, or operated over any soil type, even asphalt.

The last method that will be discussed under the category of active techniques is the metal detector. This instrument has generally been viewed as the bane of archeologists. However, some practitioners have come to see the metal detector as a valuable tool as long as it is used properly.
The metal detector operates on much the same principle as the EM. A coil inside the head sets up an electromagnetic field. This field is changed when it encounters a conductive object. Some metals conduct at different frequencies than others, and that is how the detector can distinguish between materials.

Probably the best known application of the metal detector to an archeological site is the 1984 survey conducted at Custer Battlefield by National Park Service archeologists (Scott and Fox 1986). The success of that project was not based on the fact that the instrument located artifacts from the battle, but on the precise plotting of them. The ability of the archeologists to interpret their information properly has been the reason other archeologists view the metal detector in a new light. The use of any remote sensing technique requires the field researchers to properly interpret their data for the information to be useful to archeology. This aspect will be pointed out again in the discussion on ground penetrating radar.

Only one passive technique of remote sensing, aerial photography, will be reviewed. As an archeological reconnaissance tool, photography has been used since the early decades of this century. Aerial photographs from World War I were noticed to have soil or crop marks that are
of archeological interest. The British are probably the best known for their work in this area. The first known account of archeological sites being recorded from the air was a publication titled *Wessex from the Air* in 1928 (Parrington 1983:108). Many Medieval and Roman towns were recorded by the changes they create in the crops growing above them. The plants above former streets or buildings tend to have shallower roots and the growth is stunted. The surrounding plant growth normally, creates a contrast easily seen from the air. Since that first publication on cropmarks, many studies have been done to understand the circumstances that create cropmarks in different plants and at various moisture levels (Parrington 1983:109). In this country early use of aerial photography was made by Charles Lindberg in 1929, on several pueblo sites in the Southwest (Lyons 1976).

The United States National Park Service has published a number of monographs and bulletins devoted entirely to aerial remote sensing, and many of them are regionally specific (Lyons and Avery 1977). In addition to black and white pictures there is infrared photography, the value of which is in the ability to detect very subtle differences in soil or plant moisture that is not observed in black and white photos. This method of photography has been used archeologically for nearly 20 years. The highway
departments of many states take infrared photos, and these can be purchased by archeologists (William Kelso, personal communication 1990).

Recently published information from Great Britain has revealed new features on Medieval and Roman sites that had not been visible before (Griffith 1990). The new features and even new sites were noticed because of the drought of 1989. Aerial photography has proven very useful in locating large sites, but its potential for historic graves is low. This is not to say that the technique has not located individual graves; it has in England (Parrington 1983:106). However, other techniques of remote sensing have proven to locate burials much more effectively.

**Magnetic Detection**

The magnetometer was originally designed for geologic studies. As such, the instrument is intended to detect the spatial changes in the earth's magnetic field due to the geologic structure. The structure is deduced from both the geometry of the rock body, and the magnetization of the body. Geologic anomalies tend to be larger and stronger than archeological anomalies, but the geologic substructure must be considered when planning to conduct a magnetic archeological survey. Fortunately, in the areas of the
present study, there is little geologically-produced magnetic disturbance having wavelengths as small as those attributed to archeological features (William Hanna, personal communication 1989). While conducting magnetic surveys, it is also necessary to consider magnetic disturbances associated with power lines, fences, radio towers, automobiles, and pipe lines. These features can adversely affect the magnetometer survey data, making it important to either avoid them, or to correct for them when processing the data.

This section discusses what the magnetometer is detecting, which necessitates defining a few terms used in geophysics. These geophysical terms have been limited to those needed by an archeologist. The proton precession magnetometer, or simply the proton magnetometer, is a total-field magnetometer, that detects all the combined effects of the earth's field at a particular place and time. The earth's geomagnetic field may be considered as being composed of three parts:

1) The main field, which is of internal origin and varies slowly through time, presumably caused by electrical currents flowing in the earth's core.
2) The external field, which is small relative to the main field. It varies rapidly, part cyclically, and part
randomly. Its origin is electrical currents in the atmosphere.

3) An internal field, smaller than the main field, which is caused by contrasts of magnetization in the earth's crust and uppermost mantle.

The source of the main field is known only theoretically, and it is thought to be caused by movements or currents in the liquid center of the earth (Bloxam and Gubbins 1989; Hoffman 1988; Jeanloz 1983; Telford et al. 1976). This is 99 percent of the geomagnetic field. The main field has been studied for centuries. As a result, researchers are aware of magnetic shifts. The declination of magnetic north from geographic north has been known to shift as much as 35 degrees in a relatively short period of time (Telford et al. 1976:117). These observed changes may be regional or global in nature. Global changes which have occurred repeatedly during geologic time involve reversals of one magnetic pole to its opposite polarity, and back again. This phenomenon is manifested by the north magnetic pole shifting to the south pole and back.

Most of the remaining one percent of the geomagnetic field is the external field, which is caused by electric currents within the ionized layers of the earth's atmosphere, called the magnetosphere or ionosphere (Akasofu 1989). This part of the geomagnetic field is of concern to
archeologists because it shifts rapidly, relative to the
time required to conduct a magnetic survey. The shifts are
so rapid that the geomagnetic field must be monitored while
surveying.

The known shifts of the external field have several
causes, chief among which are:
1) An 11 year cycle connected to sunspot activity.
2) A daily diurnal variation, cycling every 24 hours, and
usually having an effect of tens of gammas. The cause is
largely due to the action of the solar wind on the
magnetosphere.
3) A lunar diurnal variation with a duration of 25 hours and
an effect of several gammas. The cause is an interaction of
the moon and the ionosphere.
4) Magnetic storms. These can last a few minutes to a few
days. The shift may be several hundred gammas which can
make magnetic surveying impractical. The cause is thought
to be related to sunspot activity.

Physics of Magnetism

Most physics textbooks classify magnetic materials as
diamagnetic, paramagnetic, or ferromagnetic. A single
material may possess any or all of these types of magnetism.
The diamagnetic property is manifested by a material feeling
a weak repulsive force when encountered by a magnetic field. The paramagnetic property is manifested by a material feeling a weak attractive force when encountered by a magnetic field. A ferromagnetic material is manifested by a material feeling a strong attractive force when encountered by a magnetic field. Ferromagnetism, therefore, is a strong form of paramagnetism.

Magnetism, such as that observed in soil, is governed by the electrons in an atom's nucleus. The traditional model involving electrons orbiting around the atom's nucleus as well as spinning about their own axes accounts for what is known as orbital and spin magnetic moments of electrons. The number and distribution of electrons in the atom will determine which type of magnetism is exhibited.

Archeological objects or soils can exhibit many basic types of magnetism as commonly defined by physicists. One simple classification suitable to archeology includes: diamagnetism, paramagnetism, ferromagnetism, and ferrimagnetism. The first two are of little or no importance to magnetic surveying, the latter two are very important. Diamagnetism is exhibited by all materials, but is too weak to be detected in most, except with the use of expensive, sophisticated laboratory equipment. One peculiar feature of diamagnetism is that this magnetism is aligned opposite to the external magnetic field that produces it.
Paramagnetism is also very weak, though somewhat stronger than diamagnetism, and is likewise measured by laboratory equipment. It occurs in materials containing at least some "magnetic" atoms having magnetic moments associated with electron motion. Thus, both iron (commonly called "ferrous") and magnetic soil minerals exhibit these weak types of magnetism.

Ferromagnetism is the predominant type of magnetism actually detected in iron or ferrous objects of archeological interest. This type of magnetism is caused by the spontaneous alignment of electron spin direction in the iron's atoms, and thus, the alignment of spin magnetic moments.

Somewhat similarly, ferrimagnetism is the type of magnetism exhibited by magnetic oxide minerals, such as magnetite, and its titanium-bearing family of magnetic minerals. This magnetism is the type predominantly detected in soil, magnetic rock, brick, and other fired materials of archeological interest. It is caused by distinct alignments of magnetic atoms or ions occupying different sites on the magnetic mineral's crystal lattice.

One especially interesting feature of ferromagnetism and ferrimagnetism is the "magnetic domain". A material, such as iron or magnetite, is subdivided into microscopic regions or domains, each having a spontaneous magnetization
of uniform magnetic direction within the domain. However, neighboring domains have different directions of magnetization. Thus, it is possible for a group of domains within the material to be randomly oriented in the absence of an external field, and to appear nonmagnetic, despite the fact that each one of the domains exhibits ferromagnetism or ferrimagnetism.

If an external magnetic field is applied to this material, the neighboring domain magnetic directions tend to line up. The stronger the external field, the more the domain magnetic directions tend to align. When the external magnetic field is removed, the domain magnetizations relax back toward their original directions - but not completely. Not being a complete shift back to the original positions causes a permanent change in the direction of the domains. This is called remanent or permanent magnetization. The accompanying phenomenon of alignment of domain directions only during the application of the external field is called the induced magnetization.

**Magnetization in Soils**

Archeological magnetic surveying is aimed at detecting the small changes in the earth's magnetic field caused by buried features. The known categories of archeological
features and materials that can be detected by a magnetometer include:

1) iron objects.
2) fired objects, such as brick, and fired structures, such as kilns, furnaces, ovens, and hearths.
3) pits and ditches filled with topsoil or organics.
4) walls, foundations, roads, and tombs.
5) areas of more intensive habitation.

Each of these archeological features can be detected because of the combination of remanent, and induced magnetization contained within iron or magnetic mineral of these features. The magnetic mineral is usually magnetite or a closely related iron oxide. This sum of remanent and induced magnetization is called total magnetization. The ratio of remanent to induced magnetization, called the Koenigsberger ratio, is denoted by the letter "Q." The Q value for an artifact made of basalt would be expected to range from about 10 to 100 because this volcanic rock generally has a stronger remanent than induced magnetization. The Q value of a wall foundation composed of granite might be expected to range from one one-hundredth to one-tenth because this rock generally has a stronger induced than remanent magnetization. However, each of these materials may generate a magnetic anomaly, regardless of whether remanent or induced magnetization prevails. In
fact, some materials, including some magnetite bearing soils, may have equal amounts of remanent and induced magnetization, and therefore, a Q value of about one.

In addition to the concepts of remanent, induced magnetization, and Q value, one other concept - magnetic susceptibility - is important to the archeologist. Magnetic susceptibility is really another way of expressing induced magnetization. Geophysicists reason that, because remanent magnetization is a physical property which is not dependent on the strength of an external field, it would be convenient to have some expression for the induced magnetization that is not dependent on the strength of an external magnetic field. Such an expression (magnetic susceptibility) is obtained by taking the ratio of induced magnetization to external field strength.

Both the magnetic susceptibility and the remanent magnetization of a feature or artifact can be measured with portable equipment in the field or laboratory. Once these quantities have been measured, the total magnetization and Q value may be computed. A soil or rock sample's magnetic susceptibility is a measure of the quantity of magnetic mineral dispersed throughout the sample. This quantity is especially valuable for classifying characteristics of features or artifacts.
Magnetic Susceptibility

Archeological features in categories three, four, and five mentioned earlier can be located magnetically because there is a susceptibility contrast between the features and the surrounding soil. Walls, foundations, and roads often have a lower susceptibility than the soil they are covered with (Tite and Mullins 1971:209). Subsoil generally has a lower susceptibility than the material backfilled into pits and ditches.

With regard to induced magnetization, it is of interest to archeologists that magnetic susceptibility can be enhanced in at least two ways, either fire or organic fermentation. The mechanisms for enhancement are iron oxides in the soil, the main ones being hematite, magnetite, and maghemite. Enhancement occurs when the weakly magnetic oxide hematite is converted to the strongly magnetic oxide maghemite. The process progresses from a reduction of hematite to magnetite, and then a reoxidation to maghemite. The susceptibility of magnetite and maghemite is roughly one hundred times that of hematite (Weymouth and Huggins 1976:342). The known catalysts for the reduction and oxidation are fire, or a fermentation of organic matter during wet and dry periods. Much of the literature on archeological magnetic surveying deals with enhancement of
soils due to fires for agriculture (Longworth and Tite 1977; Mullins 1977; Tite and Mullins 1971; Tite 1972a). When a field is cleared, for farming or habitation, the vegetation is burned off. In the fire, which is an anaerobic environment, the hematite is reduced to magnetite. After the fire, oxygen reenters the soil and the reoxidation to maghemite occurs. This process over time increases the percentage of conversion of oxides; therefore, a soil burned many times will have a greater susceptibility than a soil burned only a few times. The researchers cited previously all work in England where the soil has been farmed for hundreds or even a thousand years. This activity alone may have created magnetic changes in the soil that are not necessarily comparable to soils in North America. However, very little research has been done to study the process of enhancement on archeological sites in this country.

The fermentation process occurs where the soil conditions vary from wet to dry over a period of time. During the wet periods the organic matter in the soil decays and reduces hematite to magnetite. During the dry periods the reoxidation of magnetite to maghemite occurs. The wet period is an anaerobic condition similar to fire, and the dry period is an aerobic environment when oxygen reenters the soil as it does after a fire dies. The fermentation process takes longer than burning, but sites occupied over a
long period of time have a high susceptibility contrast between the topsoil and the subsoil (Tite 1972b:15).

Fire has generally been accepted as the most important human-induced factor of susceptibility enhancement. This is directly proportional to the length of habitation on a site. The length of habitation also determines the amount of organic material deposited in the soil that will decay and contribute to the conversion of oxides to a more magnetic form.

Susceptibility studies have shown that the degree of susceptibility enhancement is due in large part to the amount of iron oxides present in the soil, and the percentage of conversion to a more magnetic form (Mullins 1977; Tite and Mullins 1972; Tite 1972a). The amount of iron oxide in the soil is partly due to the parent material, and partly due to the weathering process. Weathering may either break down the parent material, and leave more magnetic oxides in concentration, or it may convert the oxides to a less magnetic form (Mullins 1977:239).

A final contributing factor to conversion of oxides in a particular soil is the grain size, and shape of the oxides (Tite and Mullins 1971; Mullins 1977; Longworth and Tite 1977). There is a threshold of sizes that determine whether a grain is single domain or multi-domain, which will influence how magnetic an individual grain is. The shape
also influences how magnetic a grain may be. Shape determines how close the magnetic poles of the grain are. If the poles are separated by a distance, then the susceptibility will be relatively high for that particular grain. The shape and size of an oxide grain are in turn influenced by the type of soils present, the weathering conditions, and the particular oxides present.

Clearly, the enhancement of susceptibility of soils is a complicated matter. To fully determine all the factors influencing the susceptibility of a soil is beyond the capability of most archeological laboratories. However, susceptibility measurements can be used as a general guide for the archeologist. By taking susceptibility readings of the important soils we can infer whether or not enhancement has occurred by careful analysis of the readings, and by noting the general use patterns on the site.

Remanent Magnetization

The other important magnetic property of soil, remanent magnetization, can be acquired by one or more processes; and it is detectable in a zero magnetic field. At least seven different types of remanent magnetization have been recognized, four of which concern the archeologist.
The most common remanent magnetization on historic archeological sites is thermoremanent magnetization (TRM). The archeological features mentioned previously that have TRM are iron objects, which are also ferromagnetic, and fired structures such as kilns, furnaces, ovens, and hearths which are ferrimagnetic. This is also true of features that are made of brick or tile. The remanent magnetization can easily be seen by placing a compass near a brick, and watching the displacement of the needle due to the magnetic field associated with its remanence. Thermoremanent magnetization is acquired when a material is cooled below a critical temperature called the Curie Point. When a sample of clay is fired above the Curie Point, many of the domains align themselves with the earth's magnetic field. As the newly fired brick cools, some domains return to their original position, but some stay aligned with the earth's field. The resulting net effect is at least a partial thermoremanent magnetization. It should be emphasized that the clay does not have to reach its Curie Point to acquire partial thermoremanent magnetization. Any elevated temperature will release some of the domains to align with the earth's field.

Viscous remanent magnetization (VRM) is acquired over long periods of exposure to an ambient magnetic field. Rocks or soil in a prolonged stationary position will
acquire a magnetization which intensifies as time progresses. For most materials VRM takes a very long time to be attained, although one study has shown that magnetite ores can acquire a significant amount of VRM in as little as 70 days (Sharma 1983:198).

Isothermal remanent magnetization (IRM) is a remanence acquired when a strong external field is applied for a short period of time at a constant temperature. The best known source for IRM is lightning. A lightning strike on magnetic rock may produce an IRM so intense that use of a magnetic compass is prohibited over a considerable area surrounding the strike.

Depositional remanent magnetism (DRM) is found in sediments that have been redeposited by wind or water. The sediments already having a magnetism acquired earlier (usually thermoremanent) act as tiny compass needles when suspended by air or water. When deposited, if there is a small amount of buoyancy, the sediments will align themselves with the earth's field at the time of deposition. This type of magnetism has been identified at Chaco Canyon in an irrigation feature (Loose and Lyons 1976:139). These types of sediments are probably rare on most archeological sites. Nevertheless, the possibility that they exist in certain features, such as pits and ditches, should not be overlooked.
The Proton Precession Magnetometer

The proton precession magnetometer is an instrument used in archeology, but borrowed from the field of geophysics. The first magnetometer was invented in the late nineteenth century as a device to locate iron ore in the earth. The first magnetometers were fairly simple devices and not sensitive enough for archeological purposes. That changed when the proton magnetometer was invented in 1954 (Tite 1972b:8). This instrument is a total field magnetometer, detecting the combined effects of the earth's magnetic field at a particular place and time. The instrument used in this study is an EG&G Geometrics model G-856 proton precession magnetometer. However, there are several other manufacturers of proton magnetometers whose instruments are not exactly like the G-856 described here. Some proton magnetometers are specially designed to operate underwater or in the air. Others display information in different ways. However, all proton magnetometers function the same way, and have the same basic components. There are also several other types of magnetometers available to archeologists. These other instruments operate under different principles, yet detect the same magnetic field as the proton magnetometer. The other instruments include the fluxgate magnetometer, and the optically pumped or alkali-
vapor magnetometer. As with the proton magnetometer, there is variation among the instruments by different manufacturers.

The G-856 proton magnetometer consists of two components which are connected by a power cord during operation. There is a sensor mounted on a staff or carried in a pouch on the operator's back, and a control unit carried in a harness around the neck. These two components are powered by a group of eight D-cell batteries mounted within the control unit.

The sensor is a plastic bottle with a wire coil inside submerged in a hydrocarbon fluid. The fluid may be alcohol, kerosene, water, or in this case decane. The wire coil is connected by the power cord to the control unit. The control unit is an aluminum box with electric circuits, and a face with touch pads that the user presses to operate the magnetometer.

The functioning of a proton magnetometer is based on the physics of the protons in the hydrocarbon and the influences of the earth's magnetic field. Protons are known to have a tendency to spin around the field line of a magnetic field. Certain hydrocarbons are more preferable for use than water because they are richer in protons (ie, have a greater number of protons per unit mass).
When the operator presses the READ button, an electric current is passed through the wire coil in the sensor. The electric current sets up a magnetic field. The protons immediately align parallel to the vector sum of the coil's field and the earth's field. When the current is abruptly shut off, the protons try to align themselves with the earth's field. In so doing they gyrate or precess, hence the name proton precession magnetometer. Precession is analogous to a child's top as it loses momentum and begins to wobble in a widening path. The precession of the protons then induces an electric current in the wire coil. This current is proportional to the earth's magnetic field, and is displayed in a unit of measure, called gammas, on the display of the control unit.

The gamma is a unit of measurement employed by geophysicists to express the intensity or magnitude of the earth's field. The gamma is equal to another unit of measure called the nanotesla, and these two units are used interchangeably. The earth's magnetic field ranges from about 30,000 gammas at the equator to over 60,000 gammas at the poles. The magnetic field of the geographical area in this study is about 54,000 gammas. The G-856 proton magnetometer has the ability to detect to one tenth of a gamma, but it can be set for various sensitivities. A
difference in readings of just a few gammas may indicate something of archeological importance.

The G-856, or any magnetometer, can be made more sensitive for the detection of weakly magnetic features by using a shorter sensor staff. The use of a shorter staff decreases the distance between the sensor and the material causing the magnetic field. Because the strength of the magnetic field is inversely related to the distance between magnetic material and sensor, the field strength increases. The staff that comes with the instrument can be used at two, four, six, or eight feet. A potential problem with setting the sensor close to the ground is that ferrous metal objects on or near the surface may produce fields of high gradient that cause the magnetometer to "drop the signal", which means that no reading is obtained.

Field Methods

Tite (1972:8) defines magnetic surveying as involving the detection of "...small localized changes in the intensity of the earth's magnetic field associated with buried features..." With this in mind, the archeologist has to make several decisions about the type of survey to be conducted. Several articles give good descriptions of the
variations one can choose from in conducting a survey (Weymouth and Huggins 1985; Weymouth 1986a).

Before beginning the survey, an examination of the observable archeological and geological features should be done. The size of the expected features and any possible geological disturbances need to be taken into consideration. Remembering that ferrous metal objects will affect the instrument, a sweep of the area with a metal detector should be made beforehand to remove spurious metal. The survey operator must also be clean of any magnetic material while operating the instrument.

The easiest way to prepare the site for survey is to drive wooden stakes on two sides of the area, spacing them at a predetermined grid interval. During survey a measured rope or a nonmagnetic tape measure is stretched between stakes on either side of the grid. The stakes on both sides should be numbered on top to ease the movement of the tape. The number then becomes a line reference and the stations are numbered sequentially throughout the survey.

The survey is accomplished by placing the sensor staff at the predetermined intervals over the site. If small features or weak anomalies are expected, a station distance of a few feet is necessary to detect these anomalies. Larger features usually create large anomalies. Hence, a course grid may be appropriate. An interval of no larger
than about one half the size of anticipated anomalies should be used (Weymouth 1986a 73:347).

The sensitivity of the magnetometer can either be set on the instrument, or if that option is unavailable, the sensor may be placed near the ground for each measurement. The sensor height must be chosen in relation to the type of expected features, as well as background noise from the variations in soil magnetization. The amount of noise increases as sensor height decreases. Small or weak anomalies will require a short staff. Conversely, strong anomalies, large features, or metal artifacts can be detected using a taller staff.

A base station must be chosen to observe, and correct for the diurnal variation. This should be a point near the grid area that is monitored during survey for constant change in the magnetic field. If the base is monitored with a second magnetometer, it cannot be so close that it affects the survey instrument. Yet it cannot be so distant that access or communication with the person monitoring is difficult. It is possible with the G-856 to have the magnetometer automatically cycle itself to monitor the diurnal variation. This requires a second instrument for the survey. If only one magnetometer is available, the base may be returned to after running each survey transect. During this study, a base station was monitored in several
different ways to experiment with ease in operation and reliability. These variations will be discussed in the next chapter.

Surveying simply entails setting the sensor staff on the grid station and pressing the READ button. When a reading is displayed, the operator calls out the measurement to a recorder. The G-856 magnetometer has the added ability to store survey data in solid state memory. This step is repeated at all survey stations. For clarity, all survey lines should be run in the same direction, either north-south or east-west.

Records of a survey should contain the operator's name, and recorder's name, if and when they switch positions, how the base was monitored, and direction of line runs. The readings should contain the line number, station number, or distance along the tape and the magnetic measurement. Time is recorded as each line is begun, in the middle, and at the end of each run. The time is used to correct diurnal variation with an automatic base station reading, which is synchronized with the recorder's watch, or the time recorded by the person monitoring the base station.

After the survey is finished, diurnal variation is corrected by subtracting the amount of gamma increase at the base station from each station that corresponds in time to
that increase. Conversely if the base records a decrease, that amount is added to each corresponding survey station.

**Interpretation of Magnetic Data**

A magnetometer survey initially results in nothing more than a group of numbers. To make the numerical information useful it must be presented in a way that is recognizable to the eye, but also displays some part of the raw data. This allows analytical treatment of the numbers to either discount background noise and surface metal, or to make size and depth calculations.

Several methods of displaying magnetic data have been developed over the years. Each has its own set of necessary computations, with advantages and disadvantages over other display methods. The five most common methods used are; the contour map, the dot-density plot, the grey scale plot, the profile, and line runs. Various researchers, most notably Scollar (Scollar 1969; Scollar et al. 1986), have tried each method adding their own improvements, but most archeologists agree that for archeological data the dot density plot has the best resolution, and is easiest to interpret.

The present study uses the contour map. Geophysicists have traditionally used the contour map, and this study was conducted with a great deal of input from a geophysicist of
the U.S. Geological Survey, Dr. William F. Hanna. At first glance none of the methods appeared to be better or worse than the others. However, after working exclusively with the contour map method, anomalies are readily visible. The data is easily interpreted in this format. Someone working with the dot-density plot exclusively would probably prefer that method over the contour map. It depends most on what the researcher has available and is familiar with.

Contour maps display magnetic data by drawing lines to points of equal value. The result is much like a topographic map with mountains, valleys, and plains. The contour map may be created with commercially available computer programs. One real advantage of contouring is that it displays numerical values of the contour lines with the anomalies. The numerical values allow the researcher to see the intensity of the anomaly in gammas. The depth and size of the anomaly source can then be estimated mathematically using the displayed values. The contour maps generated for this project have a second advantage over other methods. Each station is represented by a cross. With each station marked, the exact spot on the grid where an anomaly begins and ends can be located in the field. Other methods use symbols to display the data, and the addition of another symbol showing each station could confuse the observer. The contour map is very straightforward in its presentation.
However, not all contour programs are alike. Some of the contour maps presented by Scollar et al. (1986) do not display every station. Contouring will not always weigh every station's value. For example, a one gamma contour interval may consider each reading. Contouring at a two gamma or more interval will most likely estimate between values. However, one gamma contouring is not always possible because it could squeeze contour lines together. A contour interval must be chosen that presents all the data clearly. Too great an interval will not display weak anomalies, and too fine an interval will confuse the images.

Another disadvantage of contouring is that it does not have the resolution of the dot-density plot and the gray scale plot. With these methods, the anomalies are striking even to the untrained eye. The best use of these programs is for presentation to an untrained audience that does not need the added information of the contour map.

The dot-density plot was developed to display magnetic data that was at first glance easily recognizable and allowed for small anomalies (Scollar 1969; Scollar et al. 1986). In the immediate area of a grid station, dots are randomly placed on the map with the amount equivalent to the range of intensities detected by the magnetometer. This really produces a gray scale type image using dots as the representing symbol. The data appears with magnetic highs
as dark areas and lows as light or white areas. All the readings are considered in a dot-density plot. Even what would normally be considered background noise is used, but can be eliminated. This is an advantage over contouring, because unless a contour map can be made at a small enough interval, not all grid stations may be considered.

The gray scale plot is a combination of contouring and the dot density plot. A gray scale can be produced by several commercially available programs such as "SYMAP" (Dougenik and Sheehan 1975). The image produced by SYMAP has the advantage of displaying contours as well as darker and lighter regions of high and low magnetic intensities. Early gray scale images were symbols printed dark or light depending on the range of readings assigned to the symbol. Others used symbols of differing shape to represent magnetic ranges. These types of displays have to be looked at from a slight distance for the eye to perceive the contrasts.

Line runs, with X and Y coordinates graphed on site, became available with the advent of battery-run portable X-Y plotters in the late 1960s. The X axis is the position of the sensor, the Y axis is the reading obtained, and the lines are displayed vertically as the survey progresses. This technique is also called an isometric chart. The image looks like graph paper with bumps and pits representing the high and low magnetic readings. It is an easily interpreted
display technique. The shape of anomalies are quite plain and the individual high and low areas within an anomaly can also be recognized.

The major advantage of an X-Y display is the immediate results obtained in the field. The surveyor can pinpoint areas of interest on which to concentrate more detailed survey. Conversely, areas of little magnetic interest can be ignored. A drawback to the line run is that the data must be smoothed with mathematical filters, or the magnetometer must be set at a various sensitivities. According to Scollar, this technique favors large anomalies (Scollar et al. 1986:25). Hence, it would probably not be useful in detecting graves, which create small, weak anomalies.

The last display method used in archeology is the profile. A profile plots magnetic data of one transect at a time. The data is plotted on a graph with distance on the abscissa, and with intensity increasing upward on the ordinate. The difference in intensity of highs and lows is immediately apparent. A real disadvantage to the profile is that it only displays a small part of the survey at a time. In a survey of many acres there might be hundreds of separate profiles to display. In addition, the profile method requires an overall survey map to plot the positions of the anomalies. For a large survey area, with highs and
lows of small size, the site map would necessarily be large to plot the anomalies visibly. The profile does however, present the contrast of an anomaly to the surrounding gradient very well. The most advantageous use of this display method would be for selected anomalies within a survey, in conjunction with one of the other methods for the whole grid area.

Anomalies Produced By Local Features

Archeologists in this country are generally interested in local features that produce a predictable type of anomaly. A feature, or magnetic source, which is equidimensional in shape (a sphere for example) will produce the simplest anomaly, that of a magnetic dipole. The magnetometer measures the vector sum of magnitude of the geomagnetic field, and the weak dipole field of the source. There are three general characteristics of this type of anomaly if it is produced by induced magnetization:

1) The maximum amplitude of the magnetic anomaly occurs south of the source by approximately one-third the source-sensor distance.

2) The entire width of the profile at half maximum is approximately equal to the source-sensor distance.
3) A negative region, to the north of the high is roughly 10 percent of the maximum intensity (Weymouth and Huggins 1985:196).

For an equidimensional source containing predominantly remanent magnetization, the locations of the high and low associated with the dipolar field vary greatly, depending upon the direction of remanent magnetization. Non-equidimensional sources generate non-dipolar fields. Quantitative interpretation of these anomalies requires the construction of models which simulate the features of the magnetic sources.

Data Processing

To make magnetic data more useful, there are a myriad of mathematical processing methods that can be employed. Data processing is necessary to filter out background noise and the disturbances of any spurious metal. Processing is also used to enhance the anomalies the researcher is interested in. Many researchers in archeological prospecting have created their own processing methods based upon previously published information, as well as their own experience.

In Europe, where archeological magnetic prospecting was first employed, important reports have been written by,
Linnington (1969), Scollar (1969), Tite (1972a), and Scollar et al. (1986) among others. In the United States, important reports have been produced by authors such as Weymouth and Nickel (1977), Weymouth and Huggins (1985), and Weymouth (1986a). Much of the American's early data was processed using Scollars' method from his 1969 article. Later data was processed in various ways that they either borrowed or developed themselves (Robert Nickel, personal communication 1989).

The most general method of data processing can be described as filtering. Several types of filters can be employed. A filter will "treat the numerical data obtained in a magnetic survey in such a way as to filter out the anomalies of a desired size, and to discriminate against the undesired ones" (Scollar 1969:78). Filters are commonly designed to run on computers to maximize speed, accuracy, and efficiency. An example of an analog filter is a hand template passed over a survey map. Such a template might have a hole in the center and, say, eight holes in a circle orbiting this central hole. The distance between any one hole and the central hole is four grid units. The overall width of the template is 10 grid units. As the template is passed over the site map, the average difference between the outlying values and the center value is subtracted from the latter. The new value is then placed on a separate sheet in
the place of the original central value. This is done for every value on the site map.

This type of filter discriminates against values of a length farther than the outer circles, and it passes the shorter lengths which are of higher frequency. This is called a high-pass analog filter. A high-pass filter discriminates against very weak magnetic sources or ones which are large and deeply buried. The high-pass filter is a good mechanism to discriminate against the effects of broad geological disturbances. Although a high-pass filter enhances the effects of local disturbances - of great interest to the archeologist - it unfortunately also enhances background noise.

A low-pass filter uses the same template, but adds the average to the center value rather than subtracting it. This type of filter will discriminate against the background noise and surface disturbances. This method works because a local disturbance in the ground will only affect a few nearby readings. Averaging and adding will discriminate against that type of anomaly.

A band-pass filter is a combination of the above two filters with all their advantages. A band-pass will discriminate against large and/or weak disturbances, and also the background noise and surface disturbances.
Historic archeological sites usually contain fragments of magnetic metal. These artifacts will generate an intense anomaly if the sensor is passed near the source. A high-pass filter will not have much effect in removing such a localized, intense anomaly. To filter out the magnetic effects of spurious metal fragments, a point-source filter is used. An average of values is taken from further away than four grid points from the central value. However, "...if the central point departs absolutely...by more than a pre-set multiple from the absolute value of the average, we replace the central point by the peripheral average" (Scollar 1969:81).

A typical sequence of filtering would be the point-source filter, and then a combination of the high-pass and low-pass filters using a band-pass filter. The results obtained using this sequence have proven useful to several researchers. However, every site is different. Not all data will require filtering. The soils and underlying geology are different in Europe, the American Midwest, the Piedmont of northern Virginia, and in the Coastal Plain of southern Maryland. Archeologists must recognize that any one of the filters may actually remove the data they are interested in. A high-pass filter may eliminate the effect of a small, shallow pit of low magnetic intensity close to the range of background noise, especially if the local soil
is not very magnetically susceptible. However, the data may be there to detect the pit if the magnetometer used was sensitive enough. The deciding factors would be the type of expected features, size, depth, and probable intensity based on previous experience, susceptibility of the local soil, and even the sensitivity of the magnetometer used to obtain the data.

When using contour maps, the archeologist needs to decide upon the contour interval which is also a type of filter. Very weak anomalies can be eliminated by increasing the contour interval. A happy medium of contour interval choice, and filtering should be achieved based on all the information available.

Ground Penetrating Radar

Ground penetrating radar was developed in the early 1970s and first used on an archeological site by the National Park Service at Chaco Canyon in 1974 (Vickers et al. 1976:86; Weymouth 1986a:376). As a remote sensing technique it falls under the category of active methods. An electromagnetic field is generated into the ground via a transmitter, reflected back by objects or variations in the soil, and detected up by a receiver. The transmitter and
receiver may be in the same instrument, or separated by some distance.

GPR can detect objects such as metal, rock, brick, and even air pockets. However, the radar cannot be used directly to distinguish among these materials, interpretation is the responsibility of the operator. Each of these materials has physical properties that result in slightly different reflection patterns, thereby enabling operators to make educated interpretations. Their conclusions are based on the character of different reflection patterns and his own experience with GPR. Radar is most useful for providing information on the depth and probable shape of a reflector.

A radar unit consists of several components, all connected through a series of power cords. There are several manufacturers of GPR units, but the most widely used in archeology are units built by Geophysical Survey Systems Incorporated (GSSI). The system used in this study is an SIR 4 system, manufactured by GSSI. The most noted authority on archeological surveys with radar, Bruce Bevan, uses an SIR 7 system.

As with the magnetometer each radar model is slightly different. The system described here is the SIR 4. The main component is a control unit. This unit sends signals to the radar antenna. From the control unit several
variables can be set, such as the pulses per second and the size of the emitted wave. The unit has a window that displays the wave being transmitted. A fine tune knob allows the operator to adjust the size and shape of that transmitted wave. The normal range of pulses per second employed is 8, 16, and 32. The variables being relative to the speed the antenna travels. A rapidly moving antenna will require 32 pulses to generate enough data. Conversely, a slow moving antenna requires only eight pulses per second; 32 pulses would be too many, creating uninterpretable information on the printout.

Other variables that can be set are the sensitivity and gain. Sensitivity adjusts the amplitude of received signals. The gain adjusts the amplitude of deep returning signals without affecting the shallow returning signals. The gain may be especially useful in soils that absorb the radar pulses such as at Manassas. By turning up the gain the amplitude of the weak signals from deep within the grave shafts may be enhanced.

The control unit is attached to a recording device and the radar antenna. The recording devices available range from black and white paper graphic recorders, to color video display monitors that use VCR tapes to record all radar profiles made during a survey. Magnetic tape recorders can
also store a radar profile and be played back through the video display unit.

The antenna is the most important component of the GPR unit. Antennas are encased in box-like structures usually called sleds, that house an array of electronic equipment. The size of sleds varies according to the frequency characteristics of the antenna. The lower the frequency the bigger the sled. A 500 MHz antenna is approximately two feet square. A 100 MHz antenna is approximately four feet by three feet. The term sled and antenna are often used interchangeably by field researchers.

The sled contains a transmitter and a receiver antenna. The transmitter and receiver may be separate or the same antenna. A single antenna for receiving and transmitting is called monostatic, and separate antennas for receiving and transmitting are called bistatic. The term antenna is used interchangeably by field researchers to mean the transmitter, the receiver, or sled, whether bistatic or monostatic. This thesis uses the same delineation.

Most GPR units, including the system employed in this study, use a time-domain pulse system. A time-domain pulse system contrasts to a single frequency system in several ways. The single frequency system transmits a single frequency wave. The time-domain pulse system actually transmits a signal over several frequencies. The antenna is
then identified by the center band frequency, such as 300 MHz. Generally, the lower the frequency the greater the depth penetration, but the lower the resolution. Conversely, a high frequency antenna has higher resolution, but less penetration.

**Penetration Variables**

The depth of penetration radar may achieve is proportional to several other variables besides the antenna frequency. These include the soil type, water content, salt content, and a property of electromagnetic waves called attenuation. Attenuation is a decay of the signal over time and space. A radar wave attenuates because it creates electric fields within the soil, thereby losing energy. It is important to know or estimate the attenuation coefficient of a particular soil. This is usually done with a soil resistivity probe (Weymouth 1986a:375). If a resistivity meter is not available, it is possible to bury an object to a known depth and run the radar antenna over it. From this information the depth of penetration can often be estimated to the nearest foot or better.

In normal operation, the transmitted wave leaves the antenna and travels through the ground. If the soil is perfectly natural and no reflective objects are in the path,
only the transmitted pulse is detected by the receiver. However, if an object is in the path of the wave, then the transmitted wave and a reflected wave are detected. The reflected wave is delayed in time according to the depth of the object and the velocity of the material through which it passes. Velocity is measured in feet per nanoseconds.

A single pulse emitted from the transmitter is called a scan. The recorded graph then is a measure of time, distance, and amplitude of scan reflection. The time being nanoseconds, the distance is both in depth of penetration, and distance travelled over the surface. Amplitude is seen as dark or light on the printed display.

**Detection**

When choosing to conduct a radar survey several factors must be considered. These are the soil type, water content, depth, shape, size, and type of expected features. Radar pulses are known to attenuate more rapidly with increased moisture, and within a soil containing many ions. Thus a highly clayey soil just after a rain is not an effective medium. The soil should be allowed to dry before attempting GPR. Even then it may take a low frequency antenna to achieve much penetration. The tradeoff is loss of resolution. Various researchers have experimented with
radar attenuation, and the literature contains tables of attenuation factors for various soils (Leute 1982; Weymouth 1986a).

When deciding which antenna to use to achieve effective penetration, the probable depth of expected features is of concern. Also, the size and shape of the feature affects the strength of a reflection. If the feature is smaller than the wavelength, the strength of the reflection decreases as size decreases. A round object is considered the best kind of radar reflector. A long slender length of pipe standing on end is not as reflective as one lying on its side.

The type of expected targets is of interest in radar use. The feature must contrast electrically with the surrounding soil to be detected. The ability of the radar to detect the target involves abrupt discontinuities in the electrical properties of soil and the feature. This is related to what is known as the dielectric constant, which is a measure of how easily electrical charges will separate or polarize within the feature or soils. Metals, which are strong radar reflectors, have essentially infinite dielectric coefficients. Metals can also produce a reverberation on the record because the radar pulse is reflected up sharply and sent back down again.
A final consideration is matching the impedance of the antenna to that of the soil involved. Each antenna is designed to be operated over a ground surface with a specific set of electrical properties. If there is an impedance mismatch between the antenna and soil, then the antenna will not transmit or receive the pulse efficiently (Daniels 1989:69). An impedance mismatch usually results in what is known as ringing. Ringing indicates that the radar pulse is being reflected within the antenna, and between the ground surface and the antenna. As seen on a printed readout, no soil layers or real objects are detected; a blur of dark and light lines results.

Resolution

Resolution is often defined as the ability to distinguish a reflection from the top and bottom of the second layer in a model containing three layers (Daniels 1989:73). This definition is drawn from geophysics, but is applicable to archeology as well. Archeologists are interested in detecting soil layers as well as targets that are of possible human origin. Resolution is directly related to several characteristics of soil and the transmitted wave. These characteristics are the amplitude and wavelength of the transmitted pulse, the electrical
properties of the soil contrasting with that of the features, and the depth, size, and shape of the targets. Radar waves of higher frequencies generally have better resolution; the anomalies appear more distinct on the printed results. A target with an electrical conductivity that greatly contrasts with that of the surrounding soil will be very distinct on the printed record. A target of little conductivity contrast will be harder to define on the record. However, an operator with experience will see anomalies that the untrained observer cannot perceive. The radar record may show an anomaly associated with low contrast, but it is up to the operator to define that on the record.

The depth, size, and shape of a target affect how well the radar is reflected back. The depth determines the frequency of the antenna used as well. If an antenna of high frequency is only detecting to four feet and a target is at three and a half feet, very little will be seen on the record. The size of the target must be larger than the wavelength of the transmitted pulse to be a strong reflector. A small oddly shaped target may refract or diffract the radar wave and very little energy, if any, will be reflected back to the receiver.
Field Methods

A radar survey is relatively simple to carry out, with practice. After setting up a grid, the sled is pulled along each transect. A grid is usually set up with 10 foot intervals between transects. A radar wave transmits in a cone between 60 and 90 degrees from the antenna, so the spacing between runs can be fairly coarse for a low frequency antenna. A high frequency antenna, which is smaller, may require a finer transect interval. This is especially important if the expected features are small.

The condition of a site for a radar survey should be relatively clear of vegetation and other obstacles. The radar sled should be pulled along the ground surface with minimal jerking movements or bumps. Those motions cause false anomalies on the record.

The type of expected feature will dictate whether or not radar is actually the best remote sensing method to use. Small pits or ditches within a foot of the surface will not be detected by radar. Small features require high resolution, and shallow depths are not usually distinguishable using a high frequency antenna. Walls, foundations, compacted surfaces, and flat floored pits are generally good radar reflectors.
The expected targets will dictate the type of survey conducted. Large linear features such as walls or foundations can be detected by parallel transects. Features such as compacted surfaces of unknown dimensions should be surveyed by perpendicular transects. Graves, since they are deep and fairly long, can be located by parallel transects.

After determining the size of a survey, as well as where and how the runs will be made, a test line needs to be run. This test line should be in an area that is suspected to be free of electrically conductive disturbances, yet generally indicative of the subsurface within the grid area. A metal detector or a portable magnetic gradiometer, may be used to locate metallic or ferrous contamination within a grid. The test line should pass over a feature of known depth for penetration estimates. An object may be deliberately buried for this purpose. The best reflector is a metal sphere or horizontal section of pipe, buried at least two feet deep. The test line should then be run with all available antennas to determine which one will give the best penetration and resolution in that soil.

Depth of penetration is estimated using one of several formulas. When there is no target at a known depth, the simplest formula is: depth equals velocity, multiplied by time, divided by two. Velocity is a variable of the soil, and time is the two way travel time of the radar pulse.
The velocity can be taken from tables generalizing soil types and velocity of radar in those soils. There are a few other formulas that can be used; however, this seems to be the easiest and quickest one (Bohling et al. 1989; Ulrickson 1982).

If there is a reflector buried at a known depth, there are again several formulas to estimate depth penetration. The formula most used is: depth equals the horizontal distance traveled over the object divided by the square root of the one way travel time divided by the reflection travel time squared, minus one (Ulrickson 1982:15). The depth to a known reflector can be roughly estimated simply by measuring on the readout how far down the paper the top of the anomaly is and using that measurement as a gauge for depth penetration.

**Interpretation**

Anomalies on a radar record fall into three categories: 1) continuous reflections from horizontally layered geologic horizons; 2) reflections from two and three dimensional objects; and 3) lateral discontinuities that cause an abrupt change in the signal amplitude, diffractions, or a termination of adjacent reflections (Daniels 1989:84).
Categories two and three are the most important for the archeologist. The main reason an archeologist would choose to do a radar survey would be to detect two and three dimensional objects or features such as graves that cause the discontinuities in category three.

Reflections of objects usually appear in either a spear-head shape or as a hyperbolic arch (Figure 4). Field researchers usually call the source of these reflections a point object. The top of the anomaly is the top of the source. Point objects, especially metal and rock, show up darker on the printed readout. The dark areas indicate a greater amplitude of wave reflection.

Lateral discontinuities appear on the record as breaks in the pattern of reflections. In the case of a grave, it should appear as a hyperbolic arch extending to the surface, or as an arch with broken wave patterns directly above it. Conversely, a change in soils from one of low conductivity to one that is highly conductive will produce a light or entirely white area on the printout. A void beneath the surface will produce the same result.

Ground-penetrating radar is most effective in certain soil types. As a general rule, the least conductive soils are sand or a sandy loam. Various researchers have achieved good results in this type of soil. Some surveys have achieved penetration to depths of up to 25 feet. Silts are
another medium that produce good GPR results. Both sand and silt soils can provide a good background for detecting objects or features. This is especially true if the conductivity of the feature highly contrasts with that of the surrounding soil. Those soil conditions make interpretation easier.

Unfortunately, the earth is not covered exclusively with sand and silt. Many soils are high in clay content and generally not a good medium for GPR. Clay also contains water molecules as part of its chemical makeup; thus even dry clay contains internal water. Many clays also contain oxides that are highly conductive. The conductivity of both water molecules and oxides causes rapid attenuation in clayey soils. However, as the technology of radar advances, clay is becoming more penetrable by increasingly sophisticated radar units and antennas (Claude Petrone, personal communication 1990).

Data Processing

The data obtained from a radar survey can be processed to enhance the image just as the magnetic data can be processed. There are several approaches to filtering out background noise or enhancing certain amplitude reflections. Most of these processes involve complicated mathematical
algorithms. In most current archeological reports with radar applications no data processing has been attempted. In general, the processing of radar data has been limited to geophysical or civil engineering problems (Daniels 1989; Ulrickson 1982).
CHAPTER IV
EXAMPLES OF REMOTE SENSING SURVEYS ON HISTORIC CEMETERIES

Magnetic Surveys

Archeological magnetic prospection has been used in Europe since the 1960s to locate burials on many sites (Browning 1982; Lerici 1961; Tite 1972b). However, a majority of those sites have burial mounds which will produce a fairly large anomaly even if the mound has been plowed flat. The studies in Europe indicate the usefulness of the magnetic method on that type of site. Regardless, the historic burials found in the United States are much smaller, and produce much weaker anomalies than burial mounds. For comparative purposes the European studies are valuable only as a starting point to show that soil disturbances for burials will create some sort of magnetic anomaly.

In this country, many archeological magnetic surveys have been conducted looking for sites, and a few have located burials by chance. Magnetic surveys looking specifically for unmarked historic burials are few. Even
fewer still are surveys conducted on soils that match those of Manassas or Marshall Hall. Previous surveys conducted on clays, or sand and gravel are the most appropriate for comparison, since the success of the magnetic remote sensing method is highly soil specific.

Probably the major reason so few magnetic surveys for graves have been done is that magnetics is not generally recognized as the best remote sensing method for grave detection - radar is (Bruce Bevan, personal communication 1989). Consequently, there are fewer magnetic surveys than radar surveys locating unmarked historic graves. This section discusses a few magnetic surveys, searching for unmarked graves.

During the 1970s, Michigan State University conducted magnetic studies and follow-up excavations at Fort Ouiatenon in Indiana. The soils at the site are sandy loams and clay, which is fairly comparable to Marshall Hall (Noble and von Frese 1984; von Frese 1984). It was not until after discovering an eighteenth-century burial through excavation that the researchers noticed an alignment with a weak magnetic high. They began looking for more anomalies similar to the one that matched up with the excavated burial. Five possible graves were noted from magnetic anomalies. A total of four burials were confirmed through excavation, and the fifth awaited testing.
The magnetic anomalies indicating the graves are small in size and are quite weak. Two of the burials were partially masked by a linear anomaly caused by a wall trench. The researchers noted that to magnetically locate more graves in the immediate area would require a finer survey grid than the one they used.

Another magnetic survey on soil comparable to Marshall Hall is the one conducted on St. Catherine's Island, Georgia. Here again, the survey was aimed at locating a larger site than an unmarked grave. Nonetheless, several hundred burials were located within the confines of a church. The anomaly there was probably caused by two sources: the wall of the church, and the large number of burials. The graves may or may not have been located individually by the magnetometer. The major source of the anomaly was the daub wall of the church. It created an anomaly that would have been detected without the presence of the historic graves.

Over the past 10 years Dr. Bruce Bevan has conducted remote sensing surveys on numerous sites suspected to have unmarked graves (Bruce Bevan, personal communication 1989d). Most of Bevan's surveys use radar as the primary remote sensing method.

Bevan's work at the Plains-Sotheron Family Cemetery in St. Mary's County, Maryland is an example of a magnetic and
radar survey searching for unmarked graves. The soil of sand and gravel at the site is comparable to that of Marshall Hall. Bevan categorizes the magnetic anomalies on a map of the site from most likely to least likely to be a grave. The magnetometer was placed on extant headstones, but none disclosed detectable magnetic material below them. However, since there is brick on the surface of the site, it is possible that three of the anomalies that were detected are graves with brick vaults, or brick in them.

Another example of Bevan's work is his report of the geophysical survey at George Washington's Mount Vernon, in Fairfax County, Virginia. Here, Bevan surveyed an area believed to be the slave cemetery. He ran radar as well as the magnetometer. By a quirk of geologic fate, the clay soils at Mount Vernon are more analogous to Manassas rather than Marshall Hall, which is within sight across the Potomac River. The magnetic data obtained on the slave cemetery appears to be ambiguous at best. Bevan cautions that of the approximately 30 magnetic anomalies, only one correlates with a radar anomaly. The possible sources for the magnetic anomalies is buried iron. This is a common problem in magnetic surveying. However, the magnetic data was not corrected to the diurnal variation or treated in any way. Refinement of Bevan's data from Mount Vernon's slave cemetery may yet reveal archeological features.
In a paper presented in the fall of 1989, Bevan (1989a) suggests that the most distinctive characteristic of a grave is the altered soil from the digging. That alteration may or may not create a magnetic anomaly. If the refilled topsoil is more magnetically susceptible, or if subsoil, which is less susceptible is now on top of the grave, a magnetic anomaly may be created. These conditions can last indefinitely, if not disturbed. A major consideration in detecting the anomalies created by grave excavation is grid spacing and sensor height.

**Examples of Radar Surveys**

In the 17 years that ground-penetrating radar has been used as an archeological tool, several researchers have located graves, some intentionally, others by chance. Most discussions of GPR explain that structural features are easily identified and only mention in passing that pits, ditches, etc., can be identified. The authors do not go into detailed analysis of the location of small or subtle features, most are interested in large anomalies (Batey 1987; Bevan et al. 1984; Kenyon 1977). Much of the literature discusses discreet soil interfaces, but does not mention backfilled soil creating an interface. Still others
discuss burial, mounds which are large features and not analogous to an historic American burial (Imai et al. 1987).

In Bevan's paper presented at the November 1989 conference of the Society of Exploration Geophysicists, he suggested that the most distinctive characteristic of a grave is the soil alteration. This is especially true if the natural soils through the excavation depth were well stratified. A refilled grave shaft will have mixed soils of varying conductivity at different depths. The radar anomalies are caused by changes in moisture content and soil chemistry. These changes will be very noticeable in stratified soil; but in complex soils such as glacial deposits, the changes may be impossible to see.

Of the sites Bevan has conducted surveys on with unmarked graves, his best results have come from GPR. The following discussion goes over some of that research. As with the examples of magnetic surveys, only those sites that have soils similar to Manassas or Marshall Hall are examined. The reason is that the success of GPR is very soil specific.

The Plains-Sothron Family Cemetery and the associated slave cemetery discussed in the magnetics section was investigated by radar as well. This cemetery is a near perfect match for Marshall Hall: the soils are sand and gravel, and some of the burials are vaulted. However, the
correlation between the magnetic and radar data is not very high at the family cemetery. Only two of the three possible vaulted graves correlate with a radar echo that indicates a grave. The third magnetic possibility is near a headstone, but it is not corroborated by radar. Although most of the magnetic anomalies align with radar anomalies, only two of the possible 19 radar anomalies align with magnetic anomalies. An explanation for this problem is that not all the burials are vaulted, which is very possible. Here again, Bevan notes the hyperbolic anomaly pattern for possible graves. His traverse spacing was two and one half feet, close enough to detect an anomaly on several parallel runs. Very good correlation is attained with that fine of a grid. The slave cemetery was only surveyed with the GPR. The results showed four very distinct hyperbolic echoes that are probably burials. A magnetic survey was not done because no brick was noted at this site. One would not expect slaves to be buried in brick vaults anyway. Bevan cautions, however, that the reliability of his survey is uncertain. He points out that the radar may not have located some graves, and that some of the anomalies may not be burials. Yet, later excavations revealed that radar echoes from more than a two foot depth have a 100% correlation to interments at the family cemetery (King and Bevan 1987). The slave cemetery excavations discovered two
of three predicted graves, however two other graves were located by random testing in locations no anomalies appeared.

Two other radar surveys that Bevan conducted in the St. Mary's area were for Historic St. Mary's City during April of 1989. Bevan used radar to search for unmarked graves at the Chapel Field, and Gallows Green sites of St. Mary's City. The soil of sandy loam is fairly comparable to Marshall Hall. Although the other soils, silty loam, and clay loam subsoil present in the area are different than any at Marshall Hall or Manassas. They are however, good background for radar pulses and are analogous to sand and gravel in that sense.

At the Chapel Field site the remains of two seventeenth-century churches are present, as well as a number of graves. The brick foundation of the later church was easily identified. Bevan indicates that there are two areas where clusters of graves are probably present. He feels that if the graves are shallow - three to four feet deep, and spaced about the same - the radar returns will overlap so that individual graves cannot be isolated. An area just to the east of the brick chapel contains at least 20 graves discovered archeologically in 1983. The graves were noted but not fully excavated. The radar had trouble isolating individuals here. The second area Bevan
interprets as possibly having graves is 15 feet east of the first cluster. Here again, he remarks that closely spaced and shallow graves are probably causing overlapping radar returns.

The Gallows Green site at St. Mary's City is reputed to contain as many as one dozen historic burials (Bevan 1989c:1). Three graves are presently marked with stones. When the antenna was run over these graves, no distinctive radar echoes were noticed. Nonetheless, Bevan notes that there are four possible locations of unmarked graves in the survey area. The anomalies show typical arches or erratic soil layers. Bevan points out that the soil of the site is moderately complex and may mask grave anomalies.

To date, the grave anomalies at Gallows Green have not been tested archeologically (Timothy Riordan, personal communication 1990). A very large anomaly at the Chapel Field site was created by three lead coffins; as subsequently discovered through excavation. Although the soil at both sites seems to be good for radar pulse propagation, the results are disappointing at best (Henry Miller, personal communication 1990). Very few individual graves were located. At Chapel Field two areas containing an unknown number of graves were identified. Excavations in 1990 uncovered multiple burials closely spaced in the areas
noted by Bevan. At Gallows Green only four possible graves were noted in an area where over one dozen were expected.

In July of 1987 Bevan conducted a radar survey for the National Park Service at Voyageurs National Park and Pictured Rocks National Lakeshore. Voyageurs is in northern Minnesota, and Pictured Rocks is in northern Michigan. Both sites have sandy soil, and possibly unmarked graves. At both sites Bevan used a high resolution antenna (315 MHz) and a deep penetrating antenna (180 MHz).

At Voyageurs a known historic Indian burial within a stone circle was tested with the radar, but as Bevan (1987:3) said, "nothing out of the ordinary" was detected. A second stone circle revealed what Bevan (1987:4) called a "moderately distinctive echo." This echo is a hyperbolic arch, probably a reflection off of an underground object. There were two other areas that showed distinctive radar returns, and are somewhat deeper than the echo from the second stone circle. However, there is no stone circle present for either of these other anomalies. It is possible that a burial was made without a stone ring though.

At Pictured Rocks National Lakeshore the radar data is more uncertain than at Voyageurs. The site is apparently scattered with buried tree trunks and roots that cause radar reflections. Other returns that are not near trees or probable buried trunks Bevan feels could be graves, but he
also says that many natural features could cause echoes like those detected at the site. He concludes the report by saying that the soil at Pictured Rocks provided an excellent background for radar pulses, but that probably no graves were detected. The site at Voyageurs, while less ideal for radar investigations than Pictured Rocks, probably contains unmarked burials. The soil at Voyageurs is fairly complex and may mask grave anomalies. Complex soils and rapid attenuation of the radar signal lead Bevan to be cautious in several of his reports.

Bevan's survey of the Mount Vernon slave cemetery most closely approximates the surveys conducted for the present study. Bevan ran both ground-penetrating radar, and the magnetometer on the site in an attempt to define unmarked graves. As previously mentioned the soil is analogous to Manassas. The GPR located 51 possible graves, while the magnetometer probably did not locate any. The anomalies that were noticed from the GPR are the typical hyperbolic arches that are associated with objects underground. Bevan was able to interpret what appear to be burials up to six and one half feet below the surface with a high resolution (315 MHz) antenna. In clay soils this is very good results with that antenna. Bevan suggests several possible sources for the anomalies: the altered soils from excavation, an air filled cavity, or a change in the soil due to the decay and
collapse of a coffin. Bevan cautions the reader by stating that the radar may have missed some graves entirely. This is possible in the case of child or infant graves, or a shallow grave that did not disturb the soil much. To date, no testing of the remote sensing at the slave cemetery has been done (Esther White, personal communication 1990).

Another cemetery with soils similar to both Manassas and Marshall Hall is the Poor Farm Cemetery near Rockville, Maryland. This cemetery was also studied by Bruce Bevan. The Poor Farm was a home for the indigent of Montgomery County. Set up in the eighteenth century, it continued to operate until the mid-twentieth century (Rhodes 1987:2). The soils there contain heavy clays, silt, gravel, and sand. The clay is analogous to Manassas, and the sand and gravels are similar to Marshall Hall. Bevan located seven areas he felt were probably "clusters" of graves. Of those seven, only two actually turned out to have any burials in them. The possible explanations for the other five target areas were explained by Diane Lee Rhodes (1987) in her field report of the excavations of the site. The late eighteenth century graves may be so deteriorated that they were not seen in excavation, yet were detected by the radar because of the soil disturbances. In excavation, the graves that were observed, did not look very different from the surrounding soil. All of the recognized graves, post date
1890 (Rhodes 1987:6). The burials of the earliest dates were in very poor condition, thereby leading the excavators to reason that the eighteenth through mid-nineteenth century burials were almost completely decayed and unrecognizable. The soil patterns at the site did not suggest the presence of burials to the excavators either. Apparently the soil in a grave shaft did not differ in appearance from the surrounding matrix. The only indicator of a grave was a looser texture of the soil.

The rest of the cemetery studies discussed here were conducted at sites with sandy soil, analogous to Marshall Hall. Subsurface Consulting Ltd. conducted a study of the Gethsemane Cemetery in Little Ferry, New Jersey. As the soil is sandy, only a high resolution (500 MHz) antenna was used. The researchers recognized possible grave anomalies as hyperbolic arches. This New Jersey cemetery, for an unexplained reason, has clay pipes associated with a number of the graves. Several of the possible graves are interpreted as such because of radar echoes that appear to be caused by these clay pipes. A total of 44 possible unmarked graves were identified by the study (Mellett 1989:3). The evidence in support of the burial interpretations includes; a similar radar return from a known grave, and the almost consistent depth of between three and six feet of the radar returns. This author does
not known if the radar survey has been verified by excavation.

The last site to be discussed as an example is in Red Bay Labrador. The Red Bay site was the location of a sixteenth century Basque whaling station. The soil is described as beach deposits, covered by a thin layer of peat. The beach deposits are probably sand and gravel. The goal of the radar survey was to locate the Basque graves, and other archeological features. Initially the site was archeologically tested in 1982, and several graves were found. The following year the radar survey was conducted, hoping to locate more graves.

The initial interpretation of the radar data was that the grave material did not contrast sufficiently with the surrounding matrix to appear on the radar record. Although once the archeologists uncovered the site almost entirely, they noted a high correlation of burials to radar anomalies showing disturbed conditions. Though the authors do not specifically state so, their site map shows 22 burials, and all but four are located near radar anomalies. The anomalies were not the typical hyperbolic arch patterns as apparently expected. A problem with the radar data is that large cobbles are present and they act as pulse scatterers. The anomalies showed complex soils that were disturbed.
Even with these limitations the radar data proved useful as an indicator of graves at this site.

From the evidence gathered by several researchers, it is evident that GPR studies of historic graves is a complex issue. The success of the radar method is highly soil specific. Even so, at a site such as Gallows Green where the radar signal penetrated well, the data was rather ambiguous. A marked grave showed no distinctive radar return. The soil is moderately complex in its content and stratification. Those complexities could be masking graves. On the other hand, at Voyageurs where the soil was not complex a known historic burial did not show a significant radar return.

One of the many problems is that whether or not the soil is a suitable radar medium, the graves must be separated by enough distance and located at a sufficient depth to be individually identified. A case in point is the Mount Vernon slave cemetery. Although the soil is generally clayey, not considered good radar conditions, the echoes were distinct enough to pinpoint probable individual burials. This is presumably because the graves are separated by more than a few feet. That site contrasts with Chapel Field where the soil is favorable to radar, but the graves could only be noted in clusters, the problem being closely aligned graves.
The authors of the Red Bay article bring up an interesting point about unmarked grave detection. They stated that initial indications were that the graves did not contrast with the surrounding soil, but that later they noted "disturbed soil conditions" that were of archeological significance (Vaughan 1986:597). This scenario makes sense. The beach deposits are probably not highly stratified and a grave excavation would be similar to digging a hole in a pile of already disturbed soil and refilling with the same dirt. However, the disturbance probably caused the grave shaft to hold more water because of the loose organization of the soil. Water is a conductor, causing attenuation of the radar signal, and hence the "disturbed soil conditions" noted by the researchers. This is exactly the phenomena Bevan discussed in his paper on remote sensing of graves in 1989.

It may seem to the reader that ground-penetrating radar as a locational tool is rather limited in its usefulness. Of the reports discussed in this section, only one shows a high correlation of radar anomalies to actual graves. While those facts are true, it is also true that many of the sites listed have not been tested for verification. It is not true that GPR is very limited, however. It is by the experimenting in different soils, and over graves of varying depth and ages that we can better understand what radar can
do for the archeologist. That is the intent of this study: to combine what others have learned about radar with relation to graves, to apply that to two test cases, then verify the data. This last crucial piece of evidence is lacking on many of the sites discussed in this section.
CHAPTER V

THE MARSHALL AND BALL FAMILY CEMETERY SURVEYS

Magnetometer Survey of the Ball Family Cemetery

The magnetic data from the Ball Family Cemetery is not comprised of a single survey done at one time. It is actually a combination of several surveys done at various times and using slightly different surveying methods. Since the magnetic method was new to the author, it was decided to use the Ball Family Cemetery as a test case to learn about the magnetometer and how to use it. Only after becoming comfortable with its use and the results would the Marshall Cemetery be studied.

During the Manassas surveys the base station was monitored in three different ways. The first required a person standing with a base magnetometer manually reading and recording every minute. The second was to return to the base after every transect with the survey instrument and take a reading. The third was to have a magnetometer automatically read the base station at a preset time interval.
The magnetic surveys were carried out with two or three people; one survey magnetometer operator, one recorder, and one base operator. A two person survey excluded the base operator. Unless the G-856 magnetometer was used as an automatic recording base instrument, it was used to survey with. When used as such, the station values were stored in electronic memory as well as recorded. After concluding the survey, the field notes were verified with the stored station values, then the figures were rounded to the nearest gamma. Values from one-tenth to four-tenths of a gamma were rounded down, and from five to nine-tenths were rounded up. After this, the diurnal calculations were made. When the G-856 was used as a base instrument, either returning to the base or automatically recording, the base values were rounded in the same manner. When a second instrument was used to read the base, a G-816 magnetometer read to the nearest gamma, and no rounding was necessary.

The grid for the first magnetic survey was set up with a five-foot interval between stations outside the cemetery. Inside the walls stations were placed in four transects. One over the marked graves, another 10 feet east of the footstones, and another 20 feet east of the footstones. A few more stations were read two feet west of the headstones. The station interval was fairly random inside the cemetery. Wherever a depression seemed to be indicating an unmarked
grave, a reading was taken. Over the marked graves, two readings per graves were taken.

Before the magnetometer was ever used, the entire site was cleared of magnetic debris by a metal detector sweep. The sweep turned up tin cans, broken farm equipment, old survey flags, and occasionally metal objects buried in the soil. Objects detected more than a few inches below the surface were left in the ground.

A Shoenstadt audible gradiometer was also made available. This instrument is much more sensitive than the inexpensive metal detector that was used. This gradiometer can be thought of as a magnetic geiger counter. When it passes over ferrous objects, even brick, the gradiometer whines loudly. Otherwise its sound is merely a buzzing. High pitched whining indicates magnetic objects. The audible gradiometer consists of two magnetometer sensors mounted one on top of another. However, its only output is sound; no digital data are furnished, sensitivity and volume are the only controls.

After the grid was set, and the sweeps of the area finished, the magnetic survey progressed relatively easily. A total of 216 station values were recorded during the first survey. The data were taken back to the lab where they were processed.
The magnetic data was entered into a commercially available contouring package called SURFER. The values can be entered into the program through any word processing package. After diurnal calculations are made by hand, the data were put into a four column form in Word Perfect software. One column contains the station numbers, two others represent X and Y axis values, and the last is a Z value representing the magnetic reading. X and Y values are distances away from a 0.0 datum point on the survey grid. For all the data presented here the 0.0 point is always the southwest corner of a survey grid. Y values are distances north, and X values are distances east of the datum. The distance away from datum is registered in feet. Data in this format can then be downloaded into Surfer.

The contour plot created from the initial survey data is contained in Figure 5. This map was created by the VAX computer system at the United States Geological Survey (USGS) headquarters and drawn by a plotter. Crosses represent station locations.

Several especially interesting features were derived from the survey. First, a north-south gradient is present near the line of marked graves. Second, a strong east-west gradient is present along the north wall of the cemetery. This second gradient is so strong that it encompasses and actually bends the north-south gradient with it.
Undoubtedly, some local disturbance is causing these anomalies. The stations are close enough and the gradients strong enough to rule out any geological disturbance. Also the anomalies are too long to be a single ferrous object.

The magnetic high seen at the southeast corner and the dipole at the northeast corner of the cemetery are probably metal artifacts. These anomalies are too strong and large to be a grave. Also present is a dipolar high-low anomaly in the area of the marked graves. Dipoles are usually caused by metal or a magnetic rock, but the number of survey stations is too small to accurately locate the source. The low seemingly represents the five known graves, however, then the high would be sitting alone. This contour map was promising but lacks enough detail. It was readily apparent that many more stations were needed inside the cemetery walls to better define the anomalies.

Another survey was set up with a station distance inside the walls at two feet. Wooden stakes were driven into the ground at four-foot intervals and the two-foot interval stations were estimated between stakes. A total of 266 stations were then recorded inside the cemetery walls. The field data was treated in the same manner as before. Figure 6 is the contour plot of the data inside the walls. Figure 7 is a combination of the first and second survey, deleting the first stations inside the cemetery. The values
were matched up over the walls by a method of interpolating called krigging. Krigging is an algorithmic function that statistically estimates the values between known stations. This process was done by the USGS computers. Notice that in the southwest corner of the detailed grid (Figure 7) that a weak magnetic low exists in the same region as the five marked burials. Immediately north of that low is a small high and then another strong low. This second high-low pair is a dipolar anomaly probably caused by a ferrous metal object. The separate low, however, could be caused by the disturbed soil of the interments. Notice that the high of the dipole extends outside the north wall of the cemetery. This is the region where the north-south gradient had been present from the first survey's data. Later excavation in that area discovered a Civil War soldiers mass burial extending from near the marked graves to outside the walls. The question is whether or not the high is related to that soil disturbance, or a ferrous object.

In an attempt to determine the location and type of source causing the dipole, yet another magnetic survey was planned, this time covering only enough transects to encompass the known graves and the mass burial. Knowing the exact size of the soil disturbance provided a perfect test to determine if the feature was indeed the anomaly source. Before the last survey took place, two shallow trenches were
excavated in the northeast corner of the cemetery. Two ferrous metal objects were recovered from these excavations. A circa 1826 bayonet and a strap hinge fragment were removed, along with a plain non-magnetic brass button probably from a Civil War military uniform. With the size of the soil disturbance known, and after removing two magnetic objects, another magnetic test was expected to define the anomaly source more clearly. This next survey which extended outside the north wall, resulted in Figure 8. Comparing this data with the western half of Figure 7 reveals several changes in the anomalies. The low associated with the known graves no longer exists as a separate anomaly. Before removing the bayonet and strap hinge, the low almost fit perfectly over the graves. After removing the ferrous artifacts all of the anomalies merged. The low over the known graves is still weak, but now two lows have taken the place of the dipole.

It is very likely that more magnetic material exists in the mass burial. However, the weak low over the know graves cannot be overlooked. It is possible, even probable, that if not for ferrous artifacts a weak low would be detected over the known graves, and as part of that low, or maybe separate from it, another over the mass burial.

Susceptibility measurements taken on soil cored from Spencer Ball's graveshift and another undisturbed spot in
the cemetery were rather high. The reading for Spencer Ball's grave material was $3.48 \times 10^{-4}$ emu/cc (electromagnetic units/cubic centimeter). This evidence leads to the conclusion that remanent magnetization of the soil may be important to understanding the anomaly. The fact that the susceptibility of the soil is high and that a disturbance created a magnetic low possibly indicates that viscous remanent magnetization (VRM) is the type of magnetization responsible for the lows seen at the Ball Family Cemetery (William Hanna, personal communication 1989). The scenario that Hanna proposes is that a VRM may have been acquired by the soil, parallel to the recent Earth's ambient field, prior to the soil disturbance. The excavation of graves disturbed the soil and randomized the magnetic moments of soil particles. This destruction of the VRM causes the magnetic low.

**Ground-Penetrating Radar Survey at the Ball Family Cemetery**

The first ground-penetrating radar survey conducted at the Ball Family Cemetery was in October of 1987. A 10-foot grid was set up surrounding the stone cemetery walls. This meant that the spacing between sled runs was approximately 10 feet. The transects were lettered N, S, E, or W,
according to the cardinal directions, and then lettered consecutively starting at A for the first 10 feet away from the walls. For example, the first 10 foot transect north of the cemetery was labelled NA; 10 to 20 feet out was labelled NB, and 10 feet west of the cemetery was labelled WA, and so on.

The interior of the cemetery was profiled in three transects; one over the marked graves and two to the east of the footstone markers. These transects were simply labelled interior one, two, and three. All the transects inside were run south to north. On exterior runs the east and west sides were run north to south, with the north and south sides run east to west. As the antenna moved along each transect a marker button was pressed every 10 feet leaving a tick mark representing 10-foot intervals on the graphic printout. The 10-foot interval was used for the north and south sides, while a 20-foot interval was used for the east and west sides. The interior transects were marked at the center of four depressions thought to be graves, or at the center of each headstone.

The antenna used for the survey was 120 MHz. The settings used on the control unit that day were not recorded. This survey revealed several anomalies north of the marked graves, and possibly four to the east of the marked graves. Outside the cemetery, two possible anomalies
appeared south of the stone wall at 10 and 20 feet (lines SA and SB), but the most likely grave anomalies were within the stone walls.

The radar survey of the cemetery was done rather hurriedly at the end of a long day surveying the nearby site of Pohoke, but the initial results were encouraging. Another radar survey was needed to further define the anomalies of the cemetery. In addition, probing and coring was done outside the southern wall. This testing concluded that no unmarked graves existed south of the cemetery.

Second and third radar surveys of the Ball Family Cemetery were conducted on October 2, and 31, of 1989. These surveys were done to test three different antenna sizes, define anomalies more clearly, and record the various control unit settings. Armed with this detailed information more accurate conclusions about the anomalies can be made. These two surveys were conducted in conjunction with C.E. Petrone of the National Geographic Society and Dr. W. F. Hanna of the U.S. Geological Survey.

The ground-penetrating radar system employed is owned by the National Geographic Society. It is an SIR-4 system manufactured by Geophysical Survey Systems Incorporated. Three antennas were tested for penetration and resolution; a 120 MHz, a 300 MHz, and a 500 MHz. The control unit settings were varied with each antenna as it was run over a
test transect. The radar data was recorded on a black and white graphic recorder and magnetic tape. The magnetic tape was played back through a color video display unit. The display monitor is a 13-inch color television. The radar data moves slowly across the screen, with various colors signifying different intensities of radar returns, similar to darker lines on paper representing more intense echoes.

Before actually profiling any of the cemetery, a test line was chosen near the survey area. Four, one-foot sections of steel rebar were buried at a depth of two feet for penetration estimates. Then each of the three antennas was pulled over the test line experimenting with the control unit settings and the antenna speed.

It was quickly determined that the 500 MHz antenna barely penetrated to two feet. The 300 MHz and 120 MHz antennas achieved three and four feet respectively. However, deep penetration was not necessarily the goal. Instead, it was essential to see if the radar could differentiate between the disturbed and natural soil. The best results were achieved with the 120 MHz antenna with settings of 16 scans per second. The graphic recorder was set to record 50 lines per inch. These settings allowed the scanned information to be displayed in a recognizable manner on the printout.
Several passes were made over the known graves with all three antennas and no clear definition of grave shafts was distinguished. Part of the problem with clearly defining the graves is the fact that individual interments are within two feet of each other. The radar pulses traveling out in a cone may start in one grave shaft, but they return from the adjacent grave. The problem with close proximity is mentioned by Bevan in his Chapel Field report. Related to this trouble is the problem of finding undisturbed soils within the cemetery to profile. The graves run from the southern to the northern wall. No profiles were made that covered a significant amount of undisturbed soil before going over the graves. If that were possible, perhaps a large area of disturbance representing several graves could be identified, much the same as Bevan interpreted it at Chapel Field. North of the marked graves the initial GPR testing located what was interpreted as two unmarked graves. Soil coring and subsequent archeological excavation discovered a large area disturbed to a depth of at least two feet. The disturbance continued under and beyond the north wall by seven feet. The later GPR investigations did not define this area well on the readouts. This disturbance is probably the location of the twentieth-century interment of Civil War soldiers' remains (see Chapter 2). Radar
profiles, both inside and outside the north wall, were not able to sharply define the limits of the mass burial.

East of the row of footstones, the initial radar test detected several anomalies. Between the time of the first radar survey and the next two, that area was archeologically tested by coring and excavation. Neither method found unmarked grave shafts. The anomaly sources are probably an extensive ground hog burrow and several tree roots that seen when uncovered by the excavation. The roof of a burrow tunnel was damaged by the trenching at a depth of one-half foot. The subsequent radar investigations detected the location of the burrow. A hyperbolic arch pattern resulted from the animal's tunneling. The air space within the burrow created a fairly strong radar anomaly.

There are a number of groundhog burrow holes close to or inside the marked graves. Along with the other problems it is likely that one or more burrows are scattering the radar pulses in the graveshafts. The major problems then are; the close proximity of the known graves, the fact that little undisturbed soil was profiled within the walls, and the ground hog tunnels probably scattering the radar pulses. These problems coupled with the fact that clay is simply not a perfectly suitable radar medium, would at first glance lead to the conclusion that GPR was not highly effective at the Ball Family Cemetery. However, recognizing the
difficulties of the soil and the various other obstacles is the job of the researcher. Not many sites are perfect for radar, and not every site will be free of animal burrows or stone walls. An experienced radar technician would have noticed the problems right away, however, building upon experience is the whole idea behind this research. The radar anomaly noted north of the marked graves is indeed a grave, and as such proves the ability of the technique in this application.

Comparing the Anomalies

The correlation between the anomalies at the Ball Family Cemetery is rather good. Both methods detected the unknown location of the mass burial. Neither method was able to define the source very well, nevertheless, a first-time observer noticed the presence of an anomaly. The initial radar survey located several anomalies east of the marked burials and these were subsequently studied by later surveys, but no grave anomalies were noted.

The marked graves have associated with them a weak magnetic low which is similar to the one for the mass interment. The radar did not define those graves very well. However, that is a problem caused by the soil and close proximity of the graves.
Archeological Testing

Coring -- The use of soil coring as a technique for discovering or delineating archeological features has been traced back to the mid 1930s by Stein (1986:505). As a field technique, coring was borrowed from geology. It seems this thesis involves several procedures adapted from geology.

The whole premise of this project is to locate unmarked burials without the time and expense of standard archeological techniques. A major factor here is whether or not using a one inch diameter coring tool can distinguish disturbed from natural soil. If a single person in the field can core a few locations determined geophysically, and in the process accurately locate burials, then the methods of this thesis work.

The method of coring is very simple. A one-inch diameter coring tool is pushed into the ground at one-half foot intervals over the anomalous areas located through remote sensing. When the tool is extracted a sample of soil has been taken up into its one foot long tube. The tube is open on one side allowing the user to view the soil. The sample of dirt is scraped flat leaving a clean profile, which is then examined.
A grave shaft should exhibit a topsoil layer, depending on the site, and then mottled disturbed soil. If natural stratigraphy is present, then it is not a grave shaft. When suspected grave material is brought up in the coring tool, another foot of depth is tested for verification. The tool can test up to three feet, one-foot at a time. Attachments to the handle can make it longer, but a tool over three feet is difficult to operate; and there is always the risk of disturbing skeletal remains at depths over three feet. To exactly pinpoint the edges of a grave the coring interval is moved back and forward a few inches at a time.

At the Ball Family Cemetery the coring method discussed above was conducted on the radar and magnetometer anomalies. Before testing the anomalies, two of the known graves were cored. Coring a known grave determined what kind of soil to expect for unmarked graves. Both Alfred and Spencer Ball's graves were only cored to a depth of one foot, so as not to disturb any skeletal remains. The soil is a dark yellowish brown mottled silty clay with sandstone bits (Munsell 10YR 4/4). The sandstone comes from the subsoil level directly overlying the bedrock in the Manassas area. This type of soil rests in a belt of Triassic clays that stretches from New York to Virginia.

The two anomalies south of the cemetery were cored at different intervals. No graves were found. The first 10
feet south of the cemetery wall is littered with stones several inches below the surface. These stones may have been the cause of the radar anomalies in line SA.

The radar traverses were spaced 10 feet apart, and consequently the echoes could have come from anywhere within the 10-foot distance. The first line of core test holes ran west to east six feet south of the cemetery wall (Figure 3). The core spacing was one-half foot. To be sure that something as small as an infant grave was not missed, a line of core tests running south to north was done. The cores go from 10 feet, out to the wall at a distance of six feet east of the southwest corner. The radar anomaly in the SB line was cored at different intervals attempting to ascertain the validity of the coring method. The radar anomaly appeared between 10 and 20 feet east of the cemetery's southwest corner. Fifteen feet out from the walls the core holes were spaced one foot apart between 10 and 20 feet east. Two more sets of core holes were placed north-south at 13 and 17 feet east of the southwest corner. These last two sets were cored two feet apart, from 20 feet to 10 feet out from the wall (see Figure 3). No burial was discovered in the SB line, and no source for the anomaly was defined either. This line is a mystery.

The radar anomalies along the eastern wall inside the cemetery were cored at one half foot intervals. The line of
core tests runs south to north (see Figure 3). They were placed west of the east wall by four feet and started two feet from the south wall. The only features located were two groundhog burrow tunnels. Other than the burrow only natural stratigraphy and a few rocks were found by the coring tool. The burrows are probably the source for two of the first radar survey anomalies.

The anomaly north of the marked graves was cored initially using a one foot interval then narrowing to a half foot interval. The cores were placed six-and-one-half feet east of the west wall and ran north from Francis Ball's headstone. Four feet north of this marker the coring tool picked up disturbed soil. This soil looked very much like that cored from the two known graves. From that point north the core spacing was executed at one-half foot intervals instead of one foot. The coring, and disturbed soil continued right up to the north wall of the cemetery.

Excavations -- Trenches were excavated at the Ball Family Cemetery near the east wall, north of the marked graves, and outside of the north wall. These units were placed in the same locations as core holes to determine if the coring missed anything or to verify what the cores discovered (see Figure 3).

The first test trench was excavated from the south side of Francis Ball's headstone to 12 feet outside the north
wall. The trench was two feet wide and 31 feet long. The unit was excavated to a depth of four-tenths of one foot. This first trench illustrated how well the coring method actually worked. Four feet north of the headstone a mottled silty clay soil appeared with bits of sandstone. This same soil was cored from this area previous to digging, as well as from the known graves. This disturbed soil continued outside the north wall of the cemetery by five feet. From Francis Ball's headstone north to four feet an undisturbed natural clay was excavated.

The fact that the disturbance continues outside the cemetery suggests that the wall seen today is not in the same configuration as it was in the early part of this century. The National Park Service rebuilt parts of the walls in the 1950s (Christopher Keeney, personal communication 1989). They apparently did not realize that the mass burial was there, and the wall was placed over top of it. The 1936 letter even states that the north wall was mostly collapsed at that time. It seems likely then, that the tree in the northeast corner and Sarah Ball's grave in the southwest corner dictated the placement of the north and south walls. Then the east and west walls only needed to match up with the others.

The second excavation unit was placed in an east-west direction crossing the first unit, four feet from the north
The unit was four feet wide and 12 feet long. The eastern end of the trench extended past a standing fieldstone marker. On the floor of the excavation the delineation between disturbed and natural soil could be made. However, the difference was subtle, the best indicator being sandstone chunks found at the surface. The profile of this unit showed the shape of the mass burial. The silty clay with sandstone rises in a slope several feet past the marker stone at the eastern end. This evidence indicates the edges of the hole were sloped, sort of bowl shaped. The western edge of the mass burial was found four feet from the west wall. Coring between the west wall and unit two revealed natural soil.

Two other test units were excavated east of the known graves. The third test unit was situated in an east-west direction, 18 feet down the east wall and 10 feet in from it. This unit was excavated because a fieldstone marker similar to the ones in the first two units is standing three feet in from the east wall. The unit was excavated the size of a grave, four feet wide and six feet long centered on the marker stone. Although no radar anomaly was detected near this stone the fact that three other markers were found in association with the mass burial warranted excavation. No grave disturbance was found in this excavation. The purpose of the standing stone was not determined. A possible
explanation for it is that someone incorrectly believed that a burial existed and placed the marker stone there.

The fourth unit was placed in the same position as the core holes east of the footstones. The excavation was 19 feet long, north-south, and continued outside the south wall three feet. It was also two feet wide east-west. The unit was approximately four-tenths of a foot deep. No grave shafts were discovered in this area. The top of a groundhog burrow was exposed as were several large tree roots. These are probably the sources of three of the original radar survey anomalies.

The information acquired from the four trenches indicates clearly that the coring technique works very well. It also provided evidence that the large disturbance is most likely the mass burial mentioned in the 1936 National Park Service letter. The letter stated that 16 soldiers were interred at the Ball Family Cemetery early in the twentieth century. The large area of disturbance, coupled with a military button and bayonet, are strong evidence for the mass burial.

The investigation at the Ball Family Cemetery proves that remote sensing, in conjunction with soil coring is a relatively quick, reliable and non-invasive method of discovering soil disturbances in the silty clay of Manassas. The fact that the mass burial pit was delineated accurately
through coring and subsequent archeological test excavations provided the remote sensing application with a good field test.

Magnetic Survey at The Marshall Cemetery

The magnetometer survey of the Marshall Cemetery was set up to cover only part of the same grid the radar used several years before. The anomalies detected by radar are concentrated on the south side of the cemetery, so that is where the magnetometer investigation was limited. It was not necessary to cover all the area that the radar had investigated previously (see Figure 9).

The station interval was two feet with the grid starting 50 feet south of the cemetery's southeast corner. On the west side it extended 12 feet past the west fence. On the north the grid extends into the cemetery by 10 feet. This allowed for stations over two rows of graves. The east side of the grid aligns with the east fence. As at the Ball Family cemetery, the survey grid was swept with a metal detector before the survey took place. All surface metal was removed, but anything more than a few inches below the surface was left in place.

This survey was conducted on the afternoon of July 3, 1989. During the survey, only two people and one instrument
were present. This required that the G-856 magnetometer return to a base station after each transect. The base was read five times and an average taken for each trip to the base station.

The sensor was set on an aluminum staff six feet in length, and the operator carried both sensor and control unit. The survey lines were numbered consecutively from one to 26, west-east. That is also how the grid was surveyed. A total of 31 stations in each line were read moving north-south, and returning to the base station after each line. A total of 806 stations were read by the magnetometer. After each reading was taken, the value was called out to the recorder who wrote the number down, and repeated it aloud for verification. The operator then stored the station value in the magnetometer's memory.

Rather than driving hundreds of wooden stakes as was done as at the Ball Family Cemetery, this grid was only laid out on the north and south sides. A non-magnetic tape measure was stretched between the numbered stakes at each end. When the tape was moved the line number was called out to verify the correct position on each side. In like manner, as the survey progressed, the distance down the tape was verified and station numbers were verified with the magnetometer's automatic counter. The field data was
rounded and diurnal calculations were made the same as at the Ball Family Cemetery.

With the corrected data in hand, the X, Y, and Z values needed for the SURFER program were produced in WordPerfect 5.0 and that information was downloaded into the computer at USGS. The result is Figure 10, a contour map. Several features are immediately apparent from this contour plot. A fairly strong east-west gradient is present between 50 and 52 on the Y axis. This gradient almost perfectly aligns with the cemetery fence on the south and west sides. Immediately to the north of the gradient are two magnetic highs. The gradient was at first suspected to be caused by the fence because it so closely aligns with it. However, subsequent experimenting with the magnetometer proved otherwise. Setting the sensor one foot inside and then one foot outside the fence along the same transect gave readings differing by as much as seven gammas, and averaging five. This test was run for five transects that crossed the fence. If the fence was the cause then the readings should have been relatively close inside or out. The fact that they were not demonstrates the effect of the brick-lined burial vaults some of the Marshalls are buried in. The weak magnetic highs just inside the fence may be due to the vaults also; however, the highs do not spatially correlate with the two closest graves on the south side.
Ground-Penetrating Radar Survey at Marshall Cemetery

The ground-penetrating radar survey was conducted at Marshall Hall in the summer of 1984. The operator and equipment time were donated to the National Park Service by the Soil Conservation Service. The operator and unit were the same ones that originally surveyed the Ball Family Cemetery in October of 1987. A 120 MHz antenna was used to survey the cemetery.

The area covered by the radar investigation at Marshall Hall is many times larger than that of the Ball Family Cemetery. It covered 200 feet north-south and 110 feet east-west (see Figure 9). Unlike the initial radar survey at the Ball Family Cemetery, this investigation of the Marshall Cemetery concentrated specifically on the problem of unmarked graves. That detail coupled with the fact that the soil at Marshall Hall is Coastal Plain sands - a very good radar medium - rendered the information from 1984 very valuable and no other surveying was necessary.

After the survey was complete, an anomaly map of the Marshall cemetery was drawn based on the radar operator's interpretations. The traverses are 10 feet wide with the antenna running down the middle of each transect. The direction of each run is indicated by an arrow. The anomalies considered likely candidates for graves are drawn
as rectangles within the traverse they were detected. The length of a rectangle is proportional to the length of an anomaly as seen on the graphic printout. The suspected grave anomalies are hyperbolic arches as have been discussed throughout this thesis (Figure 11 is an example).

**Comparing The Anomalies**

In comparing the radar and magnetic data of the site only one anomaly closely matches between the two remote sensing methods. This is the strong magnetic high just outside the southeast corner of the fence which correlates with GPR anomaly 11. The other anomalies, especially the magnetic ones, are rather small and do not relate. This is a disappointing amount of correlation. The fact that only one anomaly matches between the two methods indicates that the site probably does not contain many features of archeological interest.

**Archeological Testing**

Fourteen magnetic and 13 GPR anomalies were tested through soil coring at the Marshall cemetery. Well over 100 soil cores were made. Figure 12 illustrates where the core tests for magnetic anomalies were made. The core tests for
the radar anomalies were made approximately where they are drawn on figure 9. Each core test was completed by pushing the coring tool into the ground up to the end of the tube. After extraction, the soil was scraped flat creating a profile, measurements were taken and recorded. If natural stratigraphy was seen more than three times in most anomalies, the coring was discontinued. For the radar anomalies the core test interval was one-foot. The magnetic anomaly core test interval is shown in figure 12.

The soil that came up in the coring tool is a Pleistocene formation called the Talbot Terrace Formation (Hershberger and Compy 1948:188-189). The top foot consists of a sandy loam topsoil and a sand layer. In the next foot the sand gives way to a very sandy clay. In general, this soil is an excellent medium for radar surveys. Although, Weymouth (1986a:345) states that sandy soils of low magnetic susceptibility are generally unfavorable for archaeological magnetic surveying. Susceptibility readings of several samples from this site suggest that the susceptibility is fairly low, therefore, according to Weymouth not a favorable condition for this type of survey. The susceptibility readings were made at the USGS headquarters with a Bison Magnetic Susceptibility Meter 3101A. The reading obtained for soil cored from Margaret Marshall's grave is $1.07 \times 10^{-4}$.
emu/cc compared to a relatively high reading of Spencer Ball's grave soil of $3.48 \times 10^{-4}$ emu/cc. Despite Weymouth's caution, good magnetic data was obtained from the Marshall Hall survey, including a magnetic high perfectly matching a prehistoric firehearth discovered through coring.

Still, no unmarked burials were discovered through the soil coring method. After coring was completed on the site, only two of the GPR and one the magnetic anomalies could be explained. GPR anomaly 10 is probably caused by tree root disturbance, while GPR anomaly 11, which correlates with a magnetic high, was found to be a prehistoric Archaic Period fire pit. In an area approximately five-feet in diameter, at least 12 core samples brought up either bits of charcoal or burned sand. A shovel test pit located at coordinates $X=38$ and $Y=40$ discovered one broken stone axe head, one quartz core, and several quartz flakes. The fact that both radar and magnetics located a prehistoric feature is not surprising. Both techniques have been used previously to locate these types of features on prehistoric sites (Weymouth and Huggins 1985; Weymouth 1986a, 1986b).

Susceptibility and remanent magnetization readings were taken from cores within the burned soil. Remanent magnetization was measured with a Shoenstadt specimen magnetometer PSM-1 at USGS headquarters. The readings
showed a higher remanent than induced magnetization caused by heating the soil. Passing the Shoenstadt audible gradiometer over this region of the site produced a clear signal, indicating that the remanent magnetization was fairly high in the fire pit. The susceptibility reading of the subsoil in the fire hearth was $1.24 \times 10^{-4}$ emu/cc, and the remanent magnetization was $2.55 \times 10^{-4}$ emu/cc.
CHAPTER VI

ANALYSIS

The results of this research have answered some questions, while at the same time generating other considerations. For example at neither cemetery were any missing family members located through remote sensing. A plausible answer to this problem at the Ball Family Cemetery is that the infants were buried elsewhere on the property, or even at a churchyard cemetery. The children died well before anyone else was buried at the family cemetery. The expectation was that the infant burials started the cemetery, but that impermanent markers were used for them. Later, the other family members were buried near the babies and stone markers used. Another possibility is that impermanent markers were used and consequently, the person who performed the later mass burial disturbed at least the surface evidence of the babies' graves. Unfortunately, remote sensing did not answer these historical questions.

At the Marshall Family Cemetery only one unmarked interment was sought. The person supposedly died and was buried - after the family had sold the property - in 1866.
A single burial somewhere in a cemetery described in documents as one half acre may seem like seeking the needle in the proverbial haystack. Nonetheless, family and local tradition holds that the grave is either on the south or east side of the cemetery (Donald Steiner, personal communication 1989). Two present-day sources disagree as to how many graves there actually are at the Marshall Cemetery. Long (1983:31) states that there are 24 graves. In the same volume, McGarry says there are 18 and the tradition of one more in 1866. Twenty four is definitely an incorrect number, as only 18 were recorded in a 1927 survey of the cemetery. Currently 18 gravestones are visible. The Marshall Family Bible lists 18 burials up to 1827, so it is not inconceivable that an unmarked 1866 burial is out there somewhere; however, the most appropriate question may be "does it really exist" rather than "where is it?"

Summary of Magnetometer Data

The major magnetic anomaly obtained from the Marshall Cemetery is a pronounced gradient very near the six surveyed graves. That anomaly fits very well over the fence outlining the cemetery. The fence does not tightly mark the location of the graves, which initially led to the conclusion that the fence itself created the gradient.
However, experimenting with the magnetometer along the fence proved that it did not significantly affect the readings. The magnetic field was read one-foot inside and one-foot outside the fence at a number of locations. The readings inside were generally five gammas higher than those outside. If the fence was the real source of the gradient, the readings inside or out would have matched, because the distance from the fence was the same. The Plains - Sothoron Family cemetery (which also has vaulted graves) studied by Bruce Bevan did not exhibit this type of gradient. There are several possible explanations for this: the graves are not as close together there as they are at the Marshall Cemetery; the station interval used was five feet; and the contour interval used by Bevan is much coarser than done for the Marshall Cemetery. The soils at the two sites are similar so that is probably not a factor. Had the magnetometer survey continued farther into the cemetery, and over all the graves, the resulting anomaly would probably have been one large gradient with a few small highs or lows. It is doubtful that individual graves could have been identified because they are so close together.

The Triassic clays at Manassas are very different soils from the sand and gravels at Marshall Hall, which presents an interesting problem for the magnetometer. At the Ball Family Cemetery a magnetic low was exhibited over the five
known graves, and when ferrous objects were removed from nearby, that low joined with the other over the mass burial. The fact that a low was detected at all raises the question of cause. If the source of the low is the graves, what is the cause? A decrease in remanent magnetization known as viscous remanent magnetization is a plausible answer. The decrease is due to the disturbance of the soil by the graves. If this is truly the cause of the anomalies, then it markedly differs from other research which has shown graves to cause a magnetic high.

Summary of the Radar Data

At Marshall Hall only two radar anomaly sources could be identified by the core testing. The sources of the other anomalies do not appear to be soil disturbances. In every anomaly tested only natural soil was identified except one, and that is the prehistoric firehearth. The other sources are probably natural or buried objects such as tree roots and rocks. Since no graves were identified by this method it is difficult to judge the effectiveness of the radar at the Marshall Cemetery. However, the other reports mentioned previously indicate that GPR can indeed locate individual graves in sandy soil.
The radar data obtained at Manassas proved that even in the less than desirable conditions of silty clay, radar can locate soil disturbances such as a mass grave. Here again, no individual graves were identified, but the mass burial was detected. The fact that the GPR could not define the edges of the mass burial may be due to the shallowness of the disturbance at its borders. The inability of the radar to define the known graves is due to the closeness of the grave shafts. This problem has been discussed by Bevan, and is borne out through this study. Graves that are close together present problems for the radar. The lack of definition on the marked graves not withstanding, the radar was successful in locating an unmarked mass interment.

The later radar surveys were aided with advanced knowledge about the several large tree roots and an extensive groundhog burrow east of the marked graves. When the anomalies from those sources were seen they were identified as being produced by natural sources, and not unmarked graves. This evidence simply demonstrates the difficulty of interpreting radar data. Something as innocuous as a groundhog tunnel can lead to incorrect conclusions. Realizing that those kinds of problems exist is why researchers need to be cautious about their conclusions. This example also points out the absolute necessity of verifying the interpretations. The anomaly in
the SA line originally detected by the first radar survey was not studied again. A resurvey was not deemed necessary because the cause of the anomaly was determined to be several stones that lie there. If the later radar surveys had tested there, the anomaly from the stones would assuredly have been noticed again. This example also points to experience in interpretation. The operator knows he is looking for a particular kind of target and may assume that an anomaly is what he is looking for. The fact that the operator is predisposed in his way of thinking can be trouble, creating the potential problem of a self-fulfilling prophecy. This is not to say that the first radar operator was incompetent. On the contrary, he simply may have been trying a little too hard to locate unmarked graves and not noticed that the returns could have been created by several other sources. In many reports, other researchers make statements to the effect that an anomaly could be a desired feature, but that several natural sources can create the anomaly also. The researcher must weigh all the factors and consider several possibilities when interpreting radar data.

**Effectiveness of the Remote Sensing**

The successful application and overall effectiveness of these two remote sensing methods relies very heavily on one
factor that cannot be digitally reproduced - experience. This is especially true for GPR. Many people have viewed radar as being the next champion of archeology, detecting sites without "destroying" them by excavation. This author's concept of radar before using it was much the same. However, were it not for the benefit of operators experienced with both the radar and magnetometer this particular project would probably have achieved nothing.

Remote sensing is not absolute, nor is it magic. Rather, it is a sophisticated way of looking into the ground rapidly and noninvasively, but it has its limitations. This thesis is a good example of the scientific process. Scientific analysis and archeological interpretations were made based on scientifically obtained data. In the process the procedure for obtaining and interpreting data for the magnetic technique was refined.

When all was said and done the effectiveness of these two methods was proven to be rather convincing. At the Ball Family Cemetery both methods located the mass burial. Although neither was able to define the disturbance very well, the data show that some subsurface feature exists. A target was located giving archeology a place to test with the coring tool, and the more traditional method of excavation.
One of the goals of this study was to locate individual graves, but that was not achieved. At Manassas, the soil is a major prohibitor to GPR. On the other hand, it may be the very reason that the magnetometer detected something. The problem is probably less due to electronic shortcomings than the fact that no individual interments other than those marked are present. The fact that the known graves could not be individually defined geophysically is not a dilemma. Clear definition of features is sometimes a luxury even using traditional archeological techniques (Rhodes 1987).

At Marshall Hall the results point to an absence rather than a presence of unmarked graves. No burials were detected through either of the remote sensing methods, or the coring. Other researchers have located graves in sandy soil with both the magnetometer and GPR. Which – as stated before – leads to the conclusion that it is highly unlikely any unmarked graves exist at the Marshall Family Cemetery where testing was conducted.

**Summary of Coring**

The credibility of the coring method for locating archeological features has been established for a number of years. The fact that it worked so well at Manassas proves its reliability again. Archeologists seem to be aware that
coring tools are available, but they are seldom seen on many projects. Time consuming shovel test pits have been dug following a particular feature or stratum to its boundaries when a coring tool could do the job much quicker and easier. The efficiency, reliability, and less destructive qualities of the tool seem to be overlooked by many people in the field.

There is one caveat about the coring tool that must be mentioned. In clay soils like that of Manassas, the tool does not work very well when the ground is dry. Dry clay is nearly impenetrable, however, a soaking rain makes the coring much easier. If the tool does penetrate dry clay it is very difficult to get out again. The commercially available coring tools are not made to withstand the abuse that heavy clay soils will mete out. Two of the stainless steel tubes were destroyed at Manassas. Both were twisted into a corkscrew while trying to get the tool out of the ground. A new coring tube cut from pipe steel, fitted onto the aluminum handle, will not bend or break in the difficult soil conditions of the Piedmont.

Analysis of All Field Methods Employed

In analyzing all the field methods used in this study it was determined that they worked very well. The
magnetometer survey methods were tested and improved at Manassas before moving on to Marshall Hall. The two-foot spacing proved to be the best for locating small anomalies. Other researchers discuss the station interval, and the fact that it must be small to detect graves (Bevan 1986; von Freese 1984).

The height of the detector staff is given quite a bit of consideration by many of the researchers in the field. The height used at both sites discussed here was six feet. The source to sensor distance, as it is called, should not be anymore that one-half the size of the expected anomaly. This being the case, six feet is too high to detect individual graves. Regardless, the Ball Family Cemetery is so laden with ferrous artifacts that a shorter staff caused the magnetometer to lose the signal. Bevan used a two-and-one-half-foot staff to survey the cemetery at Mount Vernon. That height apparently worked without any problems, but the information gained seemed to be unreliable according to Bevan. The difference may be the environment, and a lack of the influence of viscous remanent magnetization at Mount Vernon. Despite the general rule concerning the source to sensor distance, the magnetic data acquired for this thesis is very reliable.

The various methods of reading the base station were experimented with to determine which one was the most
efficient. At first, it seemed that the automatic reading base station would be the best. A problem though, is having to rely on the electronics to work properly. One of the Manassas surveys had to be redone because the automatic base failed to record the readings after the first couple were stored. The batteries did not die and all the settings were correct. The instrument recorded a few readings and then just stopped.

Returning to the base with the survey instrument worked well even though there is a time lag between stations at the end of a transect and the base reading. The base recording method that worked the best was using a second magnetometer, and manually recording the values every minute. This, of course, necessitates having a second instrument.

The radar survey methods could be improved upon only slightly. The 10-foot width of the traverses were too wide. A five-foot spacing, though more time consuming leaves no room for missing any graves. Bevan typically uses a five-foot spacing, and at the Mount Vernon slave cemetery he used a two-and-one-half-foot spacing.

A major consideration in using radar is the soil to be tested. The sand and sandy clay of Marshall Hall is a good radar medium, but the clays of Manassas are not particularly suitable. One way to help the radar is to survey when the
soil is very dry, or when frozen. The Manassas radar surveys were timed to allow for dry soil conditions.

The Practicality of Remote Sensing

An obvious question about this remote sensing and archeological testing is "what is its usefulness?" The cemeteries that were studied are not under any type of threat, but in today's rapidly developing world many cemeteries are being destroyed. Some of those cemeteries have unmarked burials in them. The Poor Farm Cemetery is a case in point. The cemetery was scheduled for removal, and the study was undertaken to locate unmarked graves (Rhodes 1987). The large number of reports available for the literature review demonstrates that there is a wide interest in finding unmarked burials. The need may be simply answering historic questions such as were attempted here, or because a cemetery is being moved by development. There is a concern, both legal and ethical, about leaving graves unmolested. In the state of Virginia, unlawfully disturbing the dead is a class four felony, penalized by no less than two years in prison (Friedman 1987:20).

During the summer of 1989, the Smithsonian Institution, in cooperation with St. James Episcopal Church of Brandy Station, Virginia, excavated in the churchyard cemetery to
locate Civil War dead (Douglas Owsely, personal communication 1989). The goal of the project was to determine where and how many Civil War soldiers were buried in the church cemetery. Local tradition held that soldiers were buried there after the largest cavalry engagement of the war. The church is trying to save land adjacent to it, on the grounds that there are war dead buried there. Local development pressure is encroaching on the small historic church. The excavations located a number of unmarked graves that included church members but only one soldier. It was assumed that Civil War soldiers were generally buried in quickly dug, shallow graves and that the civilians would be buried closer to the requisite depth of six feet. With the depth function of radar, it could have located the shallow soldiers burials, and discounted the other deeper graves. Conducting a radar survey previous to the excavations could have saved a lot of time in unneeded digging.

Projects similar to Brandy Station could benefit from the depth estimations that radar operators can make. Other cemetery owners simply wanting to know if burials were made in an area could use the magnetometer to determine the location of a number of graves. The soil coring could then locate the individual interments. A magnetometer survey would be less costly than a radar search. The instruments themselves differ in price by thousands of dollars. The
researcher interested in very specific information such as depth and size would need the radar. On the other hand, the researcher interested in more general information could use the magnetometer. The soil coring methodology could be used to support either type of survey discussed above. For situations such as at the Chapel Field in St. Mary's City unfortunately neither technique as yet can define individual graves that are closely spaced or one on top of another.

The disadvantage of the radar method is that it can only be conducted in a relatively clear area. The sled must move without any obstacles or jarring. The magnetic method will go anywhere a person can go. The units are small and very portable. The cost of radar is also a major prohibitor to many archeological projects. A fully outfitted unit will cost nearly one-hundred thousand dollars. The magnetometer on the other hand is about five-thousand dollars and the SURFER program is about four-hundred dollars. Despite the cost differences, given a choice, a clear survey area, and enough funding, the archeologist interested in locating unmarked graves should opt for a radar survey. Some of the researchers mentioned in the previous chapters conduct radar surveys as a full time business.

Lastly, one has to ask what is the contribution of this study to archeology? The uniqueness of this thesis is that it has assimilated remote sensing data from a number of
cemeteries, and compared that all that data with what was discovered at The Marshall and Ball Family Cemeteries, then correlated similarities or differences. This is the first study the author knows of that incorporates numerous studies in drawing conclusions about the efficiency of magnetics and radar with respect to locating historic graves in different soil types. This study also showed that grave digging can cause a magnetic low. It had generally been assumed that burials would enhance susceptibility and create a magnetic high.

**Future Considerations in Remote Sensing of Cemeteries**

Further refinement of the remote sensing capabilities for historic grave location is still possible. Some of the advances will be made by geophysicists or engineers, and others by archeologists. Some of the refinements will be in the instrumentation; others in the procedures for acquiring, processing, and interpreting the data.

For example, consider the magnetic technique. The future use of vertical magnetic gradiometry for gravesite identification, in which the outputs of two sensors - mounted vertically on a staff - are algebraically differenced, is promising. This method strongly accentuates anomalies caused by shallow sources at the expense of less
interesting deep ones. This technique has recently been tested on a suspected graveyard at Monticello. The results were promising even in the presence of underground powerlines. Horizontal magnetic gradiometry, in which the output of sensors side-by-side are algebraically differenced may also be useful in delineating individual anomalies. Future surveying might use a finer grid spacing as well. Microcomputer programs permitting the production of dot density or grayscale plots continue to be developed.

Portable, susceptometers that directly measure near-surface magnetic susceptibility are available and can be profitably used in conjunction with total-field magnetometers or gradiometers. Special portable magnetometers capable of measuring remanent magnetization in the field are available and can be used for soil samples or objects.

Because some ferrous objects of interest in magnetic surveying also possess high electrical conductivity, devices for measuring this conductivity quantitatively are useful. Two such devices are the GEONICS EM-38 and EM-31 conductivity meters, already being used in some archeological applications. The French have been leaders in this technological advancement.

The GPR technique will also improve. The newer radar units with bistatic antennas may be able to better penetrate and define anomalies in the clay soils. Also, creating a
deep penetrating antenna that emits the radar pulses in a smaller cone that what is presently available might help with the problem of graves that are close together. Another GPR technique under investigation by Gary Olhoeft and his colleagues of the U.S. Geological Survey is 3-D tomography. Color tomography may prove to be helpful for unmarked burial location. Continuing remote sensing research such as this in archeological contexts may offer resolutions to the questions left unanswered, and those posed by this particular study.
BIBLIOGRAPHY

Aitken, Martin J.


Akasofu, Syun-Ichi

Alldred, J.C.

The Ball Family Bible.

Batey, Richard A.

Beck, A.E.

Belden, Frederick L.

Bell, Edward L.
1990 "The Historical Archaeology of Mortuary Behavior: Coffin Hardware from Uxbridge, Massachusetts." In *Historical Archaeology* 24(3):54-78.

Bevan, Bruce


1989b  A Test of Ground-Penetrating Radar at St. Mary's City, Chapel Field. Geosight. Submitted to Historic St. Mary's City, Maryland.

1989c  A Ground-Penetrating Radar Survey at St. Mary's City, Gallows Green. Geosight. Submitted to Historic St. Mary's City, Maryland.

1989d  Personal Communication: Owner, Geosight.


Browning, Lyle E.

Bruintjes Tj. D.

Buikstra Jane E.

Buikstra Jane E. and Della C. Cook

Chapman Robert W.

Clark, A.J.

Conner, E.R.
1981 One Hundred Old Cemeteries of Prince William County Virginia. Lake Lithograph, Manassas, Virginia.

Costello Julia, and Phillip L. Walker
1987 "Burials from the Santa Barbara Presidio Chapel." In Historical Archaeology 21(1)3-17.

Daniels, Jeffrey J.

Davis, John
1802 Travels in America, 1798 - 1802. A condensation by Violet Davis Thatcher. Privately Published, Fairfax Virginia.
Dobrin, Milton B.

Dougenik, J.A., and D.E. Sheehan
Laboratory For Computer Graphics And Spatial Analysis, Harvard University.

Ebert, James I.
1984 "Remote Sensing Applications In Archaeology." In
*Advances In Archaeological Method and Theory,* vol.

Ellwood Brooks B.
1990 "Electrical Resistivity Surveys in Two Historical
Cemeteries in Northeast Texas: A Method for
Delineating Unidentified Burial Shafts." In
*Historical Archaeology* 24(2)91-98.

Fremmer Ray
1973 "Dishes in Colonial Graves: Evidence from Jamaica."
In *Historical Archaeology* 7:58-62.

Friedman, Carol D.

Geophysical Survey Systems, Incorporated

Gerald, Herbert P.
1927 "Marshall Family Burying Ground at Marshall Hall
Maryland." *National Genealogical Society Quarterly*

Gjessing, Dag T.
Science Publishers, Ann Arbor.

Griffith F.M.
1990 "Aerial Reconnaissance in Mainland Britain in the
Summer of 1989." In *Antiquity* 64(242)14-33.

Hanna, William F.
1989 Personal Communication. Chief Geophysicist, United
States Geological Survey.
Hanson, Joseph Mills  
1936  Letter to: Branch Spalding, Assistant Director  
Branch of Historic Sites and Buildings, National  
Park Service, Washington D.C. On File At Manassas  
National Battlefield Park.

Hershberger, Merl F. and E.Z.W. Compy  
1948  "The Soils of Charles County." In The Physical  
Features of Charles County, edited by Joseph T.  
Singewald, pp. 185-202. Baltimore: State of  
Maryland Board of Natural Resources Department of  
Geology, Mines, and Water Resources.

Hester Thomas R., Robert F. Heizer, and John A. Graham  
1975  Field Methods in Archaeology. 6th ed. Mayfield  
Publishing Co., Palo Alto, California.

Hughes, Brady A. and Sarah S. Hughes  
1985  A Historical Study of the Marshal Site, 1634 to  
Submitted to the National Park Service, Contract  
No. CX3000-4-0154.

Imai, Tsuneo, Toshihiko Sakayama, and Takashi Kanemori  
1987  "Use of Ground-Probing Radar and Resistivity  
Surveys for Archaeological Investigations."  
Geophysics 52(2):137-150.

Jeanloz, Raymond  
1983  "The Earth's Core." Scientific American 255(4):56-  
65.

Johnston, Richard B.  
1964  Proton Magnetometry and its Application to  
Archaeology: An Evaluation at Angel Site.  
Prehistory Research Series vol. 4 no. 2. Indiana  
Historical Society.

Joukowsky, Martha  
1980  A Complete Manual of Field Archaeology. Prentice  
Hall, Englewood Cliffs, New Jersey.

Keeney, Christopher  
1989  Personal Communication. Maintenance Foreman,  
Manassas National Battlefield Park.

Kellock, Kathrine A.  
1962  Colonial Piscataway in Maryland. The Alice  
Ferguson Foundation, Accokeek, Maryland.
Kelso, William L.
1990 Personal Communication. Director of Archeology, Corporation For Jefferson's Poplar Forest.

Kenyon, Jeff L.

King, Julia A. and Bruce W. Bevan
1987 The Reliability of Geophysical Surveys at Historic Period Cemeteries: An Example from The Plains. Paper presented at the annual meeting of the Council For Northeastern Historical Archaeology, St. Mary's City.

King, Julia A. and Patricia J. Mcguire
1987 Archaeological Investigations at the Slave Cemetery, The Plains, Mechanicsville, Maryland. Ms. on file, Jefferson Patterson Park, Maryland.

Lane Rebecca A. and Audrey J. Sublett

Lerici, C.M.
1961 "Archaeological Surveys With the Proton Magnetometer in Italy." Archaeometry 4:76-82.

Logan Judith A. and James A. Tuck

Leute, Ulrich

Long, Susan

Longworth, G. and Michael S. Tite
Loose, Richard W. and Thomas R. Lyons  

Mann Robert  
1990 Unpublished Ms. on file at the Smithsonian Institution.

McGarry Thomas E.  

Mellet, James S.  

Miller, Henry  

Mullins, C.E.  

Nelson, Harry and Robert Jurmain  

Nickel, Robert  
1989 Personal Communication. Staff Archeologist Midwest Archeological Center, National Park Service.

Neiman, Frazer D.  

Owsley, Douglas  
Parasnis, D.S.

Parker Kathleen A., and Jacqueline L. Hernigle

Parrington, Michael

Parrington, Michael and Janet Wideman

Petrone, Claude E.
1990 Personal Communication. Manager, Special Photographic Projects, National Geographic Society.

Prince William County Deed Book Q.
Prince William County Deed Book 4, Role 9.
Prince William County Court Records. Will Book M. N. R.

Ralph, Elizabeth K.
Rathbun, Ted A.

Regan, R.D.

Rhodes, Diane L.
1987 Archeological Investigations at the Poor Farm Cemetery. National Park Service Denver Service Center Rockville, Maryland. Submitted to Montgomery County, Maryland, Cooperative Agreement CA1200-5-004.

Ries, H., and R.E. Somers

Riordan, Timothy
1990 Personal Communication. Staff Archaeologist, Historic St. Mary's City Commission.

Scollar, Irwin

Scollar, Irwin, Bernard Weidner, and Karl Segeth

Scott, Douglas D. and Richard A. Fox

Shapiro, Gary

Sharma, P.V.
Steiner, Donald
1990  Personal Communication. Park Ranger, Piscataway National Park, Maryland.

Stein, Julie K.

Tabbaugh, A., G. Boussuet, and H. Becker

Tarling, D.H.

Telford, William M., D.A. keys, L.P. Geldart, and R.E. Sheriff

Thomas, David H.

Thomas, David H., Ervan G. Garrison, and James G. Baker

Tite, Michael S.


Tite, Michael S. and C.E. Mullins
Toogood, Anna C.  1969  *Piscataway Park Maryland, Historical Background Study.* Office of Archaeology and Historical Preservation, United States Department of the Interior, National Park Service.


1986b  "Archaeological Site Surveying Program at The University of Nebraska."  *Geophysics* 51(3):538-552.
Weymouth, John W., and Robert Huggins

Weymouth, John W. and Robert Nickel

White, Esther

Wynn J.C.
Figure 1. Partial family tree of the Carter and Ball families, number beside names indicates a grave in the cemetery.
FIGURE 1

Robert "King" Carter

Robert Carter II

Robert "Councillor" Carter III

George Carter

Elizabeth Landon 2 Carter Ball

m.Spencer 1 Ball

m.Sarah 5 Ball

Alfred 4 Ball

Frances Tasker Ball Lewis

Francis 3 Ball

Churchill? Elizabeth? Ball

Frank Lewis

m.Frances "Fannie" Lewis

Fannie Tasker Lewis

Rosa Lewis

Robert Lee Lewis

Warner Lewis

Robert Lee Lewis Jr.

Janice Lewis

sold the property out of the family
Figure 2. Family tree of the Marshalls from 1640 – 1867 number beside names indicates a grave in the cemetery, note that number 18 is missing from the tree. (after Hughes and Hughes 1985).
FIGURE 2

THE MARSHALL FAMILY, 1640-1867

William I
Immigrated to Maryland c. 1640
(1673)
m. Katherine Hebden

William II
(c. 1670-1698)
Joshua
Elizabeth

m. 1. Elizabeth Hanson (m. 2. John Fendall)

William III
(1690-1734)
Barbara
(1692- )
Thomas I
(1695-1759)
Richard
(1697- )

m. 1. Elizabeth Bishop Stoddert
(1693-1750)
m. 2. Sabina Trouman Greenfield
(1715-1768)

Elizabeth
(1727-1728)
Mary
(1729-1753)
Thomas Hanson II
(1731-1801)
Elizabeth
(1733-1740)
Sarah
(1735-1795)

m. 1. Rebeckah Dent
(1737-1770)

(Dr.) Thomas III
(1757-1829)
Ann
(1759-1785)
George Dent
(1763-1764)
Elizabeth
(1765-after 1785)
Mary
(1767-1789)
George Hanson
(1770-1775)

m. 1. Anne Clagett
(1778-1805)
m. 2. Margaret Marshall
(1766-1837)

Thomas Hanson IV
(1796-1843)
Richard Henry
(1799-1884)
Rebeckah Maria
(1801-1802)
George Dent
(1802-1822)

m. 1. Eleanor Ann Hardesty
(1801-1852)

Eleanor
Rebeckah
(1822-1829)
Margaret
(1824-1833)
Thomas V
(1826-1903)
Mary
Catherine
(1829-1833)
Eleanor
Douglas
(1828-1833)
George
Richard
Henry
(1832-after 1888)
Harriet
Rebeckah
(1833-1863)

m. 1. Sarah Lyles
(1827-1855)
six children
m. 2. Henrietta E. Lyles
(1837-1880)
ten children
Figure 3. Map of features and archeological testing at the Ball Family Cemetery
Figure 4. A typical hyperbolic arch radar anomaly.
Figure 5. Contour map of the magnetometer data from the first Ball Family Cemetery survey, crosses indicate station locations.
Figure 6. Map showing station locations inside the Ball Family Cemetery, using a two foot station interval, crosses indicate station locations.
Figure 7. Contour map combining first and second Ball Family Cemetery surveys, crosses indicate station locations.
FIGURE 7
Figure 8. Contour map, west half of Ball Family Cemetery, surveyed after trenching and removal of ferrous objects, asterisks indicate station locations.
FIGURE 8

Edge of Mass Burial

Wall
Figure 9. Map showing location of ground penetrating radar anomalies at the Marshall Family Cemetery.
FIGURE 9

Key:

— x —
Fence

— — —
Magnetometer Survey

Radar Anomalies

GPR Run Direction

Tree

Marker Stones

Scale:

0 ft.  20 ft.
Figure 10. Contour map of magnetic data from the Marshall Family Cemetery, asterisks indicate station locations.
Figure 11. Hyperbolic radar anomaly from the Marshall Family Cemetery, anomaly number 10.
Figure 12. Map showing areas cored for the magnetic anomalies at the Marshall Family Cemetery.
FIGURE 12

Core tests
VITA

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