

THE ROLE OF GEOPHYSICAL SURVEY IN BURIED ARCHAEOLOGICAL SITE DISCOVERY AND EVALUATION

Staffan Peterson¹ and G. William Monaghan²

Glenn A. Black Laboratory of Archaeology, Indiana University
423 North Fess Ave., Bloomington, Indiana 47408 USA
Email: 1stapeter@indiana.edu; 2gmonagha@indiana.edu

Abstract

While vast improvements in equipment and data processing over the past few decades have resulted in the regular application of geophysical prospection in archaeological survey, little is known about the relative costs and outcomes of such survey relative to invasive methods of survey for deeply buried cultural strata. This paper presents some results from the Minnesota Deep Test Protocol (MDTP) project, which directly compared the costs and outcomes of several geoarchaeological methods, including solid-earth coring, backhoe trenching, and geophysical survey. The results indicate that costs, but not outcomes, for all of the methods are similar and backhoe trenching procedures, followed by solid-earth coring, are more reliable techniques for buried site discovery than most geophysical methods. In deep testing situations, geophysical survey appears most effective for guiding excavation during site evaluation once basic stratigraphy, lithology and sedimentology are known via geoarchaeological testing.

Introduction

Over the past few decades, cultural resources management (CRM) regulations have become important driving factors for archaeological research. While much effort has been directed toward developing scientifically sound procedures for the discovery and evaluation of surface archaeological sites, much less effort has been directed toward formulating clear and concise protocols for more deeply buried cultural resources (deposits below the limit of standard surface survey techniques, e.g. >1m below surface) (Monaghan & Lovis, 2005). CRM practitioners have come to recognize the scientific merit and archaeological value of discovering such buried and potentially stratified prehistoric sites, and also the very serious consequences that may result from not discovering them (e.g. MacDonald, 2006). Even though testing for deeply buried sites has become an increasingly important in the compliance process, basic guidelines for such testing provided to the CRM industry are variable, and may reflect the particular training or biases of agency archaeologists rather than guidance based on comparative tests of methods and procedures (Monaghan & Lovis, 2005).

Though a variety of techniques can be employed to identify buried archaeological resources, archaeologists have traditionally employed invasive testing techniques such as hand and mechanical coring, augering or trenching (Monaghan & Lovis, 2005). Noninvasive geophysical prospection techniques are increasingly utilized because of their lack of impact on buried archaeological resources. While their use for general site discovery has been advocated (Dalan, 2001; Dalan & Bevan, 2002), less is known about the effectiveness of remote sensing techniques for discovering deeply buried resources. This is particularly true for the types of low-density sites often encountered in alluvial settings.

The question of effectiveness is paramount because, regardless of cost or relative disturbance, if a survey technique cannot reliably discover its intended target it is of little value in the deep test process. Within a regulatory compliance setting, finding a balance between reliable detection, minimal disturbance and cost effectiveness is particularly critical and difficult. Moreover, without direct comparisons and assessments of the relative costs and effectiveness of the commonly employed deep test methods, this task is impossible. This paper describes such a comparative trial – the Minnesota Deep Test Protocol (MDTP) project. The goal was to provide such data by directly comparing the costs and outcomes for a number of commonly used deep test procedures within six test locales (Monaghan et al., 2006). The results of the MDTP project indicate that from a cost-benefit standpoint, direct

sampling - particularly backhoe trenching - is the most effective means of discovering buried archaeological resources both in terms of cost and benefit. This study also found that geophysical methods often have limited value for deeply buried site discovery, but can provide significant information during the initial evaluation of buried sites.

Geophysical survey within a CRM context.

Application of geophysical survey in the CRM contexts has been sporadic. Reasons for this may include at one extreme skepticism among compliance officials based upon a lack of understanding of the strengths and limitations of geophysical survey, or at the other extreme, inappropriate use where regulatory have become enamored of the technology for its own sake. Both these extremes are detrimental of sound CRM practices. In the first case geophysical surveys may simply be underutilized, and in the second, applied in contexts where they probably cannot succeed (Isaacson et al. 1999; Schurr, 1997). Both of these can lead to poor survey results, serving only to further confuse or disappoint managers, practitioners and clients. In spite of these concerns, geophysical survey and its promise of rapid, non-invasive investigation of cultural resources continues to gain in interest and visibility in the CRM realm and the public at large.

Efficacy and cost concerns are only multiplied in alluvial settings. Such surveys are even more problematic and fraught with compliance difficulties than those in shallow-site situations because of the complex relationship between the geophysical properties of cultural and geological strata commonly found in deeply buried settings (Clark, 1992; English Heritage, 1995, Somers & Hargrave, 2004). One of the most significant challenges here is under-determination of the sources of geophysical anomalies, arising from survey design, sampling choices, and low signal-to-noise ratios typical in complex alluvial settings (Bates & Bates, 2000; Hey & Lacey, 2001). In addition, sequential ephemeral occupations typical in prehistoric floodplain sites and the regular stratification during floodplain inundations, results in overall poor magnetic susceptibility contrast. Similarly, low resistivity contrasts are common where poorly sorted gravels, highly variable grain-size distributions in vertical profile, and other sedimentary and stratigraphic issues are present (e.g. Linford and Linford, 1995; Scollar et al., 1990; Weston, 2001).

These concerns underscore the desirability of developing a well-constructed stratigraphic model of the subsurface prior to geophysical investigation, including detailed physical and geophysical properties of soils and sediments. For compliance purposes, a geophysical survey can neither be adequately designed nor accurately interpreted without basic understanding of soil and sediment geophysical properties. Clearly, testing in deep alluvium is best addressed by a combination of field techniques centered on invasive (e.g. English Heritage 1995:12). The MDTP study also reached this conclusion in regards to the relative place of geophysical survey in the deep testing process. This observation is especially true for the types of low-density, buried sites common for prehistoric North America and underscores the role that geophysical survey should play in the deep test process. Ultimately, using geophysical survey for the discovery of buried sites in settings where stratigraphy and sedimentology are poorly understood will generally be unproductive, which is consistent with our experience in the Midwest USA.

While geophysical methods may have limited utility for deeply buried site discovery, these methods have great value when they can be part of the development of a holistic understanding of the sedimentological and geoarchaeological realm for the site (Monaghan et al., 2006). Regardless of setting, geophysical techniques require some knowledge of the subsurface to be properly designed and interpreted, a caveat of heightened importance in alluvial settings (Somers and Hargrave (2004).

Geophysical Survey and the Minnesota Deep Test Protocol (MDTP) Project.

The MDTP project included three types of methods, each highlighting different needs and approaches in site discovery and evaluation. These methods, commonly used in archaeological deep testing (Monaghan & Lovis 2005), included: 1) three complementary geophysical survey methods; 2) a sequential coring and augering process; and 3) mechanical trenching (Monaghan et al., 2006). In the

MDTP project, backhoe trenching consisted of excavating several ca. 1 m x 5 m trenches within each testing locale and examining and/or sampling trench walls for archaeological material and features. Coring and augering also directly sampled the subsurface and proceeded in steps. Subsurface horizons believed to be of high potential for containing buried cultural material were first identified from a set of continuous, solid-earth cores collected using a GeoProbe™ hydraulic device. The presence of cultural material was then tested by screening samples of the “target” horizons acquired with flight augers (see Monaghan et al., 2006 for detailed descriptions of coring/augering and trench procedures).

Though a number of well-established geophysical methods can be used to detect shallow subsurface features (Parasnis, 1997), the particular techniques and instruments used in this study were selected because they are the most commonly employed in modern archaeological survey. Geophysical surveys included magnetometry (Geoscan FM36 magnetic gradiometer), multi-probe resistivity (Geoscan RM15 and MPX15 multiplexed earth resistance meter), and GPR (Sensors and Software Noggin SmartCart 250 MHz GPR unit; Monaghan et al., 2006). Magnetic survey data is typically restricted to two-dimensional measures of the relative intensity of magnetic fields present near the ground surface (i.e., < 1 m depths). Resistivity, when used as multi-probe arrays, and ground penetrating radar (GPR) can provide deeper, three-dimensional information not only about the depths and configurations of anthropogenic features, but also about soil and sediment textures, subsurface moisture conditions, depths to bedrock, and presence of underground voids (Conyers 19XX). In addition, these methods, particularly GPR, can provide detailed images of subsurface sedimentary structures and/or cultural features.

The geophysical surveys were conducted by sampling at regular intervals along consistently spaced parallel transects (.5m transect spacing for magnetometry and GPR; 5m wide resistivity multiplexed twin array with 1m interprobe spacing) within each test locale. Sampling intervals for the surveys were chosen to be appropriate to the scale and geophysical contrast of subsurface features (Somers & Hargrave, 2004) and, as best as could be done, reflected the relationship between soil composition, soil moisture, and feature geometry as suggested by Weymouth (1986). The three deep test methods used for the MDTP project (trenching, coring, geophysical survey) have their own advantages and disadvantages, and significantly, have different levels of impact to the subsurface. For example, the geophysical surveys are non-invasive while coring and trenching have minimal to very large impacts (respectively). These impacts, however, allow the coring and trenching procedures to stratigraphically expose and directly sample the subsurface for archaeological material and features, although each differs in the “scale” of the subsurface exposure. Backhoe trenching exposes several meter-long profiles where details of even ephemeral soil, sediment and archaeological horizons become clear. Solid-earth coring, on the other hand, allows only a few-cm-diameter core, which results in far less detail than trench exposures. Accordingly, as concluded by Monaghan & Lovis (2005), trenching is the best alternative for deeply buried site discovery in alluvial settings because cultural features are more likely to be revealed and details of sedimentary and weathering (soil) environments are more clearly distinguished in trench profiles. A similar conclusion was reached by Hey and Lacey (2001:31).

The detailed information derived from trenching is of course very destructive to buried sites. Conversely, coring disturbs the subsurface far less while also revealing less subsurface information. Hence the basic tradeoff: more impact to the subsurface in exchange for more detail on the subsurface. While geoarchaeologists typically are comfortable with the amount of disturbance required by the invasive methods, many archaeologists and compliance officials are not. As a result, non-invasive geophysical methods are of particular interest to cultural resource managers and archaeologists. Part of our project was designed to assess the utility of noninvasive, geophysical techniques for buried site discovery. In addition, we investigated the utility of multi-method survey techniques for accurate characterizations of the different properties of the subsurface and whether such multi-method tests overcome some of the problems inherent for individual methods (Monaghan et al., 2006).

The goal of the MDTP project was to directly compare the results and costs of each deep test procedure. Six approximately 0.4ha (1 acre) areas, each with differing depositional and archaeological characteristics were chosen for deep testing from various locales in Minnesota (Figure 1). Four of these areas had never been surveyed and two had recorded sites. Independent survey teams applied their deep test method to the test area for each locale and reported their results without knowledge of the other survey results.

Individual methods were applied in order of their level of invasiveness - from non-invasive geophysical survey, to minimally invasive coring procedures, to highly invasive backhoe trenching. Costs for the surveys were calculated and outcomes (i.e., whether sites were discovered or not) were evaluated to achieve a cost-benefit analysis for the various methods. Clearly, such an analysis is inherently subjective, particularly in relation to outcomes/benefits.

Summaries of project survey results are shown in Table 1 and costs in Table 2 (also see Monaghan et al., 2006, Appendix A). For site discovery, trenching was most effective with a 66 percent overall detection rate (including a 50 percent new-site discovery rate) (Table 1; Monaghan et al., 2006). Coring/augering was somewhat less effective with a 33 percent overall detection rate and a 25 percent new-site discovery rate. While the geophysical surveys suggested that archaeological deposits may be buried in four of the six locales, which equals the success rate of trenching, actual site identification was problematic (Figure 1, Table 1). For example, a buried cultural feature (Feature 1, Test Unit 3B) found by invasive methods at the Hoff Deep site were also detected by magnetometry but without any contextual information on the site available to the geophysicist an a priori judgment on possible source of the anomaly prior to trenching/coring was not feasible. Moreover, by experimental design, ground-truthing of anomalies was not intentionally performed, biasing the potential discovery rate for geophysics. This example points up the tension between the often equivocal nature of geophysical anomalies and the need for actionable assessments in compliance settings. Conversely, the trenching and coring data indicates that some of the apparent cultural features identified at the City Property site (Figure 1, Table 1) were probably natural sedimentary features (Monaghan et al., 2006). Basic issues in using geophysics for deep site discovery are revealed in discussions of these uncertainties below, e.g. what was missed or uniquely by geophysics. The varied outcomes of the geophysical surveys also informs as to when their application have greatest utility in the deep test process.

While numerous cultural features were observed with all three geophysical methods, especially at the Anderson, Clement, and the City test locales (Table 1), the quality and usefulness of the data varied depending on specific conditions at each of the sites. The test locales where GPR was most successful and exhibited the best GPR characteristics and penetration (Anderson, Clement, and City; Figure 1), are well-drained and coarser-grained sites, while the poorest results were obtained from the Hoff Deep test locale, which is the finest-grained. Given the limitations imposed by radar signal attenuation within fine-grained depositional sequences (Conyers 2004; Jol & Bristow 2003), this is not surprising.

The magnetic data suggest that both historic and prehistoric occupational features probably exist at the Anderson, Hoff Deep and Fritsche Creek II test locales (Figure 1, Table 1; Monaghan et al. 2006; Appendix A)., Ground truthing, however showed that these features were present only in the upper meter, a predictable outcome given the magnetic contrast of the more deeply buried features and instrument configuration (Monaghan et al. 2006). These results demonstrate the usefulness of such data for understanding and mapping relatively shallow feature distribution, but also suggest the limited utility of magnetometry survey for buried site discovery.

The resistivity survey obtained the deepest penetration, up to ~4m, but also produced the coarsest data and generally is most useful for detection of broad trends in depositional frameworks including large, probable erosional cut-and-fill sedimentary structures, and groundwater conditions. From the perspective of buried archaeological site detection, resistivity was somewhat disappointing. Only limited success toward detecting buried archaeological features or buried horizons was obtained with the resistivity data (Monaghan et al. 2006). This probably reflects the relatively larger and coarser grid node spacing and probe separation distances that were required to actually penetrate to the depths

desired for this survey, and not something inherent in the method. A long-array resistivity “string” system may have provided additional detail in such settings, but at the expense of areal coverage (a sampling strategy more like that of backhoe trenching).

Judging the success of the methodologies was straightforward, but assessing cost was not (Monaghan et al., 2006). Cost assessments show that trenching is the most expensive in terms of *implementation* costs and geophysical survey is lowest (Table 2:). However, when *logistical costs* were added, the geophysics is the most costly, and trenching/coring the least. This reflects the fact that geophysical survey can be person-intensive and mechanical testing is typically not. (A caveat here is that we employed an uncommonly wide array of geophysical tests in the project, each with its own personnel costs, while a typical field survey employs only one or two methods, correspondingly lowering the total cost of geophysics – but at the expense of geophysical “breadth” in the data.) Regardless of a technique’s cost rank, cost differences are insignificant (Table 2). This suggests that cost should not drive choice of method for buried site discovery. Rather, outcome (Table 1) and “benefit” should serve as the basis for a deep test protocol.

Benefit assessment for the project derived from a qualitative assessment of methodological outcome (i.e., success in finding buried archaeological deposits) as well as its effectiveness in providing independent lines of evidence to support the presence or absence of an archaeological site and how much additional information about the stratigraphy and development of the prehistoric landscape can be gleaned from each of the methods (Monaghan et al., 2006). As stated above, from a site discovery standpoint backhoe trenching was most successful, followed by coring/augering, and the geophysical surveys usually left some uncertainty as to the significance of what was detected. The successes of trenching compared to coring/augering is due to the fact that archaeological deposits are more visible in long, deep trench profiles than a 5-cm-diameter solid-earth core, regardless of site size or sample density. Given that the site discovery probability is directly related to sample area (Hey & Lacey, 2001; Kintigh, 1988), it is not surprising that sites missed by coring/augering were very low density artifact clusters within ephemeral soil horizons (Clement; Table 1) or sites where augering was not performed because the subsurface archaeology was not associated with clear subsurface depositional or soil horizons (Anderson; Table 1; Monaghan et al. 2006).

The interpretive uncertainties and problems with buried site identification from the geophysical data largely relate to a basic problem of separating geomorphological and cultural features at the types of low artifact and feature-density prehistoric sites typically associated with buried, ephemeral paleosols. Without some general idea of the size, intensity, and geophysical contrast of expected cultural targets, it becomes almost impossible to distinguish between cultural and natural geophysical anomalies in some settings and with some techniques (GPR data was the most confusing on this point, and magnetometry the least). As mentioned, individual analysts had no knowledge of the other test results, an atypical situation in non-experimental settings. Modeling without constraints ultimately means that the geophysical analyst must address an ill-posed question. This is of particular concern in a CRM compliance context where site identification is critically important. For reasons discussed below, stand-alone or multi-method geophysical survey is simply not well-suited for use in deep site discovery in alluvial settings where the subsurface and other contextual data are completely unknown. More reasonably, geophysical survey should ideally be a part of site evaluation in concert with invasive coring, augering and trenching methods (Monaghan et al., 2006).

The Role of Geophysical Survey in Buried Site Discovery and Evaluation.

A central issue in CRM is balancing mitigation costs with surveys which still meet regulatory standards. The foremost issue in effective yet economical survey of buried sites is finding appropriate spatial and physical sampling strategies for both the geological and archaeological contexts (Orton 2000; Hey & Lacey 2000). A cost-benefit approach can serve as a framework for selecting and applying reasonable assessment procedures under the following conditions: that we recognize that it is not always definitive; and that outcome, defined here as the successful assessment of the deep subsurface, is critical. Ultimately, outcome is particularly vital within a CRM context where the failure of the deep test process can be extremely high (see MacDonald, 2006).

“Failures” in the deep test process can here broadly be categorized as *false-positive* and *false-negative* results (Monaghan et al., 2006). False-negatives occur when a site that was actually present in the subsurface was not discovered during the deep test process. This usually arises because a deep test method could not adequately evaluate the subsurface for the presence of buried archaeological material because it was not correctly applied or interpreted (English Heritage, 2004). False-negatives in deep testing in the CRM setting will at best result in delays or even lead to serious financial consequences. False-positives occur when an anomaly is detected in the subsurface but is not accurately diagnosed by the geophysicist. Geophysical survey can be prone to false-positive errors and unless the structure of the subsurface is well understood, buried anomalies that may reasonably appear to be cultural can easily turn out to be natural (Linford & Linford, 2001). Both false-negative and false-positive errors are particularly problematic in settings typical of prehistoric buried sites, where archaeological features are frequently composed of small scatters of artifacts within thin, ephemeral paleosol sequences. The MDTP project makes it clear that the geophysical signature of any given feature is site-specific and that no single method provides data for every test locale (see Dalan and Bevan 2002:807). In such circumstances, direct invasive techniques such as coring and trenching may be inherently more reliable than most geophysical procedures for detecting and defining buried archaeological resources (English Heritage, 1995; Frederick & Abbot, 1992).

A useful way to assess the benefit of the geophysical surveys conducted for the MDTP project is to first think of general categories of utility for such surveys. For example, Somers and Hargrave (2004) describe three goal-oriented classes of geophysical survey: archaeological site detection, site mapping, and site integrity assessment. Each of these goals sets different criteria for successful survey, such as sampling interval and instrumentation specifications. These goals also require early collaboration on “the objective of the survey, soil characteristics, expectations about the nature of prehistoric and/or historic archaeological features that may be present at the site, and the nature of factors (such as recent metallic debris) that may complicate the survey” (Somers and Hargrave 2004:5).

Although the results of this project suggest that geophysical survey may be of limited utility for site discovery, it can be of high utility in the evaluation stage of buried archaeological sites (Monaghan et al. 2006). For example, valuable geoarchaeological information can be derived from geophysical survey in alluvial settings (Bates & Bates, 2000; Frederick & Abbot, 1992; Isaacson et al., 1999:228; Weston 2001). This project comes to the conclusion that in complex alluvial settings, geophysical survey techniques are best employed after more invasive subsurface testing (coring, augering, trenching, etc.) has established the stratigraphical, pedological and archaeological character of a study area. For example, once the depth, thickness, and lithology of a buried cultural or natural stratigraphic horizon is defined, the optimal geophysical method/s can be specified. This information can also provide the basis for accurate forward modeling of the data. The horizon can then be traced across the site using the optimal geophysical survey technique. Such an approach leverages the descriptive power of geophysics, resulting in more efficient testing with fewer deep test “failures” (Monaghan et al., 2006).

Discussion and Conclusions

Because of the complexity and expense of assessing buried cultural deposits in CRM contexts, efficient and effective deep testing is critical. The experiences of the MDTP and other deep testing projects show that particular survey approaches and methods are better suited to particular phases of survey than others. Our finding is that for deeply buried prehistoric site discovery in alluvial settings in the upper Midwest USA, backhoe trenching is the most effective and efficient method. It also allows the discovered archaeological material and features to be placed into their proper depositional and landform context (Monaghan & Lovis, 2005; Monaghan et al., 2006). However, because it is so destructive, trenching should be used parsimoniously to evaluate the size and significance of newly discovered buried sites. Coring/augering and geophysical methods, which have little or no impact on buried archaeological components, are ideal. In order to trace buried deposits and discover potential buried features in more detail, coring/augering and geophysical survey should be employed. These should be employed regularly in the buried site evaluation phase, well before more formal, traditional

archaeological excavations (Monaghan et al., 2006). Pre-excavation geoarchaeological investigations can provide a firm basis the development of an efficient, cost-effective and scientifically sound archaeological mitigation plan (Monaghan et al., 2006).

A staged approach to deep-testing allows multiple site discovery and evaluation methods to be employed at those times in the process when they are most productive. Data derived during initial site-discovery trenching can provide very detailed information on specific subsurface configuration and chronology of sediments and paleosols in which the cultural material occurs, but these are essentially point-source observations of conditions which may not be representative of the survey as a whole. However, these horizons and buried surfaces, can be traced from beyond the trench and mapped across the site using coring and geophysical methods without significant disturbance of the cultural resources. From this perspective, trenching and then coring provides detailed point-source pedological, sedimentological and cultural strata that can be traced by appropriate geophysical survey methods to place the entire archaeological site and associated landform into a three-dimensional subsurface framework (Monaghan and Lovis, 2005; Monaghan et al., 2006).

In order to support management decisions in CRM compliance situations, clear scientific evidence must be brought forth. Discovery and evaluation of deeply buried archaeological sites is fundamentally geoarchaeological and is ideally undertaken as a multidisciplinary endeavor that includes archaeologists and earth scientists (Monaghan & Lovis, 2005). This results of this project strongly suggest that deep testing for buried sites is most productive as a two-step *geoarchaeological* process: the first, discovery, emphasizes the *geo* while the second step, evaluation, focuses more on the *archaeological* (Monaghan et al., 2006). The success of a particular deep testing method, and confidence that the deep testing process can accurately determine whether buried archaeological deposits are present, are as critical to efficient CRM projects as cost. The costs of failure, particularly false-negative deep test results, are simply too high to rely on anything other than the most reliable methods for buried site discovery. We believe that the two-step deep test process advocated by Monaghan et al. (2006) (maintaining a consciously multidisciplinary, geoarchaeological approach (Monaghan & Lovis, 2005)) is critical to successfully discovering and evaluating buried archaeological sites. Ultimately, management decisions in a CRM context will be more informed if geological development and archaeological site formation, as well as the interrelation between these processes, are understood (Monaghan et al., 2006).

Acknowledgement

The authors wish to thank the Minnesota Department of Transportation (Mn/DOT) for their support of some of the research described in this article. The opinions and conclusions expressed herein, however, are ours and are not necessarily shared by Mn/DOT. We also thank Commonwealth Cultural Resources Group, Jackson, Michigan.

References

- Bates, MR and CR Bates 2000, Multidisciplinary Approaches to the Geoarchaeological Evaluation of Deeply Stratified Sedimentary Sequences: Examples from Pleistocene and Holocene Deposits in Southern England, United Kingdom, *Journal of Archaeological Science*, 27:845-858.
- Butler, B, B Clay, M Hargrave, S Peterson, and P Welch 2004, Geophysical Investigations of Kincaid Mounds, Poster presented to the Southeastern Archaeological Conference and the Midwestern Archaeological Conference, St. Louis, Missouri.
- Clark, AJ 1992, Archaeogeophysical prospecting on alluvium, in *Alluvial Archaeology in Britain* (eds. S Needham and M G Macklin), *Oxbow Monographs* 27, 43-49, Oxford.
- 1996, *Seeing Beneath the Soil: Prospecting Methods in Archaeology*, Revised Edition, BT Batsford Ltd., London.
- Conyers, LB, 2004, *Ground-penetrating Radar for Archaeology*, AltaMira Press: Walnut Creek, CA.
- Dalan, RA, 2001, a magnetic susceptibility logger for archaeological application, *Geoarchaeology* 16:263-273.

- Dalan, RA and BW Bevan, 2002, Geophysical Indicators of Culturally Emplaced Soils and Sediments, *Geoarchaeology* 17:779-810.
- English Heritage 1995, Geophysical Survey in Archaeological Field Evaluation, Research and Professional Services Guideline No. 1, English Heritage, London.
- English Heritage 2004, *Geoarchaeology: Using earth sciences to understand the archaeological record*, English Heritage, Swindon.
- Frederick, CD and JT Abbott 1992, Magnetic Prospection of Prehistoric Sites in an Alluvial Environment: Examples from NW and West-central Texas, *Journal of Field Archaeology*, 19:139-153.
- Gaffney, C and J Gater 2003, *Revealing the buried past: geophysics for archaeologists*, Stroud: Tempus.
- Hey, G and M Lacey 2001, *Evaluation of Archaeological Decision-making Processes and Sampling Strategies*, Oxford Archaeological Unit / English Heritage and Kent County Council.
- Isaacson, R, E Hollinger, D, Gundrum, J, Baird, A Controlled Archaeological Test Site Facility in Illinois: Training and Research in Archaeogeophysics, *Journal of Field Archaeology*, 26(2):227-236.
- Jol HM, Bristow CS, 2003, GPR in sediments: advice on data collection, basic processing and interpretation, a good practice guide, In *Ground Penetrating Radar in Sediments*, Bristow CS, Jol HM (eds.), Special Publication 211, Geological Society Publishing House: Bath; 9–27.
- Kintigh, KW, 1988, The Effectiveness of Subsurface Testing: A Simulation Approach, *American Antiquity* 53:686-707.
- Kvamme, KL 2003, Multidimensional Prospecting in North American Great Plains Village Sites, *Archaeological Prospection* 10:131-142.
- Linford PK and NT Linford 1995, Cleeve Abby, Washford, Somerset, Report of Geophysical Survey, 1995, English Heritage Ancient Monuments Laboratory Report 1/95.
- 2001, Burnfoot Farm, Longtown, Cumbria: Report on Geophysical Survey, August 2001, English Heritage Ancient Monuments Laboratory Report 27/2001.
- Lynott, MJ 2005, Archaeological Research at the Hopeton Earthworks, Ross County, OH, Paper presented at the Midwest Archaeological Conference, Dayton, OH.
- MacDonald, DB 2006, A Report to the Governor and Legislature of the State of Washington, The Hood Canal Bridge Rehabilitation Project and Graving Dock Program, Washington State Secretary of Transportation Commission, Seattle.
http://www.wsdot.wa.gov/accountability/hcbgravingdock/pdf/GravingDock_FullReport.pdf
- Monaghan, GW and WA Lovis 2005, *Modeling Archaeological Site Burial in Southern Michigan: A Geoarchaeological Synthesis*, Michigan State University Press, East Lansing, MI.
- Monaghan, GW, KC Egan-Bruhy, MJ Hambacher, DR Hayes, MF Kolb, S Peterson, J,A, Robertson, N,R, Shaffer, 2006 Minnesota Deep Test Protocol Project,
http://www.mnmodel.dot.state.mn.us/deep_site/0TableofContentsScreen.pdf
- Orton, C, 2000, *Sampling in Archaeology*, Cambridge: Cambridge University Press.
- Pasquinucci, M and F Trément (eds.) 2000, *Non-Destructive Techniques Applied to Landscape Archaeology: The Archaeology of Mediterranean Landscapes 4*, Oxbow Books, Oxford.
- Peterson, S 2003, New Data on the Angel Mounds Site, Indiana, from Geophysical Remote Sensing, Poster presented to the 68th Annual Meeting of the Society for American Archaeology, Milwaukee, Wisconsin.
- 2005, Recent Excavations at Angel Mounds, Indiana, Poster presented to the Midwest Archaeological Conference, Dayton, Ohio.
- Schurr MR, 1997, Using the Concept of the Learning Curve to Increase the Productivity of Geophysical Surveys, *Archaeological Prospection* 4(2):69-83.
- Scollar, IA, A Tabbagh, Hesse, and I, Herzog 1990, *Archaeological Prospecting and Remote Sensing*, Cambridge University Press, Cambridge.
- Somers, LI, and ML Hargrave 2004, *Geophysical Surveys in Archaeology: Guidance for Surveyors and Sponsors*, Technical Report SR-03-21, Engineer Research and Development Center Construction Engineering Research Laboratory, Champaign, IL.
- Weston, DG, 2001, Alluvium and Geophysical Prospection, *Archaeological Prospection* 8:265-72.
- Weymouth, JW 1986, Geophysical Methods of Archaeological Site Surveying, In *Advances in Archaeological Method and Theory* 9, ed. MB Schiffer, pp, 311-395, Academic Press, Orlando, Florida.

Table 1.
Summary of Outcomes from Minnesota Deep Test Protocol (MDTP) Project by Location¹

Test Locale (Site No.) ²	Known Buried Site ³	Buried Archaeology Detected ⁴	Properties Buried Archaeological Deposits and Landform/Sediment Characteristics ⁵	Buried Archaeology Detected (by Method)		
				Geophysics	Coring	Trenching
Clement (21SH0047)	No	Yes (~70-90 cm) (1 Trench)	Sandy-to-silty-sand alluvium within levee landform. One small pit feature and artifacts (CC, cB, FCR, FL) associated with ephemeral A/C soil horizon in one trench.	Maybe	No	Yes
Root River	No	No	Sandy-to-silty-clay alluvium grading downward to channel sand/gravel in floodplain landform.	No	No	No
Anderson (21AN0008)	Yes	Yes (0-100 cm) (6 Trenches; Magnetometry)	Sandy eolian (dune) overlying sand/pebble glaciofluvial deposits. Small and large pit features (CR, FCR, CC, FL/TL). No apparent buried surface; subsurface artifacts likely derive by cultural and/or bioturbation processes.	Yes	No	Yes
Fritsche Creek II (21NL0063)	Yes	Yes (0-250 cm) (6 Trenches; 5 Cores)	Sandy-to-silty and sand/gravel deposits within colluvial-to-alluvial fan landform. Small pit feature and artifacts (cB, FL, FCR, CC). Most artifacts from two paleosols (70-100 cm and 230-250 cm deep).	Maybe	Yes	Yes
City Property	No	No	Sandy-to-silty-clay alluvium and channel sand/gravel in floodplain/levee landform.	Maybe	No	No
Hoff Deep (21NR0065)	No	Yes (0-130 cm) (4 Trenches; 9 Cores)	Clayey-silty-to-clay alluvium overlying clayey glaciolacustrine deposits within floodplain/terrace landform. Few pit features; (CC, cB, FL, CR) in several ephemeral-to-well-developed paleosols.	No	Yes	Yes

Notes:

¹ After Monaghan et al. (2006)

² Test locale name (locations shown on Figure 1); Smithsonian archaeological site number in parentheses.

³ Indicates whether location contained a previously known buried archaeological site.

⁴ Indicates if buried archaeological deposits were discovered by any method. 1st parenthesis indicates depths range for archaeological material; 2nd parenthesis indicates number of trenches or cores in which buried deposits discovered (from Monaghan et al., 2006).

⁵ General characteristics of landform buried archaeological deposits (from Monaghan et al., 2006). CC=charcoal; cB=calcined bone; FCR=fire-cracked rock; FL=stone flake (debitage); TL=stone tool; CR=ceramic sherd.

Table 2. Summary of Average Costs of Deep Test Methods from MDTP Project¹

Deep Test Methods²	Implementa- tion⁴ (cost/ha.)	Logis- tical (cost/ ha.)	Total (cost/ha)
Geophysical Surveys	\$936	\$627	1,564
Coring/a ugering	\$1,081	\$267	1,348
Coring/a ugering (selected sites) ³	\$1,488	\$348	1,836
Backhoe Trenching	\$1,233	\$231	1,497

Notes:

¹ after Monaghan et. al. (2006) .

² Methods evaluated during MDTP project:

Geophysical Survey includes magnetometer, resistivity, and GPR surveys; coring augering includes solid earth coring and augering of potential archaeological horizons; backhoe trenching includes trenching and examination of profile wall.

³ Cost/hectare reflect only the coring/augering processes for sites where significant coring was performed (i.e., excludes Root River, Clement and City Property [Table 1; Figure 1]).

⁴ Average per hectare cost to implement survey (i.e., excludes field expenses and other logistical costs; in 2005 USD).



Figure 1. Map of the state of Minnesota showing locations of the MDTP project test locales.