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Archaeological Geophysics

Archaeological geophysics is a method of data collection that allows field archaeologists to discover and map buried archaeological features in ways not possible using traditional field methods. Using a variety of instruments, physical and chemical changes in the ground related to the presence or absence of buried materials of interest can be measured and mapped. When these changes can be related to certain aspects of archaeological sites such as architecture, use areas, or other associated cultural features, high-definition maps and images of buried remains can be produced. Geophysical techniques are usually most effective at buried sites where artifacts and features of interest are located within 2 to 3 meters of the surface, but they have occasionally been used for more deeply buried deposits.

A small but growing community of archaeologists have been incorporating geophysical mapping techniques as a routine field procedure for many years (Gaffney and Gater 2003). Their maps act as primary data that can be used to guide the placement of excavations or to define sensitive areas containing cultural remains to avoid. Some archaeological geophysicists have also started using these methods as a way to place archaeological sites within a broader environmental context to study human interaction with and adaptation to ancient landscapes (Kvamme 2003).

Ground-penetrating radar (GPR) is one of these geophysical methods that involves the transmission of high-frequency radar pulses from a surface antenna into the ground. The elapsed time between when this energy is transmitted, reflected from buried materials or sediment and soil changes in the ground, and then received back at the surface is measured. When many thousands of radar reflections are measured and recorded as antennas are moved along transects within a grid, a three-dimensional picture of soil, sediment, and feature changes can be created.

Mapping using GPR as well as other geophysical techniques has recently become so accurate that the possibility now exists to test any number of working hypotheses concerning a broad range of anthropological, geological, and environmental questions. Some of those could be related to social organization and social change, when these cultural attributes can be directly related to the placement, orientation, size, geometry, or distribution of certain architectural and ancillary features on the landscape. Determining geological and environmental aspects of ancient landscapes such as soil changes and the nature of buried topographic features is also possible (Conyers 1995; Conyers and Spetzler 2002; Conyers et al. 2002). Most important, GPR and other geophysical methods can gather a great deal of information about the near surface in a totally nondestructive way, allowing large areas with buried remains to be studied efficiently and accurately, while at the same time preserving and protecting them.

Recent advances in all near-surface geophysical methods, including GPR, have captured the imagination of many in the archeological community and have prompted some field archaeologists to routinely employ geophysical techniques in their own research. Although only a small fraction of field archaeologists, especially in the Western Hemisphere, are routinely including GPR and other methods as part of their "bag of tricks," the field is growing rapidly and will soon become, one hopes, a standard and accepted operating field procedure. Cultural resource managers have rapidly grasped the power of geophysical methods to quickly, efficiently, and nondestructively discover and map sites for selective excavation or avoidance, producing greater economy of time and resources (Johnson 2004). Research archaeologists have also been drawn to the power of geophysics not only to discover buried remains but also to place subsurface information from standard excavations into an overall site context. In this way, a limited amount of information from the known can be projected to areas of a site that remain buried and often will remain so. Ultimately, geophysical mapping allows for a more complete analysis of many archaeological sites in ways that could only be dreamed about just a few years ago because of its ability to evaluate large areas of buried and otherwise invisible archaeological sites quickly and accurately.

The goal of this book is to introduce all types of archaeological researchers to the power of GPR and to inform and guide those who hope to use, or have al-ready used, these techniques in their work. This will be done by discussing the most commonly used data collection and processing methods, using case studies from around the world to illustrate both successes and failures, in order to demonstrate the power as well as pitfalls of the method. While these procedures can vary depending on the questions asked, local conditions encountered, equipment used, and the data collection, processing, and interpretation methods employed, most of the basic methods will be discussed.

GEOPHYSICAL METHODS FOR ARCHAEOLOGICAL MAPPING

The most common near-surface geophysical methods used in archaeology are magnetometry, resistivity, electromagnetic conductivity, and the topic of this book, GPR (Clark 1990; Gaffney and Gater 2003). Magnetic methods employ passive devices that measure small changes in the Earth's magnetic field that are influenced by changes in soils and buried materials below the surface. These changes, if related to cultural or geological phenomena of interest, are then mapped spatially and can tell much about the patterning of some magnetic features in the near surface. The other three common geophysical methods are active methods, in that they transmit energy into the ground and then measure how that energy is affected by cultural, geological, or environmental changes in the ground. As with magnetometry, it is hoped that the mapped changes can be related to phenomena of interest to the archaeologist, such as the presence or absence of buried cultural features or geological changes that are meaningful. Resistivity transmits an electrical current into the ground and measures the differences in voltage between the transmitting device and a recording device some distance away. A similar method of energy transmittal is used in electromagnetic (EM) conductivity, except a geometrically complex EM field is induced into the ground, and measurements are made of the effect of that field on the underlying deposits. In this method, both electrical and magnetic properties of the ground can be measured.

Many other geophysical techniques can be used to measure other properties of materials in the near surface, which are either not commonly used or still in the experimental stages. One of these is thermal imaging, which measures the radiation of heat from the ground over periods of time. Changes in radiation are theoretically related to differences in materials near the surface. Spontaneous potential measures the background electrical potential of buried materials, which differ based on their composition and water content (Reynolds 1998). Magnetic susceptibility is a technique that takes readings of the ground directly through boreholes or probes in order to measure the remnant magnetism of buried materials. These readings can often be related to soil property changes that are affected by human modification of the landscape, or natural soil and sediment formation processes. Seismic reflection and refraction is similar to ground-penetrating radar except the active energy source propagated into the ground is sonic waves and not radar energy. In the future, the seismic method has the potential to map buried sites in three dimensions much like GPR, but at present it is hampered somewhat by its expense and the slowness in collecting and processing data (Hildebrand et al. 2002; Ovenden 1994).

HISTORY OF GEOPHYSICAL SURVEYS IN ARCHAEOLOGY

Archaeologists have long experimented with methods that will allow them to see or visualize in some way what is below the ground, sometimes resorting to many relatively crude methods such as random or systematic shovel tests, trenching, soundings, probing, and even nose-sensitive dogs or other even less scientific techniques such as dowsing (van Leusen 1998). These approaches, for the most part, have proved to be less than accurate, often expensive, potentially destructive, or producing small looks at the subsurface that are not statistically representative. As a result, many deeply buried or otherwise invisible sites remained mostly hidden and unstudied. It is those buried sites that are most suitable for discovery and mapping using near-surface geophysics.

A few rudimentary geophysical surveys that attempted to map buried cultural remains were carried out in Europe and North America in the1920s and 1930s, but these proved to be, at best, anomaly-generating exercises that were difficult to interpret (Gaffney and Gater 2003: 14). These early experiments were conducted primarily with magnetic and electrical tools developed for mining and petroleum exploration applications, and the anomalies recorded by them were often found to be related more to geological changes rather than to the presence of archaeological features in the ground.

Beginning in earnest during the 1950s, a few pioneering geophysicists began experimenting with electrical and magnetic methods as a way to quantify ground conditions and potentially discover and map hidden archaeological remains (Bevan 2000). In contrast with many of today's techniques, these initial attempts at "seeing below the soil" were crude but still effective enough to generate usable maps of buried sites, which piqued the interest of some archaeologists. Some of these early surveys were conducted with equipment as simple as a car battery, wires, and a voltmeter (Bevan 1998). Others were little more than sophisticated metal detectors, but ultimately these early studies (Aitken 1958) paved the way for all future work.

For the most part, early geophysical surveys collected data that were recorded as data points on paper, for later hand mapping. Some data were recorded on magnetic tape, which could later be digitized, but those more sophisticated data storage and processing attempts were generally the exception. Sometimes field data, as in the case of early ground-penetrating radar reflections, were printed on paper and could later be analyzed in three dimensions, but often this step was time-consuming and fraught with processing and interpretation problems (Bevan and Kenyon 1975). Having to write data points collected in the field on paper, or use paper copies of field records, and then attempt to make sense of them later on limited the amount of area that could be surveyed and the types and quality of data processing that could be accomplished.

With the advent of fast and relatively inexpensive computers in the mid-1980s, geophysical systems evolved rapidly into tools that could record data digitally on computer disks or tape, and then allow those data to be processed after returning from the field. This enhanced their quality and speeded mapping and subsequent interpretation. Collecting data digitally allowed much larger areas of ground to be covered and increased the data density dramatically, creating maps and images of much greater precision. The small but enthusiastic archaeological geophysical community quickly recognized the power of computer collection and processing, and near-surface geophysical techniques advanced rapidly throughout the 1990s.

Today, with some systems, many megabytes (sometimes hundreds of megabytes) of data can be recorded each day, covering large areas of land with very dense grids of potentially meaningful data. With the computer-processing power now available, these data can be readily made into usable maps, sometimes within hours of collection, giving geophysics for archaeology the "immediate gratification" component that was heretofore reserved for those archaeologists digging and observing artifacts and features in standard excavations. This ability to quickly produce accurate images of below ground features in a way that can be immediately interpreted not only is useful but also gives these methods a greater legitimacy with the more traditional archaeologists. It is this power to produce usable images of buried materials quickly and accurately that has transformed geophysics from what would otherwise appear to be strange squiggles on a computer screen, or streams of data on a computer hard drive, into a technique that produces understandable and immediately usable maps. Geophysical maps can then be readily interpreted by field archaeologists in order to plan excavations and understand the nature of buried deposits. Most important, the output is in a form that the human brain can readily interpret, which is one of the reasons that archaeological geophysics has recently seen such a surge of interest from the archaeological community.

ARCHAEOLOGICAL GEOPHYSICS TODAY AND THE GOALS OF THIS BOOK

Many techniques of archaeological geophysics used today have been borrowed or modified from other disciplines, making this subfield of archaeology, by necessity, multidisciplinary. Most of the early techniques that showed promise were developed by researchers with physics or geology backgrounds, and they were often applied to archaeological sites as an adjunct to other more important data-gathering tasks. Magnetometry was originally developed by researchers hoping to locate geological structures capable of containing economically valuable minerals or other deposits (Aitkin 1958). Some of those electromagnetic tools were developed to map deposits as varied as hazardous wastes, volcanic intrusions, and groundwater deposits (Reynolds 1998). Ground-penetrating radar as we know it today was originally developed for the U.S. space program to map the depth and variation of deposits on the moon (Simmons et al. 1972). The technique, as with many other geophysical methods, was quickly modified and adapted for many geotechnical applications and ultimately to archaeology.

Today most of the near-surface geophysical instruments are still manufactured for applications other than archaeology, as no manufacturer can afford to develop these expensive tools for the archaeological market alone. As a result, the archaeological community is almost always forced to use "off-the-shelf" geophysical systems, whose manufacturers are motivated by profit (little of which is generated from archaeological customers). The archaeological community by necessity has had to learn how to make these geophysical systems developed for other types of studies work for their own needs. This can be both a blessing and a curse. While it is nice to have geophysical systems that are well tested and supported by manufacturers that can be used for archaeological mapping, often the systems' standard data collection and processing procedures must be modified for archaeological needs. Also, much of the standard software processing and imaging packages were developed for scientists more interested in finding buried pipes or geological deposits, and therefore they must be diligently applied and often modified for archaeological requirements. Recently, by necessity, archaeological geophysicists have had to produce their own software programs specifically for archaeological applications.

Today almost all field archaeologists, at least in the Western Hemisphere, are trained in anthropology departments, although there are always a few students that make their way to archaeology from other disciplines. Those of us who teach in anthropology departments are quite aware that many of our students were drawn to archaeology for a number of nonscientific reasons, such as their joy of finding or working with interesting artifacts, perhaps their inability to get through advanced mathematics or science courses, and even the romance of archaeology in popular culture. In the recent past, this has often meant that many anthropology students had a very difficult time comprehending the physics or math that is necessary to understand geophysics, which may be one reason archaeological geophysics has grown relatively slowly compared to geophysics employed in other disciplines. This situation is now changing rapidly as a younger generation, raised with computers and not necessarily terrified by the prospect of analyzing digital data, has entered the field. It is encouraging that many of this new generation of archaeology students are ready both to learn and apply geophysical techniques in their own research, but unfortunately many are still not introduced to the subject in their typical college class work. This situation can only improve as geophysical methods become more common and are shown to be successful, and as a new generation of computer-savvy students move into leadership, management, and teaching positions.

This book is not intended to be a complete "how-to," step-by-step manual to the GPR method for archaeological mapping. Its goal, instead, is to introduce archaeologists to the method both theoretically and methodologically, with examples of both successes and failures. Complicated formulas, electronic wiring diagrams, and especially step-by-step instructions on how to work each GPR device by choice are *not* included. There are simply too many systems available, and a corresponding abundance of processing and image generating programs for each. To delve into the details of their own chosen GPR system or software package, readers will have to refer to the cited reference material, equipment manuals, or other technical sources, which are continually being modified and advanced by each GPR system manufacturer and researcher.

Most published articles that include any component of archeological geophysics always emphasize the successes, often with striking images of spectacular buried features, leading many to believe, often erroneously, that one or the other method is the greatest thing in archaeology since the invention of radiocarbon dating. This tendency to focus only on geophysical successes, while relegating failures elsewhere, is something all archaeological geophysicists are guilty of. Unfortunately, it leaves the impression on some that geophysics can do most anything, or on others that one method "works well" while others may not. These impressions are unfortunate, especially when an attempted survey cannot do what is desired for one reason or another, leaving the geophysically uninitiated with the erroneous impression that some techniques "don't work," giving all geophysical methods a bad name. It is therefore extremely important that geophysical archaeology be done in a deliberate manner, allowing for multiple working hypotheses to be tested and modified during the course of data collection and processing. Most important, when a survey is not successful in producing the results anticipated, the geophysical data and other information about the site should be reanalyzed and evaluated in order to determine why the final product did not produce the desired results. All the factors that could conceivably have affected the quality of the final product each step of the way must be understood by all involved in order for any results to be useful. Unfortunately, this type of thoughtful and reflective analysis is rarely the case, as most archaeologists neither want to nor have the background to understand the complexities of both the geophysical methods employed and the nature of the geological and archaeological complexities they may have confronted in the near surface. This is one of the many ongoing problems this book hopes, at least partially, to overcome.

It is doubtful that a totally uninitiated enthusiast of geophysical archaeology will pick up this book, read it, and be able to immediately go to the field and collect and interpret meaningful GPR data. It takes most beginners a fair amount of time to become proficient with the mechanics of data collection, transfer, processing, map making, and, most important, interpretation of results. Often it is necessary first to collect data, process them, perhaps test a site with auger holes or excavations for subsurface confirmation, and then think about what the maps that have been produced are illustrating about what lies below the surface. In all cases, GPR is measuring "something" in the ground, but determining exactly what that is always takes some thought and, most important, experience.

It is hoped, therefore, that this book will serve three purposes: first, to initiate archaeologists to GPR so they can begin to understand why and how the method works, depending on the problems to be solved; second, to provide a sufficient background so that archaeologists can set up their GPR surveys in a manner that the data collected will have the correct acquisition parameters for production of optimum images; third, once data are processed and interpretation becomes necessary, to provide a background with which to evaluate what is actually being measured and illustrated, and how those measurements change with differing field conditions. When GPR data are processed, but may not be immediately interpretable (a fairly common occurrence for the unexperienced), it is hoped that readers will be able to refer back to this book and other references in order to rethink what was done. They may need to reprocess databases or even repeat data collection or processing steps in a different way, sometimes with different tools, in order to refine and modify techniques for more positive outcomes.

Geophysical data collection and interpretation are not like learning to type or use a generic software program. Each site where geophysical data are collected is different in many ways, archaeologically, geologically, and environmentally. The variables that must be controlled for, and the collection and processing techniques that must be modified to produce a usable final product, are numerous, which is what makes the methods described here both challenging and potentially rewarding.

This book will begin with a discussion of GPR theory and method so that readers can become versed in how radar waves travel and are reflected in the ground. Only then will field setup and GPR collection procedures become meaningful, as they must be modified every time a new site is studied for what are always unique conditions. As simple as some field setup and calibrations seem to many, the thought that goes into a geophysical survey at the outset with regard to grid size, transect orientation and spacing, and ground surface preparation can often drastically affect a survey's final outcome. Often general equipment setup procedures must be altered and modified based on knowledge of both surface and subsurface ground conditions, size and orientation of potential archaeological features, and surface irregularities and disturbances. Most important, the type of the equipment being used and its unique acquisition parameters must be modified and possibly altered when information about the site conditions becomes apparent. If survey methods and procedures are not well thought out before the first bits of data are collected, the accuracy and interpretability of the final product will often be in doubt.

Appropriate processing and interpretation techniques for the GPR method are also an extremely important part of the technique and often the most difficult to master. Processing methods are constantly changing as new computer software is developed and improvements made to older "standard" techniques. As a result of this rapidly changing software environment, specific programs and techniques will not be discussed in detail, as this information would be made quickly obsolete. Therefore, only general methods, which are common to most GPR processing programs, will be covered. Each reader must search out the most appropriate programs for his or her needs, with the help of others working and developing methods for each GPR system.

Accurate and useful interpretation of the data, however, always comes with experience. Many successes and some possible pitfalls are included here, with information on how the data were processed and then interpreted for each. Readers, however, will likely be faced with new and different problems for each survey that is conducted, and therefore all techniques must by necessity remain somewhat fluid as different conditions are encountered and new and better field and laboratory methods are discovered and improved upon.