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Application of advanced geophysical methods and engineering principles in an emerging scientific archaeology

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Archaeology is routinely considered to be a field where individual scholars set out to find rare artifacts or long lost civilizations. Indeed, Hollywood would lead us to believe that archaeology is composed of a set of introverted practitioners who work with a singular esoteric focus that ultimately leads to intrigue and glory. In reality, archaeologists are struggling scientists, not unlike geologists or biologists. However, archaeologists labour under an additional burden. As a discipline archaeology is only just emerging as a full-fledged science.

Much of the current practice of archaeology was developed in the late 19th and early 20th centuries when the goal of the discipline was to mine artifacts or employ workers on government-funded Depression relief projects. Recently, a new frontier in archaeological field techniques has developed that is pushing the discipline towards the direction of science. At this frontier, a few archaeologists are working to develop theory and apply integrated, cutting-edge technologies that will, in the not-too-distant future, revolutionize the field. With these two linked areas of development, we predict that not only will the way in which archaeology is conducted be forever changed but these efforts form the basis of an archaeological science.

This revolution is focused on the use of near surface remote sensing and geophysical techniques. We argue that the implementation of geophysical theory and methods and the use of engineering principles and practices are playing a major role in changing archaeology from 19th century speculations to a legitimate scientific endeavour. These techniques allow us to rapidly and efficiently generate information about the archaeological record on spatial scales that are unthinkable using traditional approaches.

Combined with developments in the integration of evolutionary theory and archaeology, the way in which we think about and conduct archaeological research is being entirely re-formulated. In our view, the archaeology of the future will be constructed in a manner that has an interdisciplinary approach as its foundational base that taps the intellectual and creative strengths of practitioners from many fields of expertise. These fields include biology, geology, materials engineering and other areas in the biological and geosciences. Through such partnerships archaeology can have great relevance to humanity since these efforts can lead us towards the construction of scientific explanations of technological, social, and economic change.

In this article we will provide a brief discussion regarding the historical context of geophysical methods in archaeology; discuss new developments in geophysical methods and applications in archaeology including GPR, magnetometry, and resistivity; show specific examples of our research from a Bronze-Iron Age site in Northern Ireland, the earliest railroad site in California, a large fortified prehistoric community in the Mississippi Valley of the Eastern United States, and from early platform construction on Rapa Nui in the South Pacific; and conclude with a discussion regarding the future of the integration of geophysical theory and engineering principles within a scientific archaeology.

Archaeology is the study of materials that have attributes as a function of human activity. These materials can come in the form of artifacts, architectural features, and settlement distributions and consist of a vast array of empirical entities at many spatial scales. While much attention is given towards attempts to reconstruct cultural chronologies and past lifeways, the ultimate mission of archaeology is to explain why human societies changed through time and over space. Our natural laboratory is global in extent and involves over 7.5 million years of prehistory. The ways in which we measure the archaeological record are extensive and diverse. For example, we use satellite images taken from space to reconstruct paleoenvironmental surfaces covering thousands

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of square kilometers. At the other end of the spatial spectrum, we use Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to measure the chemical makeup of objects in parts per trillion.

Our research often calls us to conduct laboratory tests to precisely measure the strength of objects thereby providing insights into the principles of past engineering design and the impact of evolutionary processes. The empirical world of archaeology is fascinating and the challenge to make archaeology more than just speculation is daunting and requires a strict adherence to principles of science. Like geophysics and engineering, our methods of measurement must be reliable and accurate and experiments must be replicable by other scientists. For the archaeologists interested in building a science, new technology and theoretical developments present an opportunity to revolutionize archaeology both in terms of its methods and explanatory frameworks.

The focus of this article is on the implementation of geophysical techniques in the study of archaeology. The use of engineering design and its relevance to the study of the past is also briefly discussed where relevant.

History and background

The use of geophysics in archaeology – particularly in Europe – has had a long history. Magnetometry, for example, was first used in the 1950s by Belshe (1957) and Aitken (Aitken, Webster & Rees 1958). Resistivity was first used in the 1940s (Atkinson 1952). Ground penetrating radar first appeared in the early 1970s (Cook 1974; Dolphin, Tanzi & Beatty 1978; Moffat 1974; Morey 1974; Ulriksen 1982; Vickers & Dolphin 1974). The value and application of geophysical methods in archaeology have been amply discussed by several eminent scholars (see Daniels 1978; Scollar, Tabbagh, Hesse & Herzog 1990; Weymouth & Huggins 1985; Wynn 1986, 1990). Due to the limitation of this presentation we do not endeavour to review this volume of literature nor present details about the history and use of the equipment and methods employed; rather, we will briefly present the current context of our use of geophysics in archaeology.

European archaeologists and geophysicists have developed and pioneered many of the scientific applications discussed here. Importantly, many countries have developed comprehensive heritage programmes designed to preserve prehistoric and historic sites that are significant to education and cultural value systems. This effort has resulted in an increase in the use of geophysics in archaeology, at least in Europe. The United Kingdom, for example, has developed progressive policy and management programmes that have geophysical inventories as their cornerstone. As a result, in the United Kingdom, hundreds of geophysical projects take place annually and many sites have been saved from the impacts of development and construction. The results demonstrate that there is a great value in the use of geophysics as an inventory tool. In the United States, however, the use of geophysical technology has been limited. In fact, less than 1% of government-sponsored archaeological and preservation programmes have a geophysical program associated with them. This is an issue that concerns us greatly and we will discuss our view at the end of this article.

Principles of application

The archaeological literature for geophysical applications reflects a number of opinions concerning the conditions and scope of appropriate applications. We make use of five principles to guide our integration of geophysical research tools in archaeology. First, it is wise to apply multiple geophysical methods so that the particular strengths of each technique are incorporated into the research. Integrated surveys using magnetometers, ground penetrating radar, and resistivity are especially apt in this regard (see below). Second, collaboration between archaeologists and geophysicists during the planning, implementation, and interpretive phases is essential for the development of an effective research program. This is particularly important in data and image post-processing. Third, geophysical interpretations should be followed by field-testing procedures to evaluate the relations between the geophysical information and compositional characteristics of sub-surface deposits. We caution that geophysical interpretation should not by itself be the sole basis for decision-making; verification must be based on test excavations and other types of sub-surface evaluations.

Fourth, the geophysical record contains evidence about previous environments as well as past human behaviour. Thus, artifactual information can be obtained through measures of electromagnetic spectra beyond the human visual range. Much of the archaeological record, in fact, may exist as phenomena only detectable using geophysical methods. Our research has resulted in the discovery of magnetic features that can be discerned as postholes, fire hearths, walls, and burial chambers. With currently-available equipment and processing techniques, large and small communities can be almost completely reconstructed and described in detail. Most importantly, these measurements can be made with minimal disturbance to the archaeological record and at low cost.

Fifth, it should be stressed that the geophysical data produced by GPR, magnetometer surveys, and resistivity provide information about post-depositional processes. Geophysical survey data can identify areas that have been significantly modified by erosion, agricultural activities, and other physical factors. In the absence of the geophysical survey data, processes that have impacted the composition and arrangement of the archaeological record may not be recognizable and therefore not considered as a potential bias in data generation. In summary, the decrease in cost and increase in precision and sensitivity in today's technology provides us with an unprecedented opportunity to explore the past in ways that were unthinkable just a few years ago.

The application of engineering principles to archaeological problems has great relevance. Artifacts and technologies change through time and our role is to explain why such change occurred. We take an evolutionary approach to the study of human cultural variation. In this explanatory framework, it is assumed that humans create artifacts for a variety of reasons but the *persistence and success* of functional artifacts depends on their performance. Those artifacts that performed the best in particular environments relative to other variants are those artifacts which will increase in frequency. Thus, small engineering improvements in strength and speed, for example, may result in the selection for specific artifact types and their eventual increase in relative abundance. We call this *replicative success*. Understanding the structure of materials and the engineering properties of tools is a necessary part of any evolutionary analysis of artifact. Our objective in archaeology and material sciences is to determine what physical attributes or engineering design or both provided an advantage in specific circumstances.

We can use this approach to study portable artifacts such as tools as well as non-portable cultural features such as architecture. When we examine remnants of a ceremonial structure, for example, we can study it in terms of engineering principles. The labour that went into the building of the structure, the materials used in its construction and the principles involved in its structure, are all subject to differential replicative success and thus the processes of evolution. In this way, we argue that the study of human history is the exploration between the linkages between variation in materials and design and their performances in changing environments. The history of artifactual or architectural change is often the result of evolution where successful variants outcompete and out-perform other designs. Thus, if our objective is to explain the process of historic events, an understanding of materials science and engineering principles is critical and tightly coupled to the future of archaeology as a science.

Approach and equipment

Over the last decade, members from the Departments of Anthropology and Geological Sciences at California State University Long Beach have set the development of a state-of-the-art geophysical programme in archaeology and geology as their highest priority. Our purpose is to advance research in the field and to train our undergraduate and graduate students in what will be the field research techniques of the future. In this process we have acquired excellent equipment and have conducted experiments throughout the world. This work includes investigations at sites ranging from neolithic villages in Spain to the first railroad station in downtown Los Angeles. We have also used our equipment in criminal/forensic investigations at homicide sites and areas of buried ordinances and hazardous materials.

Figure 1 *Students on Rapa Nui, Chile conducting a resistivity study of Anakena. The resistivity unit consists of a data collector and integrated GPS system.*

Figure 2 *Gradiometer survey in progress. The insert shows the panel of the Geometrics 858 instrument and display.*

Considerations for archaeological applications

To apply geophysical methods to archaeological problems, we have initiated a long-term research programme that incorporates several major components. First, we strive to provide theoretical rationalization about all aspects of the data generation process. Archaeological theory is the cornerstone of any research design. All considerations about the past must be based on implicit (commonsense) or explicit theoretical constructs. There are no observations without theory (Hanson 1958). As archaeologists we generate questions, choose units of archaeological and geophysical observation, sample the geophysical and archaeological records, and structure our data generation strategies in purposeful ways. Each step in field work must be linked to a theoretical

Figure 3 *Aerial photograph of Navan Fort in Northern Ireland showing the large earthen mound and surrounding ditch.*

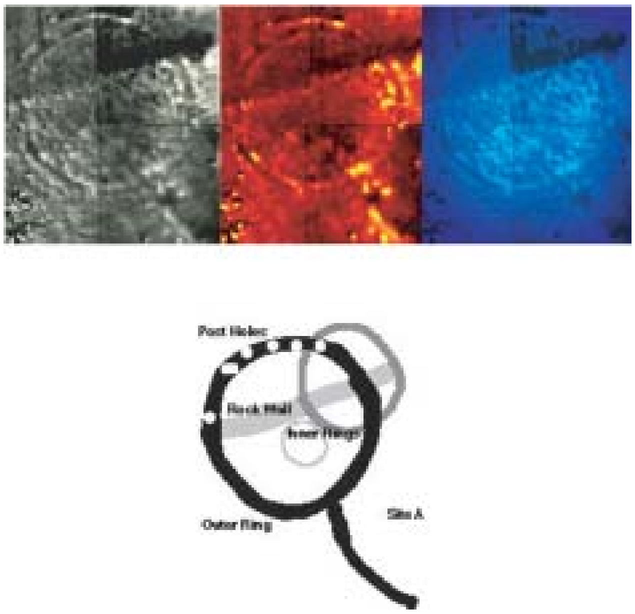


Figure 4 *Processed gradiometer data for the double ring structure at Navan Fort.*

framework and a highly focused research plan.

A second aspect of our research programme is our efforts to develop means of studying the archaeological record that minimize impact to non-renewable archaeological record. In our work, we strive to generate *only* the data needed to resolve specific research questions. This goal seeks to minimize cost and damage to the archaeological record. Geophysical techniques are ideally suited in this regard given their ability to generate information about subsurface features with minimal expense and impact to deposits. Once features in the archaeological record are described using geophysical techniques, follow-up measures can be made to examine different classes of information. For example, features detected by high-resolution geophysical methods can be further studied through small incremental bore samples, shovel test pits, column samples, and other limited test excavations. Significantly, excavation procedures are limited to only those cases in which additional information is required that cannot be retrieved by means of geophysical measurements. These classes of data include material for chronological analyses (e.g., radiocarbon dating, dendrochronology, luminescence dating), environmental information (e.g., pollen, tree-ring samples), and compositional information (e.g., artifacts, faunal remains, plants remains). All of the sources of information collected from the archaeological record (i.e., geophysical, compositional, chronological, artifactual) ultimately feed back into the research design and allow us to evaluate our hypotheses for cultural change. In the following sections we discuss our specific approach, which uses a variety of geophysical prospecting methods.

Recent advances and case studies

Prompted by the ubiquity of lightweight, inexpensive and powerful computer components and other technological achievements, geophysics has enjoyed a surge in new equipment and renewed promise. For about $20,000 we can obtain a caesium vapour magnetometer that is capable of rapidly collecting high precision magnetic data. For not much more, we can get a resistivity meter that is capable of collecting nearly continuous resistance measurements over a wide range of surfaces. With the addition of integrated GPS units we can map these results as quickly as we can tow the sensors and with great spatial precision (Figure 1). Using ground penetrating radar and new data processing software, we can now construct three-dimensional images of subsurface features, cut them into slices, and rotate them in space. Remarkably, we have never had more easily available and powerful capabilities to probe the archaeological record and have never enjoyed a more sophisticated means for analyzing the data that these machines produce. In the remainder of this article we will describe our equipment, our methods, and several case studies that are particularly interesting.

Magnetometer surveys

We employ the Geometrics 856 proton precession magnetometer as a base station for diurnal magnetic correction and the Geometrics 858 caesium vapour magnetometer and gradiometer for survey purposes. Both magnetometers measure the rates of change of certain atomic structures in the presence of a superimposed magnetic field (see Telford,, Geldart, & Sheriff 1990; Burger 1992 for information concerning the operating principles of these instruments). The caesium vapour magnetometer was engineered to achieve higher precision measurements over the proton precession magnetometers. The total magnetic field can generally be measured by a caesium vapour magnetometer to a precision of 0.05 nT (nanoteslas or gammas), while the proton precession magnetometer attains a precision of less than 0.5-1 nT. In addition to the high-resolution, the 858 Geometrics caesium vapour magnetometer generates 10 measurements every second. The density of measurements possible in an archaeological context is phenomenal. Measurement speed and other factors associated with the use of the caesium magnetometer (equipment set up, data logging, and reduced number of crew) allows for a large number of magnetic measurements (over 8100 measurements per 20m x 20m unit with transect intervals of .50 m) and greater aerial coverage per field day (Figure 2). Under exceptional conditions, an 80m x 80m survey unit can be completed in just one hour.

The Geometrics 858 gradiometer differs in a number of respects from the cesium magnetometer. The gradiometer entails the use of two sensors which can be oriented vertically and horizontally. There are significant advantages in measuring the vertical magnetic gradient, particularly when mapping shallow targets at archaeological sites. The gradiometer provides improved resolution of multiple targets and allows one to separate nearby features from more distant objects. In experiments conducted by Geometrics, the 858 gradiometer was found to detect a larger number of small surface anomalies than the single-sensor magnetometer. This feature of the gradiometer potentially makes it of great importance for archaeological research.

The Geometrics 858 system includes an electronic console, carrying belt, shoulder straps, a handheld, counter-balanced staff with a mounted sensor. The console contains electronics to acquire magnetic field data and an LCD screen which displays magnetic data and position during field operations. The console also emits audible tones that indicate magnetic field changes and survey cadence (pace). This feature allows the operator to survey in a 'head up' mode. Data are stored in non-volatile RAM. Approximately, 250 000 compressed magnetic readings and associated positions and times can be collected before downloading is required. When the field survey is complete, data can be quickly downloaded to a processing computer for statistical assessment, exploratory data investigation, filtering, and visual processing. Position information can be derived from regularly spaced fiducial marks placed in a pre-determined grid system or, with an integrated GPS unit. With the latter approach, spatial precision up to 1 cm is possible when a real-time kinematic GPS system is employed. Included with the system is a comprehensive software package that allows one to download data, perform diurnal corrections, and convert magnetic data into 2D and 3D contour image formats. Statistical analyses, exploratory data investigations, and visual processing are all conducted using third party software. In the sections that follow we present case studies that support our argument that the use of geophysical techniques in archaeology is critical to good science.

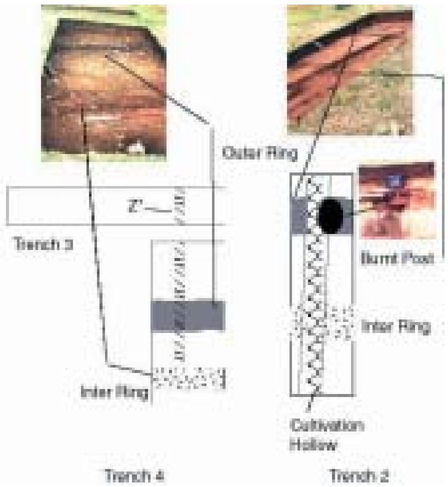


Figure 5 *Image of the excavated rings, postholes, and burnt areas at Navan Fort.*

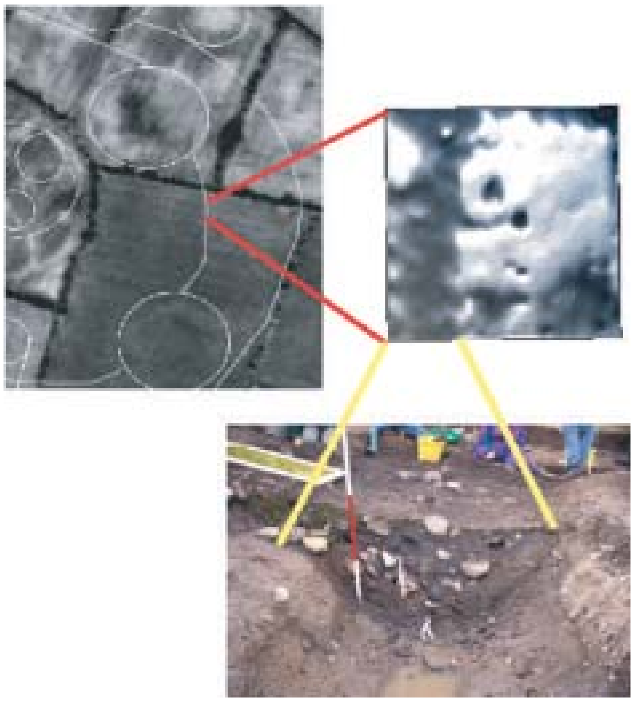


Figure 6 *Haughey's Fort outer ditch, excavated after detection by geophysical survey.*

Navan archaeological complex context

The excellent investigative efforts of the Navan Archaeology Research Group have made it increasingly clear that the legendary prehistoric capital of Ulster at Navan, in County Armagh, Northern Ireland evidences a sizable archaeological complex (Mallory 1987; Lynn 1992). Two prominent site areas of interest here are Navan Fort and Haughey's Fort, which are Late Bronze and Iron Age hillforts dating between

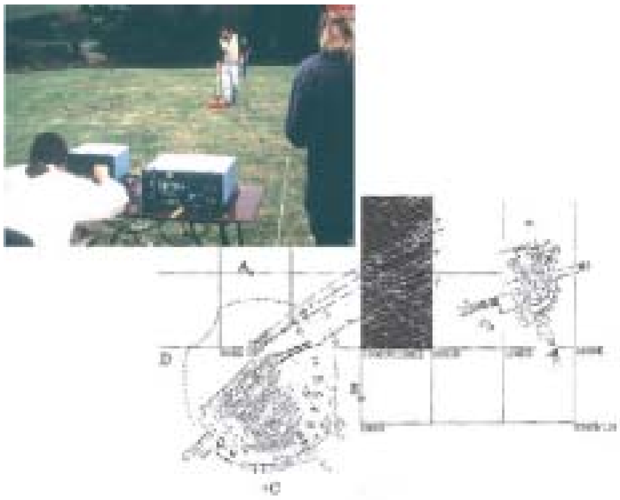


Figure 7 *GPR survey in progress and the resulting map from Navan Fort.*

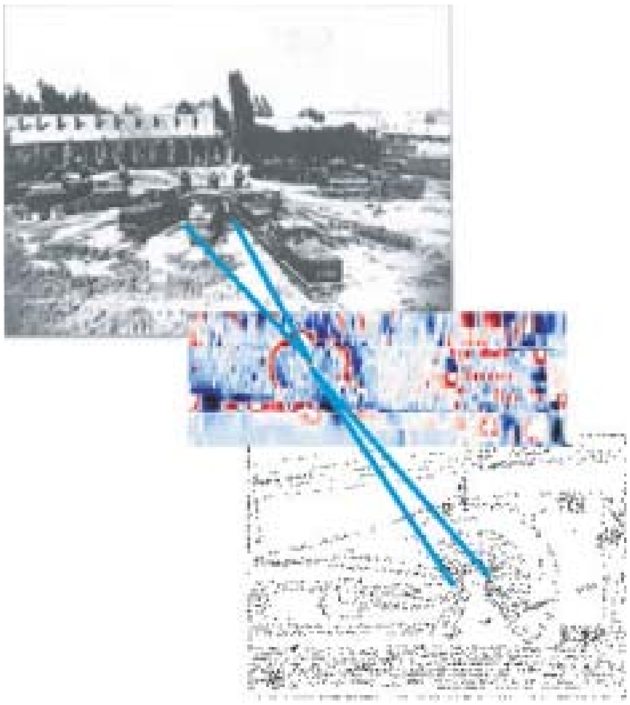


Figure 8 *Historic photograph of Los Angeles railroad station taken during the late 1800s with roundhouse and turntable in the foreground.*

B.C. 400 and A.D 200 (Mallory 1987; Lynn 1992). These sites are more than 300 m across and contain multiple features and subsurface structures. Indeed, the Navan Complex is similar to other major ritual complexes in Ireland like Tara and Rathcroghan (Waddell 1988). The human labour required to construct these features was extraordinary indeed. Both forts produced evidence for intensive occupation, with iron, gold, and bronze artifacts. Evidence of exceptionally large dogs and cattle, and rare exotic trade items (an ape skull from Northern Africa) all suggest that high status individuals resided at these sites (Figure 3).

Results of the caesium vapour magnetometer surveys

For the purpose of brevity, we limited our presentation to two geophysical survey areas: a 40m x 40m section between sites A and B at Navan Fort, and the upper ditch identified in the aerial photographic survey at Haughey's Fort. The caesium vapour gradiometer surveys produced a high-resolution image of a double-ring structure, approximately 30 m in diameter (Figure 4). In our research, various filters (e.g., gaussian, Fourier transform, low pass) were applied to data and multiple images were closely examined on high resolution computer screens for subtle anomalies which may evidence interesting targets of past behaviour of Bronze and Iron Age populations.

The new double-ring structure was not previously identified from past excavation work. The magnetic anomaly that cuts diagonally through the double-ring feature is an historic field boundary and it is the only feature visible on the ground surface when one walks over the site (also see Lynn 1996). The magnetic dipole features (paired positive and negative anomalies) or dark areas in Figure 4 well reflect the position of structural timber. That is, the dipole structures appear as 'bull's eyes' within the double-ring with sub-meter dimensions). We predicted that such features may indicate a burnt posthole. Targets like this are extremely important for obtaining dendrochronological and radiocarbon samples. We also detected a possible superimposed structure in the northwest corner of the double ring structure. Lastly, we found what appear to be several interior, circular features of some sort. Subsequent extensive excavation efforts have revealed that our predictions were 90% accurate (Figure 5).

At Haughey's Fort, the precise location of the outer ditch was determined. The location of the caesium magnetometer survey was identified on the ground using enhanced aerial photographs. A 20 m x 20 m grid was surveyed with the geophysical equipment. This survey detected a deep linear structure approximately 15 m wide (Figure 6). Scholars are particularly interested in the study of material derived from these features because of the extraordinary preservation of archaeological materials and environmental data in deep ditches (i.e., pollen, plants, insects, and dendrochronological specimens).

Ground penetrating radar (GPR) method

Data collected using ground penetrating radar (GPR) at the Navan Fort site corroborate the magnetometer evidence for the existence of the new ring structure between Sites A and B. Although the operational details regarding GPR are not discussed here, we present a brief overview of the instrument design, field operation, and data analysis procedures.

We use a GSSI SIR-10 GPR instrument for our data collection, and the GSSI Radan and 3rd party software for data processing. From a broadband antenna source the GPR unit transmits electromagnetic wave energy into the ground. At Navan the source antenna was pulled along the 20 m transects at 1 m intervals. Changes in radar reflections occur where abrupt changes in subsurface materials take place. In this way, stone alignments, soil to bedrock, dry soil to wet soil, and soil to buried walls and/or floors can be identified. At Navan Fort, we predicted that prominent reflections between soil and limestone bedrock, and between the loose and packed soil that characterizes the floors of ring structures. Our processing steps included filtering and data compression, and then integration of two-dimensional data profiles taken from individual transects into a single three-dimensional data volume.

Figure 7 clearly shows that there was strong correspondence between the magnetometry and the GPR measurements. We note, however, that other features in this image proved to be wheel tracks that were produced by animal-drawn carts. These tracks were not detected by the magnetic surveys but were very apparent in the excavation units that we subsequently made in this area.

Based on magnetometry and GPR geophysical surveys, these sites show significant effort in construction. Our subsequent work has been focusing on the development of engineering models that will provide information as to the resource and labour investment that went into the construction of these mounds. For example, determining the means by which the roof was held up at a community structure and the weight it could bear will provide us insights into the technologies of people who occupied the landscape over two thousand years ago. In the same way, we are looking at the structure of the ditch features. Was the site designed for defensive purposes or were the ditches simply designed to drain the surface area of the community? We think that engineering studies and subsequent archaeological investigations designed to explore architectural characteristics of Navan and Haughey's Fort will provide us with the answers. A full-scale archaeological research design and excavation programme can now be designed to guide archaeological exploration at Navan and Haughey's Fort for years to come.

The 1876 Southern Pacific Railroad

Historic records reveal that peoples from all regions of the world came through the River Railroad Station in Southern California in pursuit of their dreams. This is a very important place that could be considered the Ellis Island for the West Coast of the United States. The study region is located in downtown Los Angeles nestled in an area bounded by 'Chinatown/Sonorantown/Elysian Hills' on the south and west, North Spring Street or Old San Fernando Street and the

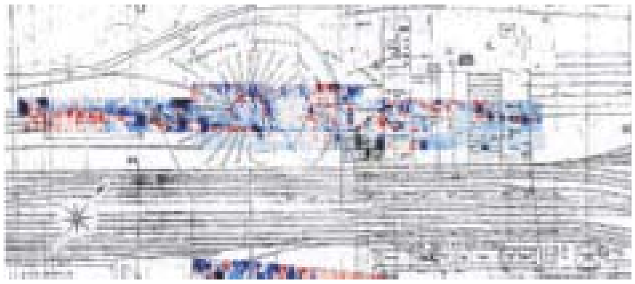


Figure 9 *Magnetometer data draped over the 1876 Sanborn Map for Los Angeles.*

Figure 10 *The Landgon site in Southeastern Missouri is a large Mississippian town. A resistivity and magnetometer survey was conducted across the northern edge of the rectangular town deposit.*

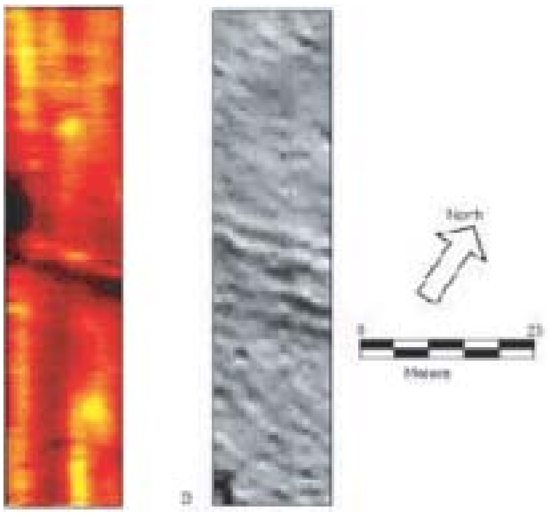


Figure 11 *Magnetometer and resistivity data generated from a survey across the edge of the town deposit at Langdon. The images show evidence of multiple wall and ditch structures.*

Figure 12 *Anakena is a major prehistoric site located on Rapa Nui, Chile. The site consists of a large platform (ahu) and set of statues (moai). This site has not been subject to previous geophysical survey work.*

Figure 13 *A CSULB student using the integrated real-time kinematic global positioning system and magnetometer. This integrated design allows one to simultaneously collect magnetic and spatial information.*

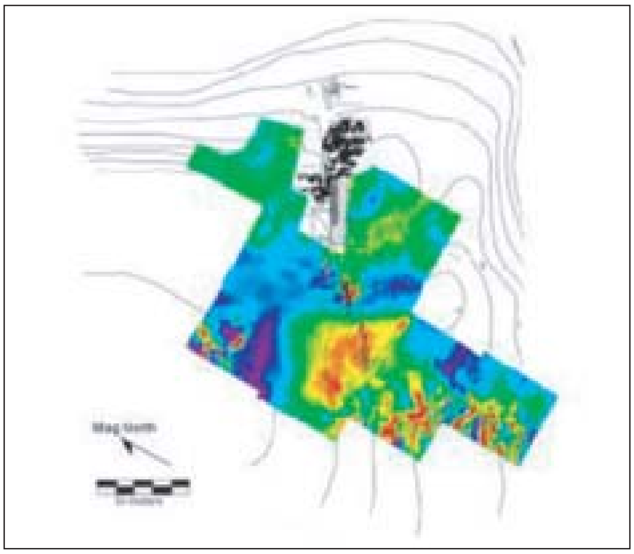


Figure 14 *Map of magnetic data for the area around Ahu Nau Nau at Anakena, Rapa Nui.*

Los Angeles River to the east, and the North Broadway Bridge to the north.

The proximity of the Cornfield/River Station property to the Los Angeles River made it a very suitable location in 1869 for the first railroad yard and station. The tracks and associated buildings were built in order to connect the growing city of Los Angeles to the Pacific port of Wilmington approximately 10 miles to the south. Between 1873 and 1876 the Southern Pacific Rail Road came to Los Angeles and the property at the River Station expanded to include a depot, two-story hotel (Pacific Hotel), roundhouse, machine shop, car shop, icehouse, warehouses, blacksmith shops, railroad tracks, and privies (Figure 8). Construction crews consisted of many ethnic groups and the sweat and muscle of these people resulted in the emergence of California as a political, social, and economic entity. Over the years, Los Angeles continued to grow in prominence and to become integral to the functioning of the United States. In this way, the economic, social and political future of the West was established at this railroad station of a once sleepy little pueblo.

Results of the caesium vapour magnetometer surveys

As no remains of the railway station remained, we conducted a magnetic survey of the area in an attempt to determine if any evidence of its former location could be identified. A significant result of caesium vapour gradiometer surveys was the location of numerous metal and brick anomalies. Figure 9 shows an overlay of our survey grids, potential presence of historic structures as identified from the 1888 Sanborn Map, and the possible geophysical fingerprints of those historic features. Clearly identifiable in the images are the roundhouse turntable and associated roundhouse structure in which the locomotives were repaired and maintained. This feature is visible in the Sanborn Overlay Map as well as the individual grid maps. The machine shop and car shop floors and foundations are also identifiable. Interestingly, the powerhouse floor and related features are represented by two very high anomalies that were perhaps the foundations for turbines. Equally impressive is the delineation of the Southern Pacific Railroad depot, hotel, boilers, and icehouse. Once we had identified the depot/hotel complex we returned to the field and found foundation stones along the walls and at corners as indicated in the magnetic images. Broken, fired bricks associated with the construction of these building was also scattered about as well as fragments of china and other glass and metal artifacts dating to the late 1800s. Subsequent test excavations confirmed our findings.

Overall, we were able to uncover the outlines of the railroad facilities using just the geophysical measurements. This accomplishment is significant since there were no surface remains and the site was considered complete destroyed. As we discovered, when the station was abandoned by the railroad, the area was capped with a soil overburden that preserved the site. The state now plans to build an interpretive centre to celebrate the achievements of these early pioneers. With the geophysical data and the newly-discovered foundation stones we can now, by the simple use of geometry, locate any of the areas where previous structures once stood. The archaeological research potential of the railroad site with only a few days of geophysical survey has been greatly enhanced.

The railroad site, covering over 25 ha, is a laboratory of past railroad engineering and construction activities. If we examine the archaeological remains of the roundhouse turntable, which is still in place below the ground surface, we can glimpse 19th century mechanical engineering and determine if modifications were made to the original design, all of which may not have been recorded. So, the remaining evidence of this aspect of the history of Los Angeles is safely buried beneath overburden. The railroad site is an important historical chapter in a book waiting to be opened by geophysical and archaeological methods.

Fortified late prehistoric villages of the Mississippi river valley

Beginning around AD 1200, the Mississippi river valley was the scene of striking cultural developments. At this time, large fortified villages emerged along the backwaters and bayous of the valley that consisted of tightly-packed groups of houses surrounded by high rectangular outer walls and moats (Phillips, Ford & Griffin 1951). From existing archaeological evidence, it appears that these walls were covered in clay and provided a thick barrier to protect the village inhabitants (O'Brien 2001). At the same time, the record shows the formation of hierarchical settlement patterns where secondary and tertiary-sized villages interacted through a dominant 'primary' village (Lipo 2001). Taken as a whole, the Mississippi valley appears to have been the scene of tremendous changes in social organization not previously witnessed in the southeastern United State, what we refer to as 'complex societies.'

Results of aerial and near surface surveys

Beginning in the Spring of 2003, we initiated a project to study these fortification structures. Our work has made significant use of modern aerial and near-surface remote-sensing techniques as a means of generating data about the structure of the archaeological record on a scale that is capable of rapidly and efficiently mapping community structures. For example, using freely available aerial images from the United State Geological Survey enables us to detail the outline of Mississippian towns such Langdon in Missouri (Figure 10). Using this information, we have conducted near-surface magnetic and resistance surveys.

The results of this work demonstrate the feasibility of rapidly collecting geophysical data for entire communities. During a two-day reconnaissance we were able to cover areas of two deposits spanning about 8000 m^2 and using both resistivity and magnetic instruments. During this preliminary survey, features such as fortifications, earthen structures, houses, and trash areas were easily identified against the alluvial background sediment (Figure 11). The data from this survey suggest that it is feasible to map the settlements in the valley at a resolution high enough to resolve the internal structure of each deposit, yet do the work at a reasonable cost and over a manageable length of time.

As we continue our work, we will be able to generate data necessary to posit questions about the evolution of social complexity. For example, we will be in a position to determine if there are functional differences between villages of varying sizes. Using dendrochronological data collected from buried wall posts, we will be able to determine whether the walls represent aggregate features that are composed of a series of parts or the result of a single event. The data from these surveys will provide the first solid empirical framework that is substantial and precise enough for studying the origins of social complexity in the Mississippi valley.

Rapa Nui, Chile

Rapa Nui (Easter Island, Chile) located 3700 km west of South America and 2250 km southeast of Pitcairn Island, is among the world's most isolated places. The island is only 171 km^2, but boasts magnificent megalithic sculptures, rock art, and remarkable structural remains. The prehistoric people of Rapa Nui produced nearly one thousand massive statues (*moai*) and moved hundreds of them to locations over the entire island. The statues, along with other features of the island's prehistory, have led to much archaeological speculation and research.

In collaboration with Terry Hunt of the University of Hawaii and Sergio Rapu of the University of California-Berkeley, we initiated a geophysical survey of Anakena, a beach area thought to contain some of the earliest evidence of occupation on the island (Martinsson-Wallin & Wallin 1994). This work consisted of magnetometry and resistivity surveys and focused on an area around Ahu Nau Nau, a large ceremonial platform with statues (Figure 12).

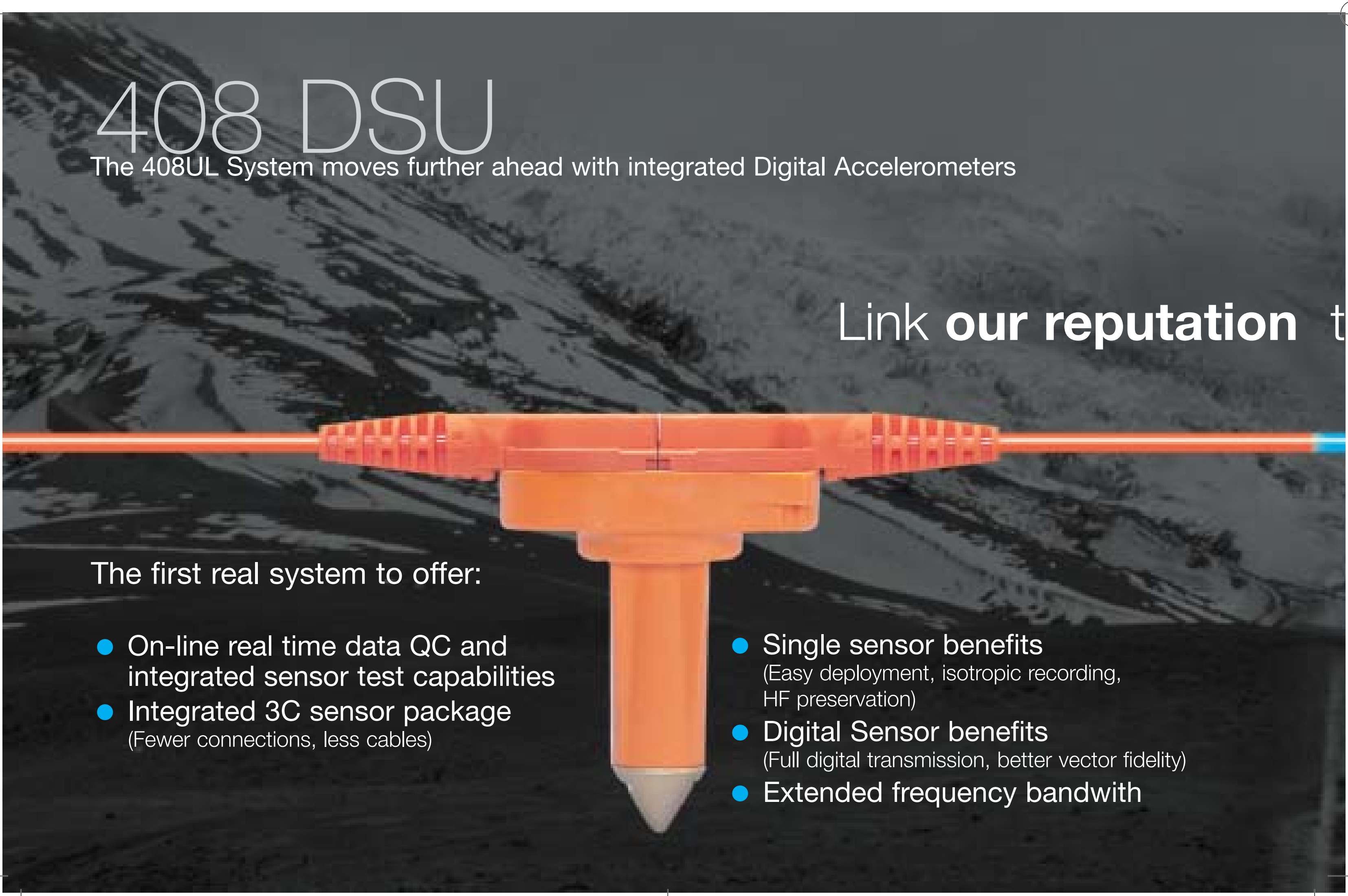
Figure 15 *Helicopter mounted geophysical gear including high sensitivity magnetometers.*

One of the unique aspects of the geophysical surveys at Rapa Nui was our use of an integrated global positioning system (GPS) to provide locational information. The GPS system we used consisted of a base station equipped with a data modem to transmit correctional information to a rover GPS unit attached to our Geometric 858 data collector (Figure 13). Known as real-time kinematic surveying (RTK), this means of positioning our sensors gave us ca. 1 cm level precision. In addition, it eliminated the need for firmly-establishing transect lines and unit corners; all measurements could be uniquely located in UTM coordinates. This ability increased the rate of data collection several-fold and allowed us to survey over 20 000 m^2 in a matter of days.

The results of the survey provide new information about the subsurface structure of the landscape around Ahu Nau Nau. In particular, the magnetic data show a long channel that appears to extend from the inland valley through the area of the platform to the beach (Figure 14). In addition, subsurface structures are visible to the west and south of the platform, possibly representing an early period of construction in the area. Ongoing excavation and a programme of coring promise to shed light on these intriguing geophysical features. Clearly, the data generated by the geophysical surveys allows us to pose hypothesis to be tested through more invasive, destructive and expensive sub-surface techniques.

Conclusions

We have briefly discussed geophysics and our application of cutting-edge technologies at four very different archaeological sites. Geophysical methods are just one part of an endeavour to make an archaeological science. We argue, however, that they are a necessary and critical part. The many projects that we have conducted throughout the world demonstrate that it is possible to investigate intra-site and inter-site settlement patterns with a high degree of resolution yet with relatively small expenditure of time and labour relative to traditional methods. The advancement in technology will continue to generate ever higher resolution geophysical data at an ever increasing rate. We predict that helicopter-mounted geophysical equipment, for example, will in the not-too-distant future change forever the way archaeologists collect surface data (Figure 15). Satellite imagery will also change archaeological research dramatically. Use of such images has already given us the opportunity to map villages in the Mississippi valley and agricultural features on Rapa Nui. Meeting our full potential will require archaeologists, geophysicists and remote sensing specialists to invest a considerable effort in learning aspects of each other's disciplines. Unquestionably,



collaborative programmes of this kind will revolutionize the field in the next decade.

It is critical to note that the implications of our work go beyond the simple use of new technology and nifty gadgets to address old problems. It is clear that the geophysical record reflects physical property of human behaviour and is rich in information about the past. This record, however, is not visible to the human eye and is often ignored when potential archaeological properties are being assessed or when research is conducted. Geophysical techniques provide a crucial means for expanding our ability to measure variability in the past and to manage this vital part of human history. If this record is not recorded using a variety of geophysical equipment then we (particularly in the United States) are discarding evidence that can never be retrieved if the archaeological record is compromised or destroyed. We must begin to view and manage the geophysical record as if it were a significant artifact or monument.

Training of future archaeologists in these advanced methods of geophysical exploration and remote-sensing will be of tremendous value to the profession. Where possible, university scholars should develop joint proposals for purchasing geophysical equipment. In the private sector, researchers can also collaborate to make the generation of archaeological data more efficient and less destructive. Once an archaeological site is subject to traditional excavation methods, the information that the deposit contains is destroyed forever. Choosing excavation over other currently-available methods such as geophysics is short-sighted especially knowing that new technology will bring new means of extracting information from the archaeological record. We should always seek to preserve the record whenever possible. In addition, since much of archaeology is funded by public either through government funded research institutes or development efforts, we must always seek means of generating better information at lower costs. If, for example, we are able to identify archaeological features with greater resolution in a shorter period of time, we will ultimately be able to save money for clients and taxpayers. The United Kingdom and other countries in Europe have excellent geophysical-enhanced archaeology programmes in place. The United States, where millions of dollars are spent annually on archaeological research, has not fully embraced the application of these new, sophisticated technologies. Our hurdle is to determine why this is so and bring change to our discipline in the Americas. It is our hope that the future will bring a New Archaeology that is capable of producing scientific knowledge using technologically sophisticated methods while responsibly managing the

archaeological record and remaining responsive to the public whom we serve.

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References

Aitken, M.J., Webster, G., and Rees, A. [1958] Magnetic prospecting. *Antiquity* 32, 270-271.

Atkinson,R.J.C. [1952] Methodeselectriquesdeprospection en archeologie. In *La Decovert de Passe* , edited by A. Laming, pp. 59-70. Picard, Paris.

Belshe, J.C. [1957] Recent magnetic investigations at Cambridge University. *Advances in Physics* **6**,192-19

Burger, H. R. [1992] *Exploration geophysics of the shallow subsurface*, Prentice-Hall, New York.

Cook, J.C. [1974] Status of ground-probing radar and some recent experience. In *Proceedings of the conference on subsurface exploration for underground excavation and heavy construction.* Conference held at New England College, Hennikei, New Hampshire, August 11-16, 1974. American Society of Civil Engineers, New York.

Daniels, B. L. [1978] *Remote sensing: a handbook for archaeologists and cultural resource managers*, National Park Service, Cultural Resource Management Division, U. S. Government Printing Office, Washington D.C.

Dolphin, L.T., Tanzi, J.D., and Beatty, W.B. [1978] Radar probing of Victorio Peak, New Mexico. *Geophysics* **43**, 1441-1448.

Hanson, N. [1958] *Patterns of discovery*. Cambridge University Press. Cambridge.

Lipo, C. [2001] *Science, style and the study of community structure: an example from the Central Mississippi River valley*. Archaeopress, London.

Lynn, C. J. [1992] The Iron Age mound in Navan Fort: a physical realization of Celtic religious beliefs? *Emania* **10**, 33-57.

Lynn, C. J. [1996] *D. M. Waterman's excavations at Navan, Co. Armagh*, HMSO, Belfast.

Martinsson-Wallin, H. and P. Wallin [1994] The settlement/activity area Nau Nau East at Anakena, Easter Island. In *Archaeological investigations at Anakena, Easter Island,* edited by Arne Skjolsvold, pp. 123-200, The Kon-Tiki Museum Occasional Papers Volume 3, Oslo.

Mallory, J. P. [1987] The literary topography of Emain Macha, *Emania* **2**, 12-18.

Moffatt, D.L. [1974] Subsurface video pulse radar. In *Proceedings of an engineering foundation conference on subsurface exploration for underground excavation and heavy Construction*, Conference held at New England College, Henniker, New Hampshire, August 11-16, American Society of Civil Engineers, New York.

Morey, R.M. [1974] Continuous subsurface profiling by impulse radar. In *Proceedings of an Engineering Foundation Conference on Subsurface Exploration for Underground Excavation and Heavy Construction*, Conference held at New England College. Henniker, New Hampshire, August 11-16. American Society of Civil Engineers, New York.

O'Brien, M. J. [2001] Mississippian community organization: the Powers Phase in southeastern Missouri. Kluwer Academic/Plenum, New York.

Phillips, P., Ford, J.A. and Griffin, J.B. [1951] *Archaeological Survey in the Lower Mississippi Alluvial Valley, 1940-1947*. Papers of the Peabody Museum of American Archaeology and Ethnology 25. Harvard University, Cambridge

Scollar, I. A., Tabbagh, A., Hesse, A., and Herzog, I. [1990] *Archaeological prospecting and remote sensing*, Cambridge University Press, Cambridge.

Telford, W. M., Geldart, J. P., and Sheriff, R. E. [1990] *Applied geophysics,* Cambridge University Press, Cambridge.

Ulriksen, C. P. F. [1982] *Application of impulse radar to civil Engineering*, Ph.D. Dissertation. Lund University of Technology, Lund.

Vickers, R., and Dolphin, LT. [1975] A communication about an archaeological radar experiment at Chaco Canyon, *Museum Applied Science Center for Archaeology, University of Pennsylvania Newsletter* 11(l).

Waddell, J. [1988] Rathcroghan in Connacht, *Emania* **5**, 15-17.

Weymouth, J. W. [1986] Archaeological site surveying program at the University of Nebraska, *Geophysics* **51**, 538-552.

Weymouth, J. W., and Huggins, R. [1985] Geophysical surveying of archaeological sites. In *Archaeological Geology,* edited by Rapp, G., and Gifford, J. A., pp. 191-235. Yale University Press, New Haven.

Wynn, J. C. [1986]Archaeological prospection: an introduction to the special issue. *Geophysics* **51**, 533-537.

Wynn, J. C. [1990] Applications of high-resolution geophysical methods in archaeology. In *Archaeological Geology of North America,* edited by Lasca, N. P., Donahue, J., pp. 603-609. Geological Society of America, Boulder.