NSGG
Near-Surface Geophysics Group

Recent Work in Archaeological Geophysics

The Geological Society
Burlington House, Piccadilly, London W1J 0BG
Tuesday 2nd December 2014

Programme

Lecture Programme:

0915-1000	**Registration and Coffee**
1000-1005	**Introduction**
1005-1020	*Geophysical detection and characterisation of a potential 1349AD 'Black Death' emergency cemetery in Central London, UK.* H C Dick, J Pringle, B Sloane, J Carver, D Roberts, S Aldridge, M Giubertoni and S Porter
1025-1040	*Tally Ho! Recovery of a Spitfire using an integrated approach.* P Masters and R Osgood
1045-1100	*Fountains Abbey: A Re-survey and New Interpretations Within the World Heritage Site.* C Gaffney, C Harris, M Newman, M Langton and R Walker
1105-1120	*Sensing the Iron Age and Roman Past: Geophysics and the Archaeology of Hertfordshire.* K Lockyear
1125-1155	**Tea/Coffee break**
1155-1210	*Model-based inversion of magnetometer data in support of archaeological interpretation: the Raganello Archaeological Project.* A Schmidt, K Armstrong, W de Neef and M van Leusen
1215-1230	*Underwater cultural heritage preservation: Waterlogged archaeological wood ultrasonic properties for in situ evaluation method* A Zisi
1235-1250	*ArchaeoPY: Constructing and Utilising Open Source Software for Archaeological Geophysics.* F Pope-Carter, C Harris, T Sparrow and C Gaffney
1255-1300	**Morning closing remarks**

ENGLISH HERITAGE

1300-1430	**Lunch (Lower Library)** – all delegates **NSGG AGM (Lecture Theatre)** – open to all Geological Society members.
1430-1445	*Geophysical Surveys for Palaeo-environmental Reconstruction in the Transition Zone.* R Bates and M Bates
1450-1505	*NDT and Geo-Archaeology in Italy: could interdisciplinarity be a solution?* P M Barone and C Ferrara
1510-1525	*Using geophysical survey in the archaeological characterisation of uplands: a case study from the later prehistoric landscape of the Yorkshire Dales.* M K Saunders, I Armit and C Gaffney
1530-1600	**Tea/Coffee break**
1600-1615	*Magnetic Susceptibility Mapping with the Geonics EM38B Electromagnetic Susceptibility/Conductivity Meter to Locate and Map Archaeological Sites.* D McNeill, J Fowler, R Ferguson, R Duggan and S Beanlands
1620-1635	*The Canterbury Hinterland Project: Multi-Method Geophysical Investigation of a Roman Enclosure at Bourne Park (With the Emphasis on the GPR Survey).* L Verdonck, L Wallace, A Mullen and P Johnson
1640-1655	*Recent Surveys at Saruq Al-Hadid, Dubai, United Arab Emirates.* D Hale and R Villis
1700-1715	*Mary, Mary, quite unwary,what could your garden geophysical survey show?* P Cheetham
1720-1730	**Conclusion**
1735-1900	**ISAP AGM (Lecture Theatre)**

Posters (09:30-19:00 in the Lower Library):

Prospecting the location of the Gessel Hoard – the Bronze Age gold discovery from Syke, Lower Saxony, Germany. C Schweitzer

The same old seasonal issue? A time-lapse investigation into the changing resistivity of archaeological soils in-situ. R Fry, C Gaffney, C Batt and A Beck

The Roman Countryside of Northwestern Noricum. L Kühne, J W E Fassbinder, R Linck and F Becker

Searching for Scandinavians: a multidisciplinary investigation at Torksey, Lincolnshire. H Brown

Locating and Delimiting Iron Age and Early Medieval Settlement Sites in Norway by Mapping Topsoil Magnetic Susceptibility. A A Stamnes

CartEasy^N –Moving from 2D tiles to three-dimensional data collection and analysis in magnetometry. F Pope-Carter, G Attwood, C Gaffney and J Gater

GPR approaches in revealing the urban planning of ancient Mantinea. A Sarris, M Manataki, J C Donati, C Cuenca-Garciá, T Kalayci, F Simon and N Papadopoulos

Geophysical Survey at Puna Pau, Rapa Nui (Easter Island), K Welham, L Shaw, C Steele, A Tucki Castro, J Downes, C Richards, and A Stanford

The Absent Line of Sight and other Survey Lessons from Westminster Abbey - a Final Chapter in a Comprehensive Church Survey. E Carrick Utsi

Electrical Resistivity Tomographies in shallow water marine environment for detecting archaeological targets. K Simyrdanis, N Papadopoulos and J-H Kim

Geophysical Explorations at ancient Onchestos, Boeotia, central Greece. N Papadopoulos, I Mylonopoulos, K Simirdanis and S Kirkou

MALÅ "Mini" MIRA (MALÅ Imaging Radar Array) Experiences. J Adcock

New findings following the magnetic survey of the port city of Berenike on the Red Sea coast in Egypt (PCMA UW–University of Delaware project). T Herbich and I Zych

LEA MAX – from now on a multi-sensor array for diverse types of magnetic gradiometers. C Meyer

Stamp collecting or diagnostic advancement? A vision for landscape survey. M Roseveare, A Roseveare, R Fry, S Purvis and D Rouse

Evidencing the part of dielectric permittivity in the in-phase EMI response: an example in Bahrain. C Benech, F Rejiba, A Tabbagh and P Lombard

A Walk Through the Lilliput Farm Barrows. O Stanley, J Oswin and R Buettner

Archaeological Geophysics and Precision Farming. H Webber

Commercial Exhibitors (09:30-19:00 in the Lower Library):

Allied Associates Geophysical Ltd

Bartington Instruments Ltd

DW Consulting

Geomatrix Ltd

Geoscan Research Ltd

Sensys Gmbh

LECTURE ABSTRACTS

GEOPHYSICAL DETECTION AND CHARACTERISATION OF A POTENTIAL 1349 AD 'BLACK DEATH' EMERGENCY CEMETERY IN CENTRAL LONDON, UK

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In 2013 the London Crossrail underground network extension discovered 25 human skeletons buried in two phases at a shallow level below ground (bgl) in Charterhouse Square, Central London (Fig. 1). The predominantly well preserved adult remains were grouped in two different alignments in individual earth-cut graves. Subsequent carbon dating gave a mid-14th Century mortality date with further analysis finding *Yersinia pestis* (Bubonic Plague) present in the skeletal remains. It is therefore believed that the skeletons are of victims of the first, most savage, outbreak of the Black Death in 1348. London's population may have been reduced by 50-60% within a year.

Fig. 1 Photograph of isolated graves discovered by Crossrail at 2.5 m – 3 m bgl. © Crossrail Ltd.

Historical records indicate the area including modern Charterhouse Square was set aside as an emergency plague cemetery in early 1349; subsequent land use was as a later cemetery for a Carthusian priory with a 15th-century chapel. After 1538, the cemetery area was developed as a London suburb. Impacts on the area include 18th-century street development and 19th-century railway, housing and WW2 water tanks. The core of the former priory survives as a hospital to this time. This project aims were to use non-invasive near-surface geophysical methods to determine if medieval burial sites could be detected and characterised.

Initial trial surveys proved promising, 225 MHz frequency GPR 2D surveys imaged multiple isolated similar-sized objects present ~1.5 – 3m bgl in the SW of the square (Fig. 2). A dipole-dipole resistivity survey was not successful. Bulk ground conductivity surveys also imaged significant heterogeneities within the square. Electrical Resistivity Imaging 2D profiles orientated at right angles to the known parish boundary (still marked by building plaques) found this was detectable.

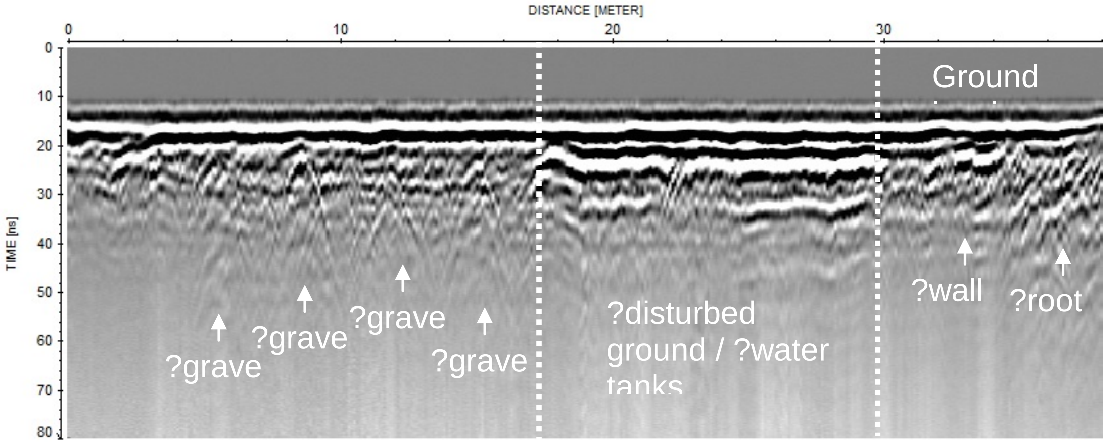

Fig. 2 GPR 2D processed 225 MHz frequency profile adjacent to discovered burials with interpreted burial objects marked (arrows). Note)m is at south end of square.

Secondary surveys collected more 2D GPR profiles, both within the square and to the North on cobbled roads and within a garden in Charterhouse itself to determine if burials could be detected further to the North of the square. The cobbled road radar data was not promising although 4 isolated below-ground radar anomalies within the garden looked promising. The 2D profiles across the eastern boundary also resolved further details about a possible cemetery boundary, with perhaps a ditch and bank being resolved which matched historical records of the parish boundary. The EM survey resolved a highly conductive area to the NW, which correlated with very strong horizontal radar reflectors, suggesting WW2 water tanks may still be present onsite. There also appeared to be a 20 m x 20 m rectangular area anomaly in the central square area which is suggested to perhaps be foundations from the demolished 15th-century chapel (Fig. 3).

While there is as yet no proof that the anomalies detected in either the Square or within the grounds of Charterhouse were graves, the regularity and apparent depth of several of them suggest that graves may have been successfully detected, although they are surprisingly widely spaced. If confirmed this would be valuable support to the theory that burials from such time periods are still geophysically detectable. Given that historical records suggest the original burial of thousands of individuals in this emergency cemetery, this would be a significant aid to mapping its extent. Charterhouse itself intends to lead a community dig on the square in Summer 2014 to validate geophysical interpretations.

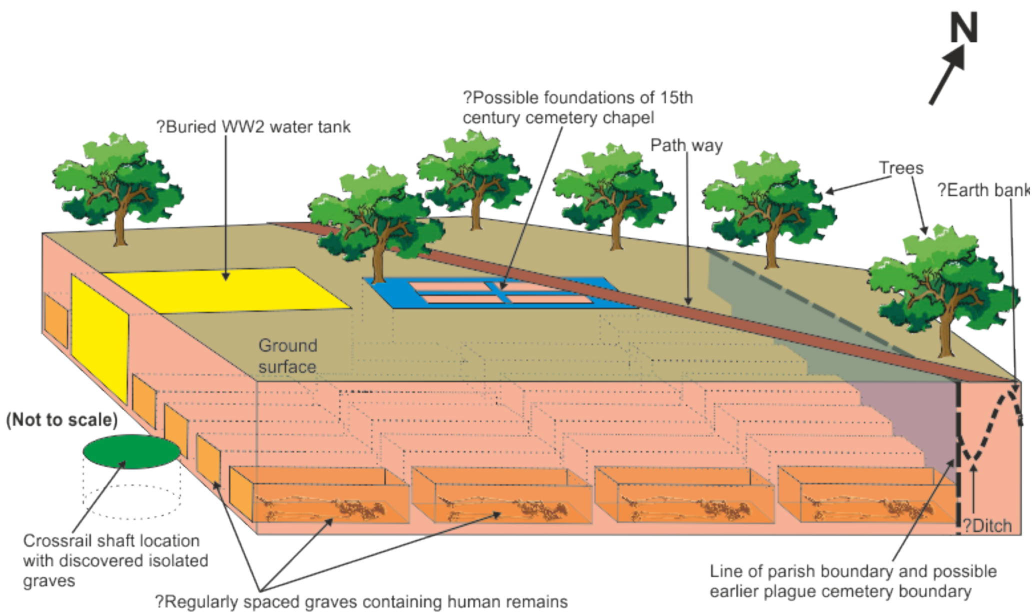

Fig. 3 Schematic annotated diagram illustrating project findings.

TALLY HO! RECOVERY OF A SPITFIRE USING AN INTEGRATED APPROACH

Peter Masters[1] and Richard Osgood[2]
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The investigation of a World War Two aircraft crash site was undertaken in the summer of 2013. In 1940, Pilot Officer Paul Baillon (Fig 1) bailed out of the aircraft towards Andover and the Spitfire crashed on Salisbury Plain where it remained buried in the earth until 2013.

Fig. 1 Pilot Officer Paul Baillon

The site was approached on the basis of recording the remains methodically using traditional and scientific methods used in archaeology from metal detecting to geophysics. This allowed us to locate the remains in order to excavate and recover aircraft parts and any other finds associated with the spitfire including personal effects (Fig 2).

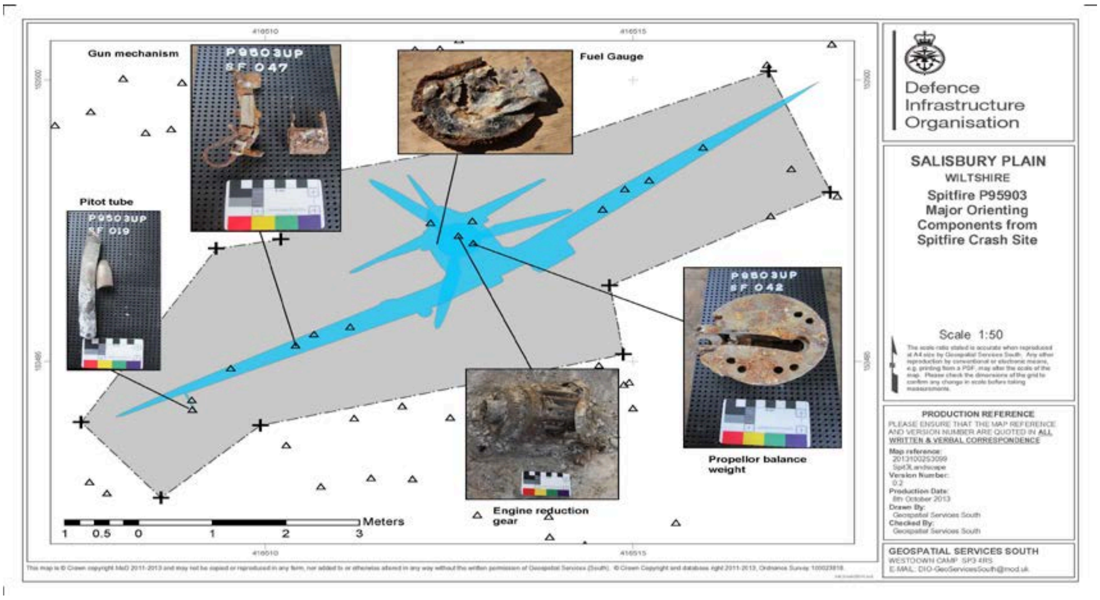

Fig. 2 Map of the Spitfire P95903 aircraft parts excavation

The recovery of Spitfire P9503 involved Operation Nightingale, an initiative to aid in the recovery process of injured soldiers that have recently returned from Afghanistan by getting them involved in archaeological investigations.

The strategy and methodology used in this investigation showed how effective and important it is to recover as much of the remains as possible to place it into a meaningful context in order to understand the reasoning for why it crashed.
This paper will demonstrate the importance of using such an integrated approach to the recovery of military aircraft from crash sites from the Second World War.

FOUNTAINS ABBEY: A RE-SURVEY AND NEW INTERPRETATIONS WITHIN THE WORLD HERITAGE SITE

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Fountains Abbey was one of the largest and wealthiest of England's Cistercian abbeys. Founded in the first half of the 12th century, the abbey was operational until the dissolution of monasteries in the mid-16th century. Shortly thereafter, Fountains Abbey and its surrounding land were sold by the Crown. Its buildings were part-demolished and sold for construction materials. The evolution of Fountains Abbey and its surrounding land would continue after its monastic decline; through the construction of Fountains Hall, to the its incorporation with the abbey and the surrounding land into the Studley Estate, and to the Estate's extensive transformation of the surrounding landscape into garden. These manor halls, grounds, and abbey ruins are all now incorporated into the Fountains Abbey and Studley Royal Water Garden UNESCO world heritage site. The area has experienced a dynamic evolution, with occupation and modification of Fountains Abbey and its associated grounds over the past nine centuries (Coppack 2003). Still, for such an important and iconic site, relatively little intrusive archaeological work has been conducted within the grounds, and much of the understanding of the site comes from written and illustrative sources.

One of the enigmatic areas of the Fountains Abbey landscape is directly southwest of the nave, which contains the buried remnants of the so-called 'third' guest house, associated building, and the cellarer's yard. This buried guest house is not drawn or discussed in the earliest plans of the ruins. What is known of this building is mostly derived from the results of an a = 0.5 m twin-probe earth resistance survey, conducted in 1992 by John Szymanski. In 2013, the University of Bradford began investigations over this area as part of a public engagement for World Heritage Day. The site proved suitable for exploration using a range of techniques, which were likely to enhance the interpretations obtained from the prior limited survey work, by providing a more holistic understanding of both the buried and upstanding remains. The 2013 investigations included earth resistance survey using linear and non-linear arrays, electrical resistivity tomography, and fluxgate gradiometer methods. The additional survey techniques suggested a more complex buried landscape than previously believed.

Further work in 2014 was conducted by the prospection group at the University of Bradford, in collaboration with MALÅ Geoscience and Geoscan Research, to better characterise and understand the buried remains, particularly any changes with depth. To accomplish this, an even wider range of geophysical techniques were employed, incorporating single- and multi-channel ground penetrating radar, cart based earth resistance and magnetometry, and multi-depth electromagnetic induction techniques (measuring conductivity and magnetic susceptibility). The 2014 approach also extended the survey area to the east of the abbey remains. Ground penetrating radar survey was conducted over this area, to evaluate the validity of historical newspaper reports of stacked monks' coffins to a burial depth of six feet.

Results:

The results of the survey are discussed through the following key examples.

Area around guest house:

Of all the methods employed, earth resistance and ground penetrating radar techniques were the most successful for detecting and delineating the structure of the guest house and surrounding buildings. While the recent earth resistance results are well correlated with the 1992 results, through the use of expanding arrays and different electrode configurations, the 2013 and 2014 earth resistance results reveal changes of features with depth, which were previously unknown through the 1992 results. Because the ground penetrating radar results quantify the changes of features with depth that are visible between the various techniques, the radar provided a baseline from which the results of the disparate techniques can better be related to one another.

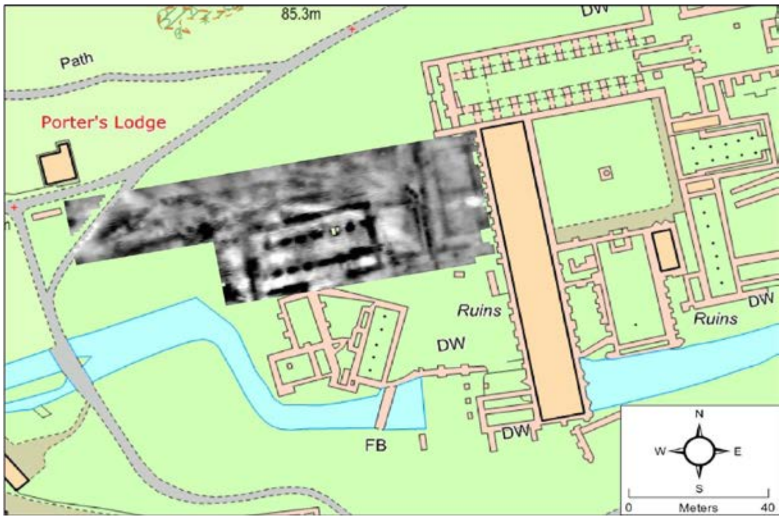

Fig. 1 2013 earth resistance results with a Geoscan RM15 using an a = 0.5 m twin-probe array, high-passed filtered, displayed to +/- 1 SD.

The 2013 earth resistance surveys utilised manual data collection (Figure 1); while the 2014 earth resistance survey utilised a cart-based system, allowing for a higher sampling density, which was able to resolve further internal structuring of the buried remains. The 2014 cart-based square gamma dataset has provided additional information regarding the structure of the guest hall's walls, which

Fig. 2 MALÅ Mira Mini 1.83 m depth slice results, referenced with a robotic total station.

combined with the radar data, has resulted in a re-evaluation of the 2013 survey results.

Fig. 3 CartEasyN system at 0.25 m x 0.25 m with Bartington 1000L fluxgate sensors.

Two cart-based (Figure 3) and one manual fluxgate gradiometer surveys were conducted over the south-western area. The gradiometer results reveal many ferrous and cable/utility responses, but do delineate some of the buried structures; although not as well as the earth resistance and radar methods. However, the gradiometer and EMI magnetic susceptibility results do show differences between the magnetic enhancement found within the structures, indicating differing activity zones. The cart-surveys, owing to a greater sampling density, shows conditionally better anomaly resolution than the manual gradiometer survey, but adds little new archaeological information, on top of the manual results.

Of all the methods applied at Fountains Abbey, the electromagnetic induction results were the least successful for detecting and delineating the buried structures. Conductivity responses were collected with an electromagnetic induction instrument (EMI) that measures three different soil volumes, corresponding to 0.5 m, 1.0 m, 1.8 m depths. The guest hall is better delineated with increasing depth. However, the conductivity datasets do not delineate any of the archaeological remains with the same resolution as the galvanic earth resistance methods. The in-phase component of the EMI instrument approximates subsurface magnetic susceptibility. Due to the site and survey conditions, only the mid-depth configuration produced useable results and these coincide well with the fluxgate gradiometer

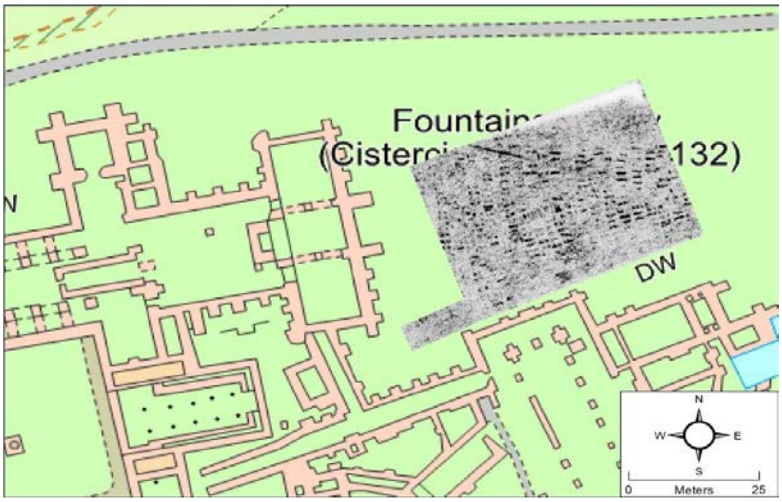

Fig. 4 MALÅ Mira Mini 1.88 m depth slice results, referenced with a robotic total station.

results. Additionally, some zones indicating intensive usage for activities that produced enhanced the magnetic properties of the subsurface were also mapped.

Area of the supposed burial ground

The eastern grounds also show complexity of features changing with depth. The shallowest depth slices are dominated by cables/utility and pedological/soil responses. Grave responses begin to explicitly appear below the 1.29 m depth slices. Before the individual graves begin appearing themselves, the earth columns between and surrounding the graves are visible, appearing like a honeycomb pattern (with responses becoming explicit in the 0.81 m – 1.29 m depth slices). It is also evident that the graves extend beyond the area that was originally thought to be the graveyard.

Conclusions

From a geophysical standpoint, the range of methods applied over the same area allows comparisons between the effectiveness of these methods, the instruments used, and the strategies employed. A higher sampling density in itself did not necessarily prove more effective for detecting the buried remains, as seen with the EMI results, but provided much better resolution with the earth resistance and fluxgate gradiometer techniques.

From an archaeological standpoint, the cumulative results from the 2013 and 2014 surveys at Fountains Abbey reveal a more complex subsurface than was previously known. The multi-method strategy proved information beyond the structure of the buried remains, by revealing the complex changes of features with depth, the properties of the remains, and even indicate areas of activity within the remains. Some of the subtle enhancements of the interpretation of the site will be discussed in this paper.

References

Coppack, G. (2003) *Fountains Abbey: the Cistercians in northern England.* Stroud & Charleston: Tempus.

SENSING THE IRON AGE AND ROMAN PAST: GEOPHYSICS AND THE ARCHAEOLOGY OF HERTFORDSHIRE

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Introduction

This project was funded by the Arts and Humanities Research Council under their Connected Communities scheme. It was a co-authored research project which involved the Institute of Archaeology, UCL, collaborating with a group of local archaeological societies, the St Albans and Welwyn Hatfield museum services, the Hertfordshire HER, and local Young Archaeologists' clubs. The principal aim was to provide access to geophysical survey equipment and, in the process of undertaking surveys of a number of late Iron Age and Roman sites in the county, create and train a cross-group team of amateur geophysicists. In the process, a number of important Iron Age and Roman sites in the county would be surveyed. In order to achieve this aim, a Foerster Ferex cart-based magnetometer with four sensors was purchased (Fig. 1). The project maintains a blog which includes preliminary results of the surveys.

Fig.1 Jarrod Burks teaches Jean Savigar the use of the Ferex system

In addition to the survey work, a week-long course in archaeological geophysics took place in July 2013 hosted by Verulamium Museum. The course was taught by the author, Andrew Bevan (UCL), Jarrod Burks (Ohio Valley Archaeological Consultants), Rinita Dalan (University of Minnesota Moorhead) and Larry Conyers (University of Denver). The course was also sponsored by Archaeology South-East.

The surveys

During 2013 and 2014 the Project has undertaken surveys at nine different sites, seven in Hertfordshire and one each in Buckinghamshire and Bedfordshire. The largest survey was that in Verulamium Park where approximately half the Roman town has been surveyed. Other sites included the Iron Age and Roman site at Ashwell from whence the Senuna treasure was recovered in 2002 and the site at Broom Hall Farm, Watton-at-Stone which has been the focus of research by the Welwyn Archaeological Society (WAS) since 2005. Given the time constraints of this paper, I will concentrate on three sites.

Broom Hall Farm, Watton-at-Stone

The first indication of the existence of this site was a Dressel 1a/b stamped amphora handle found by a local farmer in 1976 but at that time little more was found. Following discoveries by a metal detectorist in a nearby field, WAS undertook magnetometer and resistance surveys, in 2007 and 2010, which located a number of ditches. Test trenches showed that most of these ditches were of the late Iron Age/Roman transitional period. The finds included a fragment of a Dressel 1b amphora handle. In 2013, as part of the current project, the field from whence the metal detected finds came, was surveyed (Fig. 2).

Fig.2 The survey at Broom Hall Farm, Watton-at-Stone

The survey revealed a series of enclosures which correlated extremely well with the find distribution. It seems likely that the features represent a Romano-British farmstead. Curiously, the ditches located in 2010 were not detected in the field to the south.

Page's Park, Leighton Buzzard

This survey was undertaken at the request of the LBDAHS. In the mid-nineteenth century a well had been found which was thought at the time to be Roman. The approximate location of the well is marked on early OS maps, and is now in a Park in suburban Leighton Buzzard. Unsurprisingly, the survey located a number of modern services in addition to a number of linear features. As yet, these are undated. The location of the well is probably indicated by a depression which was recently filled-in with hard-core. As half the site is very uneven, a topographic survey was undertaken which greatly helped to interpret the magnetometry results.

Verulamium

The entirety of Verulamium Park was surveyed between June 2013–February 2014. In addition to the magnetometerry survey, selected areas were subject to resistance, magnetic susceptibility and GPR surveys.

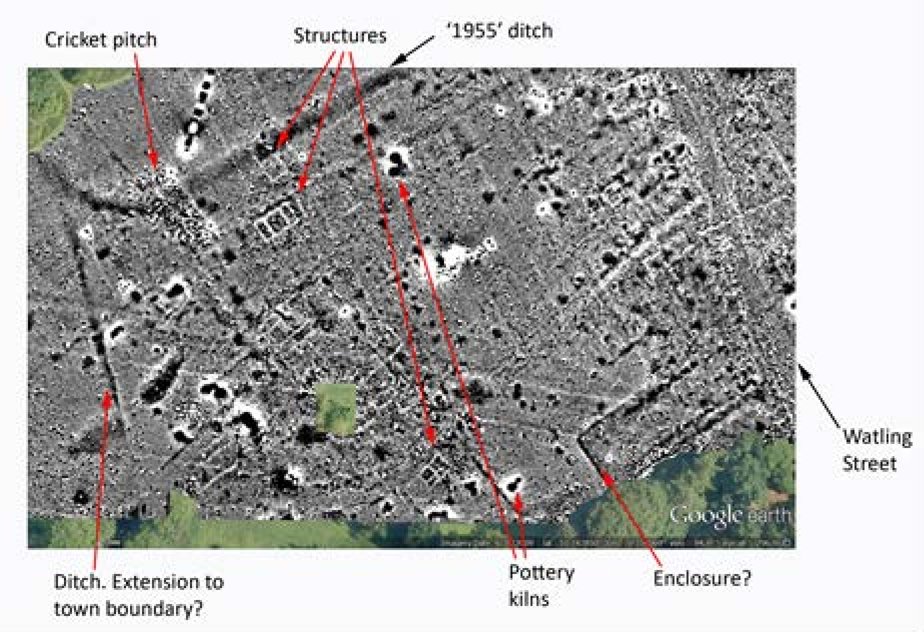

Fig. 3 Magnetometry results of the southern area of Verulamium

Many features within the Park were known from previous work including the Wheeler's excavations in the 1930s, parch marks and other geophysical surveys. Some excavated buildings, such as the famous triangular temple, do not show in the survey results whereas other structures, such as Building III.2, can be seen. This is presumably due to how thoroughly the deposits were excavated. The so-called '1955 ditch', first detected by Martin Aitkin in 1959–61 can be clearly seen. Some areas of the survey have very strong responses and are extremely 'noisy', especially close to the centre of the Roman town. This may reflect the concentration of activity in this area, or perhaps the extent of the second century fire. The southern part of the town has been very fruitful with several pottery kilns, stone structures, ditches and pits detected. One ditch may represent an extension to the town to the south, perhaps in the period between the construction of the 1955 ditch in the first century and the town walls in the third. Details of some of the stone structures were enhanced by GPR surveys by Ralph Potter (West Essex Archaeological Group) and Larry Conyers.

Conclusions

The Ferex system has been successful for this project enabling community heritage group members of all ages to participate in the surveys and allowing large areas to be covered rapidly. Although funding for the project ended in January 2014, the group continue to undertake surveys and have expanded beyond the temporal and spatial limits originally defined.

References

AHRC (2013) *Research for Community Heritage*', <http://www.ahrc.ac.uk/News-and-Events/News/Documents/AHRC%20Research%20for%20Community%20Heritage%20accessible.pdf>, last accessed 30/8/2014.

Burleigh, G. R. (forthcoming), 'Burials, Ditches and Deities: defining the boundaries of Iron Age and Romano-British Baldock', *in* Kris Lockyear (ed.) *Archaeology in Hertfordshire: Recent Research.* Hatfield: University of Hertfordshire Press.

Lockyear, Kris (forthcoming), 'The Iron Age and Roman site at Broom Hall Farm, Watton-at-Stone: a preliminary report', *in* Kris Lockyear (ed.) *Archaeology in Hertfordshire: Recent Research.* Hatfield: University of Hertfordshire Press.

Niblett, R. and I. Thompson (2005), *Alban's Buried Towns. An assessment of St Albans' archaeology up to AD 1600* (Oxbow Books: Oxford).

Wheeler, R.E.M. and T.V. Wheeler (1936), *Verulamium. A Belgic and two Roman Cities,* Reports of the Research Committee of the Society of Antiquaries of London No. XI, (London).

MODEL-BASED INVERSION OF MAGNETOMETER DATA IN SUPPORT OF ARCHAEOLOGICAL INTERPRETATION: THE RAGANELLO ARCHAEOLOGICAL PROJECT

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The Institute of Archaeology at the University of Groningen has been conducting excavations in the coastal plains of northern Calabria at a key site of the Iron Age/Greek colonial transition since 1991. The investigation of the pre-colonial period in this area had been characterized by reliance on data from excavations from few large 'central' sites and theories about their hinterlands were based on various core/periphery and territorial models. It was therefore decided to extend the investigations with substantial field-walking into the mountainous hinterland of the basin of the Raganello River (the Raganello Archaeological Project) to collect data for the refinement of such theories. Since 2011 detailed geophysical surveys were undertaken to complement results from field-walking with beneath-surface information. Since only few key-hole excavations are possible as part of this extended project, geophysical results are used to contextualise surface archaeological data. For a confident interpretation of the magnetometer data a modelling and inversion process was therefore designed.

The magnetic inverse problem has no unique solution; there are many different subsoil distributions of magnetic susceptibility and remanence that could create the same magnetic surface data, and given small variations in the recordings ('noise') an infinite number of reasonable subsurface models could be imagined. Inversion of magnetic data therefore always has to start with some assumptions. Based on the work by Li and Oldenburg (1996), most modern 3D inversion schemes rely on 'objective functions' that use a particular depth weighting to derive a single subsurface magnetic susceptibility distribution, fitting the measurement data. To include *a priori* archaeological information we have developed a model-based inversion scheme which starts with an archaeologically plausible model of the shape of possible subsurface features and proceeds in the inversion to adjust the model's constituent parts with respect to their magnetic susceptibility, size and position. The underlying rationale is that an archaeological geophysicist may use conceptual archaeological models to estimate the approximate shape and location of possible subsurface features from the anomaly map of the data, but that a numerical process is needed to refine them so that the best possible fit with the measurements can be obtained. This is achieved by composing the initial model from several polygons with chosen depth and depth extent. The inversion process then proceeds to adjust three parameters for each polygon: its magnetic susceptibility, its size (expressed as a positive or negative buffer radius), and a shift of the buffered polygon along the magnetic north-direction. Each of these parameters is adjusted separately to minimise the RMS deviation from the measured data, since it is virtually impossible to derive a Jacobian inversion matrix for a closed formulation of the forward model. The adjusted model that results from this process depends, however, on the order of the parameters that are used for the inversion as there are many local minima that can trap the process. Several runs with randomised parameter orders are therefore performed to obtain an overview of the possible solutions from which those are selected that have a low overall RMS deviation and are archaeologically plausible.

To obtain an overview of the magnetometer responses from the buried features data were initially collected over large areas with a cart-based multi-sensor system (Ullrich and De Neef 2010). More detailed surveys were subsequently undertaken with handheld magnetometers over anomalies of particular interest. For some sites this was complemented by trial-trenching and magnetic susceptibility sampling. From these results, three classes of anomalies were selected for the test of the inversion methodology: (a) U-shaped buildings, (b) C-shaped buildings and (c) pit-like anomalies (Figure 1).

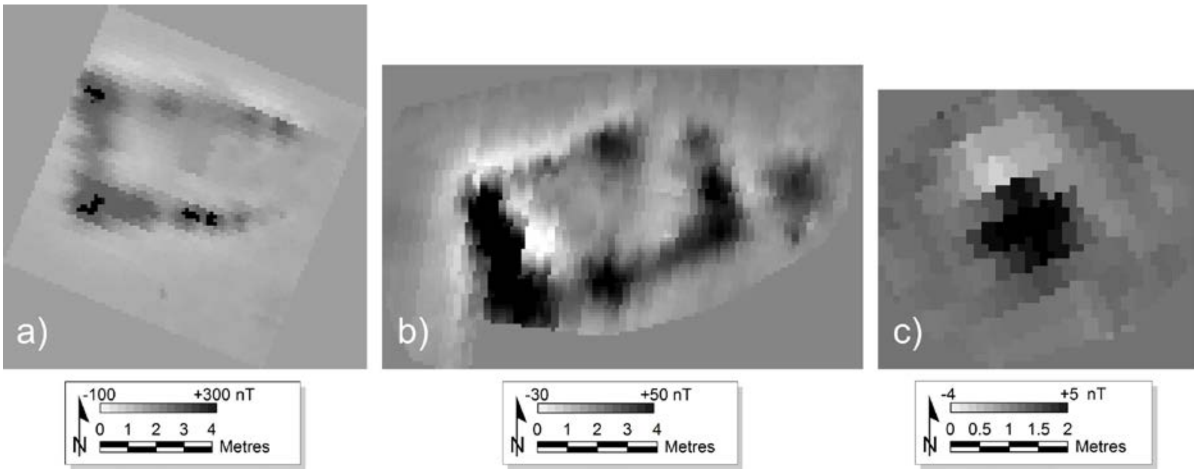

Fig. 1 examples for three classes of anomalies: (a) U-shaped building, Site T231; (b) C-shaped building A1, Site T219 and (c) pit, Site MSN

A magnetic susceptibility model for each of these classes, optimally adjusted through inversion, can be seen in Figure 2.

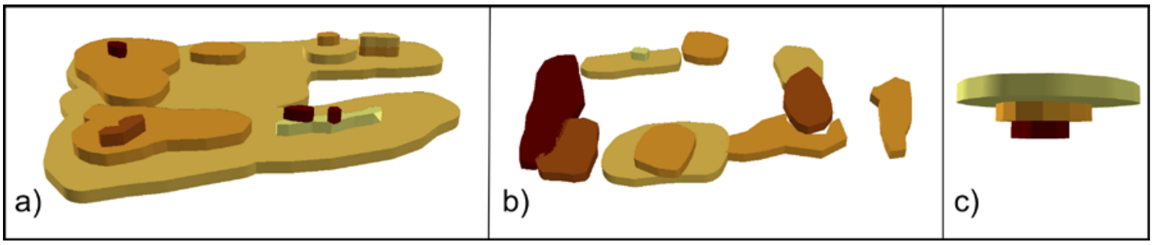

Fig. 2 inversion-adjusted models of subsurface magnetic susceptibility for the three anomalies from Figure 1. The thickness of each polygonal slice is 0.1 m, starting at the surface level for models b) and c) and 0.1 m below the surface for model a).

Slightly different starting models with randomised order of optimisation parameters were used and it was found that in some instances models with just slightly different RMS deviation could be considerably different. For instance, the anomalies on Site MSN, interpreted to be pits, were fitted best by the model shown in Figures 2c and 3a (RMS deviation 0.711 nT), but the almost inverted model shown in Figure 3b fitted nearly as well (RMS deviation of 0.715 nT, see details in Table 1).

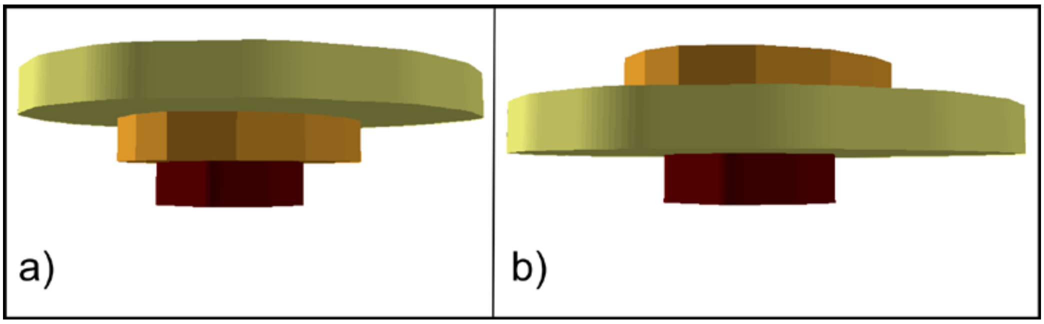

Fig. 3 Two pit models for the selected anomaly on Site MSN: (a) best fitting (see Figure 2c) and (b) second-best fitting.

Table 1: Inversion derived parameters for two well fitting models.

Depth Range	Model a – RMS Deviation 0.711 nT		Model b – RMS Deviation 0.715 nT	
	Diameter	Magnetic Volume Susceptibility	Diameter	Magnetic Volume Susceptibility
0.0.-0.1 m	2.6 m	1.0×10^{-3}	1.4 m	3.9×10^{-3}
0.1-0.2 m	1.4 m	4.4×10^{-3}	2.6 m	1.5×10^{-3}
0.2-0.3 m	0.8 m	9.2×10^{-3}	0.9 m	6.9×10^{-3}

The investigations so far show that in the starting model polygons selected for the subsurface features were often chosen too far south of their actual position (up to 0.2 m), confirming the well known bias in interpreting bipolar magnetic anomalies, which was corrected by the inversion process. The inversion also showed that in several instances the deeper layers were far larger than initially estimated. In particular the U-shaped feature in Figure 2a had an extended base layer that is interpreted as a destruction layer on the building's floor. The inversion-derived models therefore allow a far more confident interpretation of magnetometer data as buried archaeological remains, although they are still dependent on the initial choice of the starting model. Magnetic susceptibility values that resulted from the inversion process were for some anomalies considerably higher than what was recorded from soil samples. It must hence be assumed that parts of the magnetic anomalies are caused by remanent magnetisation, due to burning. At the moment the inversion does not account for the associated misalignment of the magnetisation vector.

Overall, the results provide a scientific foundation from which to interpret the geophysical data and are hence a welcome addition to the archaeological hermeneutic process.

Bibliography

Li, Y and Oldenburg, D W 1996 '3-D inversion of magnetic data', *Geophysics,* **61**(2), 394-408.

Ullrich, B and De Neef, W 2010 *Eastern Atlas Report 1021A / 2010. Geophysical Survey at the Raganello Archaeological Project near Francavilla Marittima, province of Cosenza, Calabria, Italy*, Groningen Institute of Archaeology.

UNDERWATER CULTURAL HERITAGE PRESERVATION: WATERLOGGED ARCHAEOLIGICAL WOOD ULTRASONIC PROPERTIES FOR *IN SITU* EVALUATION METHOD

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With up-to-date technology in geophysics we are now closer to being able to support needs emerging after decades of maritime archaeology and conservation practice worldwide. Action is called into preserving underwater cultural heritage whilst *in situ* in its present burial environment using reliable, robust and where possible, non-intrusive methods because intervention can narrow the research potential. Sites should thereafter be assessed and managed using techniques specifically developed to match the archaeological underwater environment and conservation ethics (Manders and Al-Hamdani, 2011; Gregory, 2012). Quite recently acoustics have been suggested as an appropriate non-intrusive method for investigating marine archaeological sites (Quinn et al., 1997), as well as a proxy for degradation of submerged archaeological timbers (Arnott et al., 2005). Preliminary work by Arnott et al., successfully led to the development of an efficient ultrasonic transmission technique for use on waterlogged archaeological wood, placing the base for its use *in situ*.

The present research has greatly advanced the method in question by filling in knowledge gaps as highlighted by this past work. A new scientific way has been developed to evaluate the degree of degradation of waterlogged archaeological wood, using a reliable relationship between its physical properties during degradation and its corresponding acoustical properties. For this purpose initial experiments have been performed on "fresh" waterlogged wood artificially degraded. The experiments led to the establishment of a reliable calibration curve between the wood's density and ultrasound velocity. To evaluate the efficiency of the calibration curve, waterlogged archaeological samples from the National Museum of Denmark were ultrasonically tested. Measurements matched well with the calibration curve.

Ongoing research is using the data produced in order to improve reflection coefficients for waterlogged archaeological wood and add on our understanding of its remote acoustic characterization whilst i*n situ*.

The present study will benefit the conservator of antiquities to make valid suggestions for the viability of the archaeological wood, as well as the archaeologist to decide upon the best way to manage the archaeological site.

References

Manders, M.R. & Al-Hamdani, Z. (2011) Guidelines for Protection of Submerged Wooden Cultural Heritage 2011 M. R. Manders, Wreck protect / FP7. http://www.machuproject.eu/documenten/Wreck_protect_Guidelines_Protection_wood.pdf

Gregory, D. (2012) Development of tools and techniques to Survey, Assess, Stabilise, Monitor And Preserve underwater archaeological sites: SASMAP / FP7. http://sasmap.eu/

Quinn, R., Bull, J.M. and Dix, J.K. (1997) Imaging wooden artefacts using Chirp sources. Archaeological Prospection, 4, (1), 25-35

Arnott, S. H. L., J.K. Dix, A.I. Best & D. Gregory (2005) Imaging of Buried Archaeological Materials: The Reflection Properties of Archaeological Wood. Marine Geophysical Researches, 26(2-4): 135–144.

ARCHAEOPY: CONSTRUCTING AND UTILISING OPEN SOURCE SOFTWARE FOR ARCHAEOLOGICAL GEOPHYSICS

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Data are the building blocks for all archaeological geophysics research. As collected data forms the basis from which an archaeological interpretation is derived, proper handling, treatment, and display of data is crucial. Because archaeological geophysics is a small, dynamically evolving field, reasonably priced commercial software is not always available for handling all the applications of archaeological geophysics research. For instance, with recent trends towards mobile, multi-method, and large-area surveys; data processing, visualisation, and presentation may be too difficult or intensive to complete manually, or consist of repetitive tasks that can be streamlined through automated data processing. Bespoke software can be developed to efficiently handle these issues. Few commercially available software packages can cope with the demands of rapidly developing survey strategies and systems. These challenges have led to the creation of ArchaeoPY, a University of Bradford based community for the development of open source software for geospatial applications.

Archaeological Sciences at the University of Bradford does not offer any formal computer science training. A number of ArchaeoPY members undertook a weekend training programme run by Software Carpentry (http://software-carpentry.org/), which concentrated on developing good practice method within the scientific software development community. A condition of this training was a requirement to pass on and develop this knowledge within the attendees' home research community.

ArchaeoPY's aim is simple: to foster a dynamic, supportive community for developing bespoke software. The ArchaeoPY community has open membership, and welcomes all interested users and developers. A problem with bespoke software is maintaining its usability through time, with issues such as obsolete programming languages, new or upgraded operating systems, and poorly documented code affecting the software's preservation with time. As a result, one of the key objectives of ArchaeoPY is to develop well documented, *open-source* code. The concept of being open requires the source being available for modification and improvement. This allows the users to take an active developer role as well, facilitating a dynamic relationship with the code they are using, which will help improve and maintain the code through time; furthermore, this dynamic relationship is not only opened between the user and the code, but the users to other users. This helps foster a collaborative effort, benefiting from the mixed backgrounds of the collective users.

One of the key issues associated with software development across users with different programming experience is the maintenance of a common developer environment. This is especially complicated within the scientific python community due to the number of external modules utilised. To combat this, ArchaeoPY decided that all development should centre on an Ipython Notebook system installed using the Anaconda Distribution. This allows the maintenance on a common python environment on systems accessible to contributors and additionally a remote Ipython Notebook server on which software can be run if no development environment is available. Furthermore, by tracking changes to the code and utilising version control, users should not worry about breaking or negatively impacting the code.

Examples of ArchaeoPY's recent work illustrate the necessity, application, and benefits of developing bespoke software. These examples include:

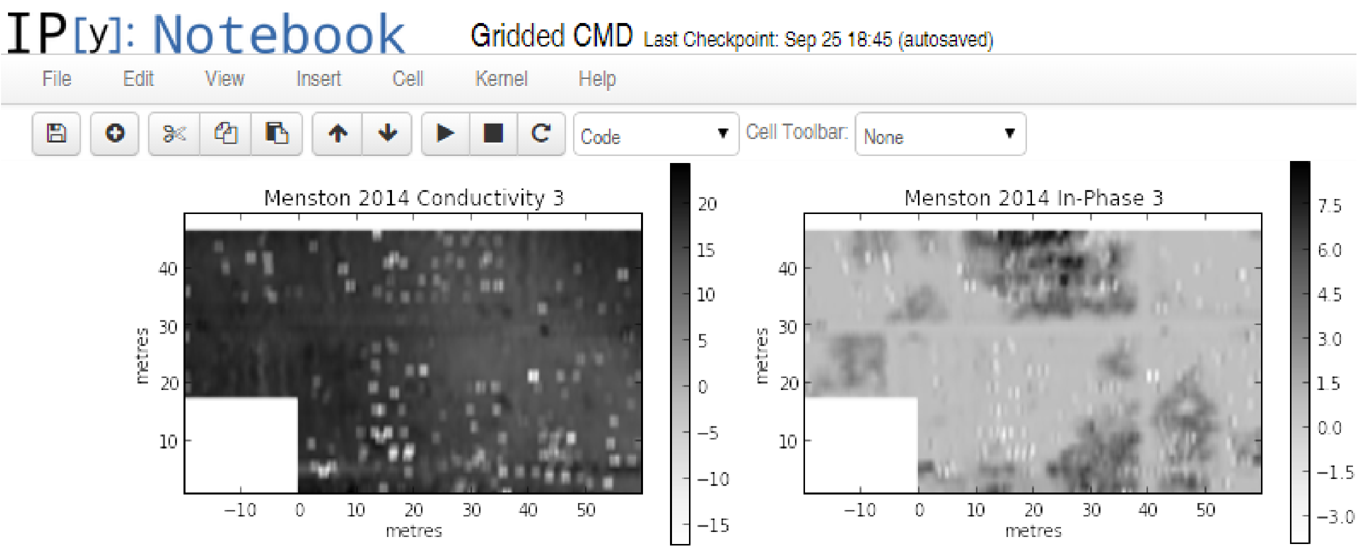

Fig. 1 Automated management and re-gridding of electromagnetic induction data, allowing an easy, streamlined importation into conventional data processing packages.

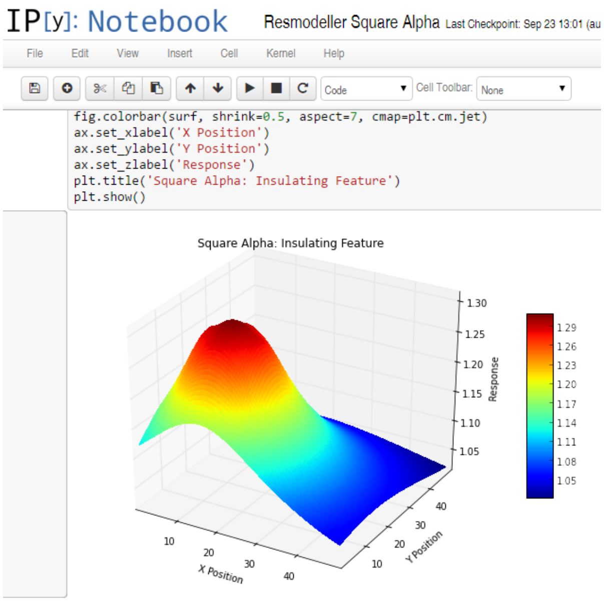

Fig. 2 Numerical modelling and display of resistivity responses over three-dimensional features.

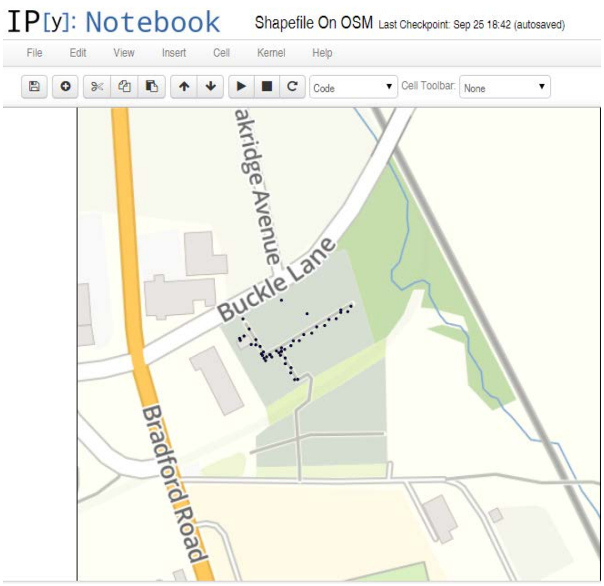

Fig. 3 Display and manipulation of geographic Datasets including shapefiles and Open Street Map basemaps.

GEOPHYSICAL SURVEYS FOR PALEO-ENVIRONMENTAL RECONSTRUCTION IN THE TRANSITION ZONE

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Introduction

Over the past two decades an increasing number of geophysical techniques have been applied to archaeological studies. This has mainly been undertaken with regard to investigation of habitation sites but also more recently, the use of geophysics has extended to the investigation and reconstruction of palaeo-landscapes. Successful projects both onshore and offshore have demonstrated the utility of the geophysics, however, few projects have attempted to link the onshore and offshore landscapes. The difficulty in using geophysical techniques to understand sedimentary sequences in the intertidal or transition zone has been well documented and no single technique is either wholly appropriate for every type of buried landscape or is readily deployable in every modern situation. Rather, different techniques are appropriate under different scenarios. Techniques that have consistently found application are seismic, electrical (in particular electric resistivity tomography – ERT) and electromagnetic (in particular frequency domain electromagnetic ground conductivity – FDEM). Each has its limitations but all have some benefits. This paper presents two recent case histories using ERT and FDEM techniques.

Borth Peat and Submerged Forest

The existence of submerged landscapes surrounding the island of Britain has been recorded and discussed since the pioneering work of Clement Reid published in 1913 in *Submerged Forests*. The west coast of Wales contains a substantial number of drowned forests that have been reported on frequently since the early part of the 20th century when Yapp *et al*. (1916) first recorded the presence of peats overlying marine clays at Borth. The peats are intermittently exposed and the storms of recent years, in conjunction with recent construction work on the foreshore for sea defences, have re-exposed large sections of the peat and forest allowing a more complete evaluation of the deposits and their context. In order to evaluate the full extent of the deposits and their relation to palaeo-river channels both ERT and FDEM data were acquired. Ground truth methods included test pits and CPT.

ERT forward modelling of the foreshore indicated that it is possible to map the contrast in bedrock with salt-saturated sand and also the thin peat layers if the resistivity contrast to surrounding salt-saturated sands is high. Figure 1 shows forward models for a steeply dipping bedrock overlain by freshwater saturated sand (a), salt-saturated sand (b), freshwater saturated sand with thin peat layer (c) and salt-saturated sand with a thin peat layer (d). The inversion results of an ERT field transect is show together with ground truth locations for CPT results in (figure 2a and 2b). Bedrock at the site is the Ordovician to Silurian gritstones that are exposed in cliffs and wavecut platform to the south of the site.The depth of Holocene sediments and beach material increases dramatically from south to north as mapped by the ERT.The presence of the shallow-buried, thin peat layer is interpreted from the data results and a comparison with the forward models.

West Street, Selsey Channel

The West Sussex coastal plain on the south coast of England is marked by extensive Pleistocene deposits that include a series of high sea level events that are truncated by a complex sedimentary sequence associated with a series of north-south trending valleys (Bates et al., 2009). On the foreshore and intertidal zone today smaller scale palaeo-channels relating, in a way that is currently difficult to ascertain, to the main marine sequences, are buried by thin modern beach deposits that offer the possibility to investigate the channel morphology with respect to palaeo-environmental signature and associated archaeological deposits. A range of channel morphologies with varying contrasts in resistivity were modelled and demonstrate that the presence of a channel should be readily discernible if its geometry and resistivity contrast in marked. It is interesting to note here that where the channel is relatively conductive compared to surrounding resistive material it is well defined while if the reverse is true the geometry becomes less obvious as a channel feature.

Figure 3a shows the results of a FDEM survey over the beach and the location of ERT transect and test pits together with inset ERT results (3b). The FDEM showed ground conductivity varying between 50mS/m and 400mS/m over the beach sands with values less than 30mS/m across the gravel deposits at the top of the beach above high tide. The ERT transect recorded apparent resistivity of less than 1 ohm-m to greater than 300ohm-m where the near surface was dominated by low resistivity (or its inverse high conductivity) as a result of saline saturated beach sand. Higher apparent resistivity values however were recorded at depth and in particular to the northwest where the line crossed disturbed beach associated with the sea groynes.

The channel margins were well defined by the EM38 where the Tertiary bedrock extends close to the surface. The top of the bedrock was also imaged in the ERT section however, the subsurface geometry of the channel was less well defined as the contrast in apparent resistivity between the intermediate values for the channel compared to the conductive beach sand and the underlying resistive bedrock together with channel thickness was perhaps not high enough for discrimination as suggested by the forward modelling.

Discussion

The use of electrical and electromagnetic techniques in these studies illustrates that they can successfully be used to obtain meaningful palaeo-environmental reconstructions in the intertidal zone if ground truth information is available for cross-reference. Forward modelling is important as it can provide useful insight as to the complex geometries that are created with different resistivity contrasts. As the techniques become more rapid for data acquisition it is anticipated that their use will become more widespread and cost effective. The geophysical surveys not only allow for ground truth data to be extrapolated but also for recognisance surveying to be undertaken prior to targeted ground truth methods. Furthermore they allow for the extrapolation of the intertidal both onshore and offshore.

References

Bates, M.R., Bates, C.R., Gibbard, P.L., Keen, D.H., Parfitt, S.A., Peglar, S.M., Schwenninger, J-L., Wenban-Smith, F.F. and Whittaker, J.E. 2009 West Street, Selsey. In: Briant, R.M., Bates, M.R., Hosfield, R.T. and Wenban-Smith, F.F. (eds.) *The Quaternary of the Solent Basin and West Sussex Raised Beaches. Field Guide*. Quaternary Research Association: London.

Reid, C. 1892 The Pleistocene deposits of the Sussex coast, and their equivalents in other districts.*Quarterly Journal of the Geological Society* **48**, 344-365.

Yapp, R. H. Johns, D. Jones, O. T. (1917) The salt marshes of the Dovey Estuary, Cambridge : Cambridge University Press, Reprinted from *The Journal of ecology Vol.IV, no.1, 1916 and Vol.V, no.2, 1917*

Fig. 1 Model sections for Borth Beach

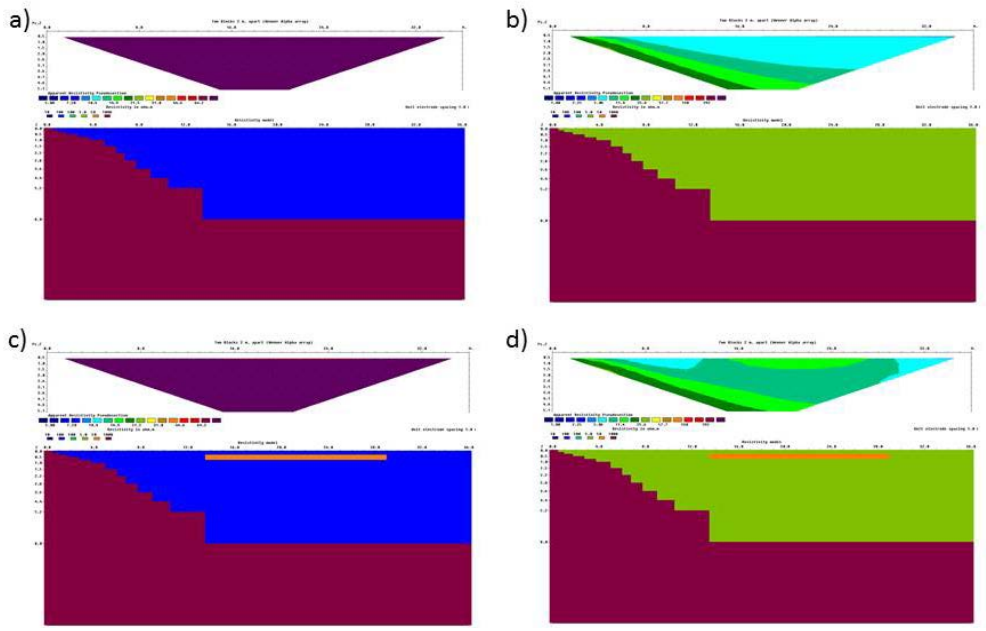


Fig. 2 BorthERT section (south to north)

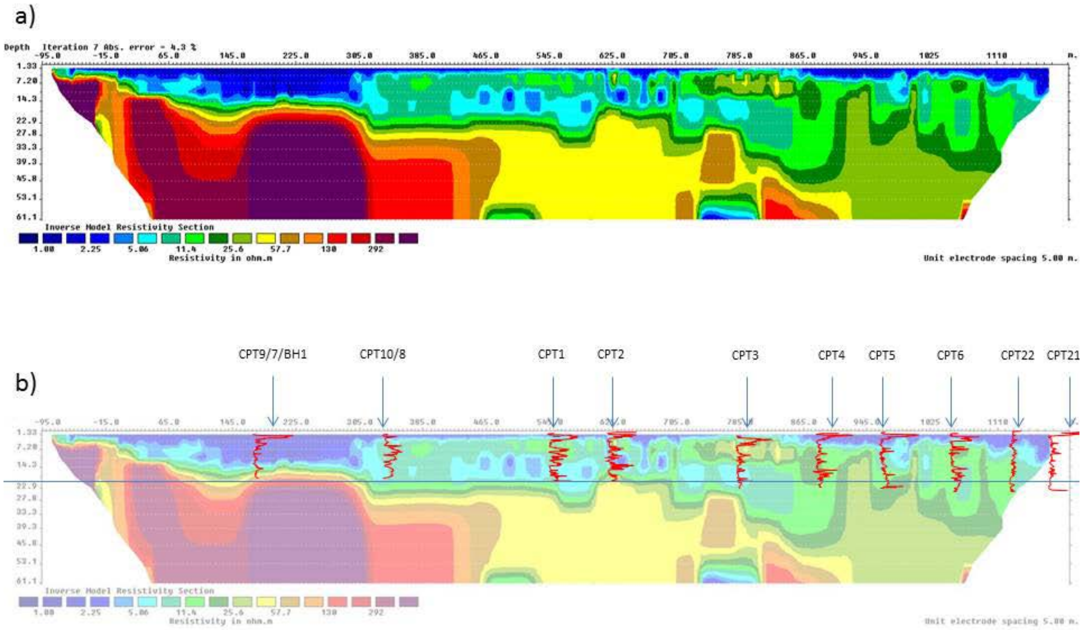
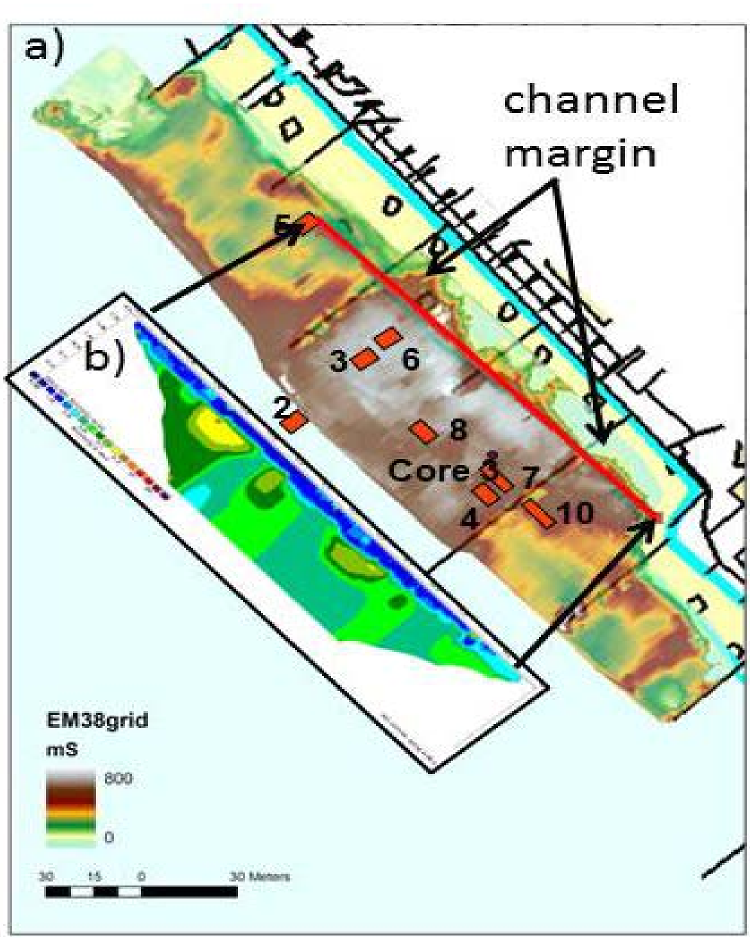


Fig. 3 West Street Selsey Channel, FDEM and ERT section



NDT AND GEO-ARCHAEOLOGY IN ITALY: COULD INTERDISCIPLINARITY BE A SOLUTION?

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The integration of interdisciplinary methods (e.g., in a GIS) allows us to spatially correlate archaeological surface scatters and anomalies detected by non-destructive techniques (NDT). The correct approach to the past should be not only to plan a *before* and *after*, but to plan a *during*, in the sense that proper planning for an excavation must include the presence of experts before and during the archaeological project. If this statement seems to be easy and expected, it is not always applied. In fact, this approach leads to the understanding that the basis for a correct investigative methodology must undoubtedly be the intelligent organisation of the team involved. But lack of money, closed minds, and sometimes ignorance produce terrible mistakes and questionable results. A genuine interdisciplinary approach proves advantageous in several ways, increased by modern (and, most important, non-destructive) scientific techniques. This paper will present both the good and bad outcomes of these integrated methods in archaeology using some Italian examples.

Among different case-studies, it will begin showing how a fortuitous discovery of an archaeological site in central Italy can create panic, bureaucratically speaking: in this case of the discovery of a subsurface archaeological target a few dozen kilometres northeast of Rome, near the proposed site for the construction of a waste-to-energy incinerator, should cause local administrations to reconsider their plans for construction at this site (Figure 1) (Barone et al., 2012).

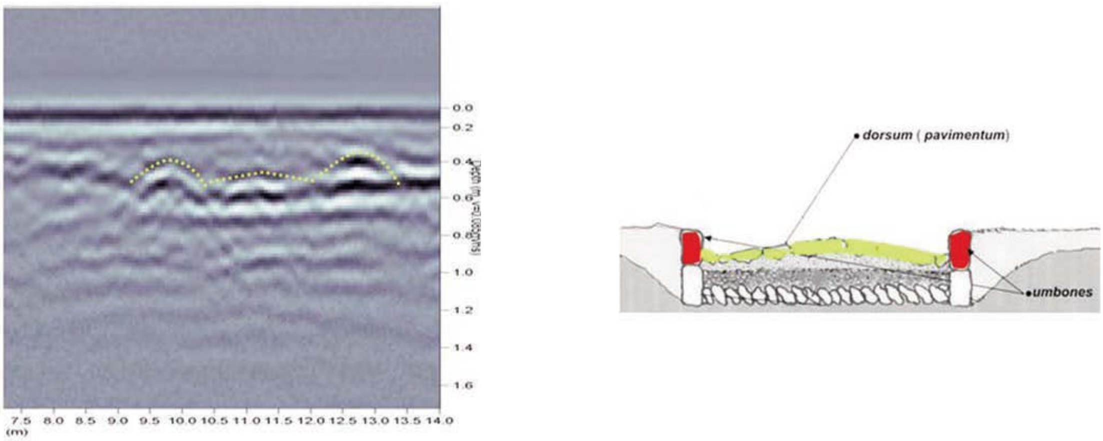

Fig. 1 -The GPR cross section (above left) and a schematic reconstruction (above right) confirm the presence of a buried Roman road.

On the other hand, it will be shown how an international project has not only saved, but also increased the potential of an extraordinary archaeological site: the church of Santa Maria Antiqua. Restoration work on the wall paintings, geophysical prospection, and final archaeological excavations have shown the presence of a quite complex stratigraphy and history (figure 2) (Barone and Ferrara, 2014).

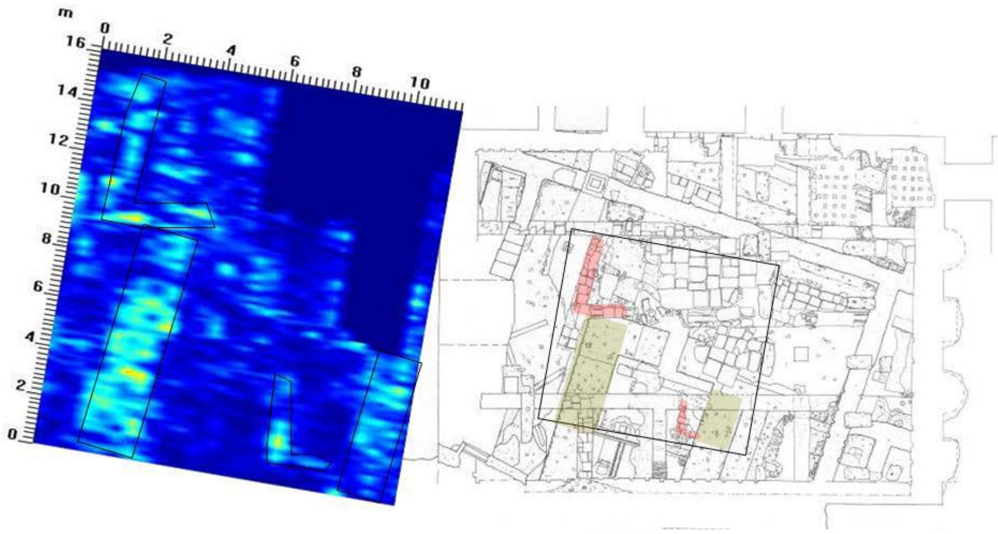

Fig. 2 The figure on the left shows the GPR map of different anomalies (elongated and right-angled) at a depth of about 1 m. The figure on the right highlights the correlation of these GPR anomalies with the archaeological excavations.

REFERENCES:

Barone P.M. – Ferrara C. (2014), You can't make an omelette without breaking some eggs: in which way can non-destructive and destructive techniques coexist?, in Proceedings of the 15th International Conference on Ground Penetrating Radar, Bruxelles 2014, IEEE.

Barone P.M. – Ferrara C. – Pettinelli E. (2012), How could Archaeo-Geophysics help the garbage disposal? A fortuitous discovery in Central Italy, in «Antiqua», DOI: 10.4081/4271

USING GEOPHYSICAL SURVEY IN THE ARCHAEOLOGICAL CHARACTERISATION OF UPLANDS: A CASE STUDY FROM THE LATER PREHISTORIC LANDSCAPE OF THE YORKSHIRE DALES

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Historic Landscape Characterisation and Historic Landuse Assessment rely on making broad brush archaeological assessments which can be used to inform any future historic environment decisions (Rippon 2007, 2013). These assessments can be very limited in their scope but in certain upland and marginal locations, where we already have multiple layers of information, geophysical survey has the potential to add a further sub surface dimension, enhancing the quality of characterisation and improving the way in which these landscapes are managed or subsequently Developed.

Fig. 1 An example of the upland and marginal landscapes of the Yorkshire Dales, north of High Pasture, Grassington, North Yorkshire.

The use of archaeological geophysical survey in upland and marginal parts of Britain has long been limited, a situation well illustrated by Jordan's 2009 work on the NW of England (Jordan 2009). Mirroring these findings, the Historic Environment Record for the nearby Yorkshire Dales contains records for only 14 geophysical surveys, with almost none considered as fully commercial projects. 44 walkover surveys are noted for the same period and 22 of these are commercial projects, while 10 relate to stewardship schemes. Although more examples of both types of survey have been undertaken, the approximate ratio indicated here still holds true. Clearly geophysical work would not have been suitable in every case where walkover was used, but might it have been appropriate in some?

In the East Sweet Side area, north of Grassington, what are considered to be later prehistoric field systems remain as extant turf and stone dykes running across the landscape. These features are part of one of the most extensive and extant examples of such systems found in the UK and are evident over thousands of hectares across the Yorkshire Dales. As a pilot study for the fieldwork component of a PhD based around these systems, a suite of geophysical survey methods were employed over this area.

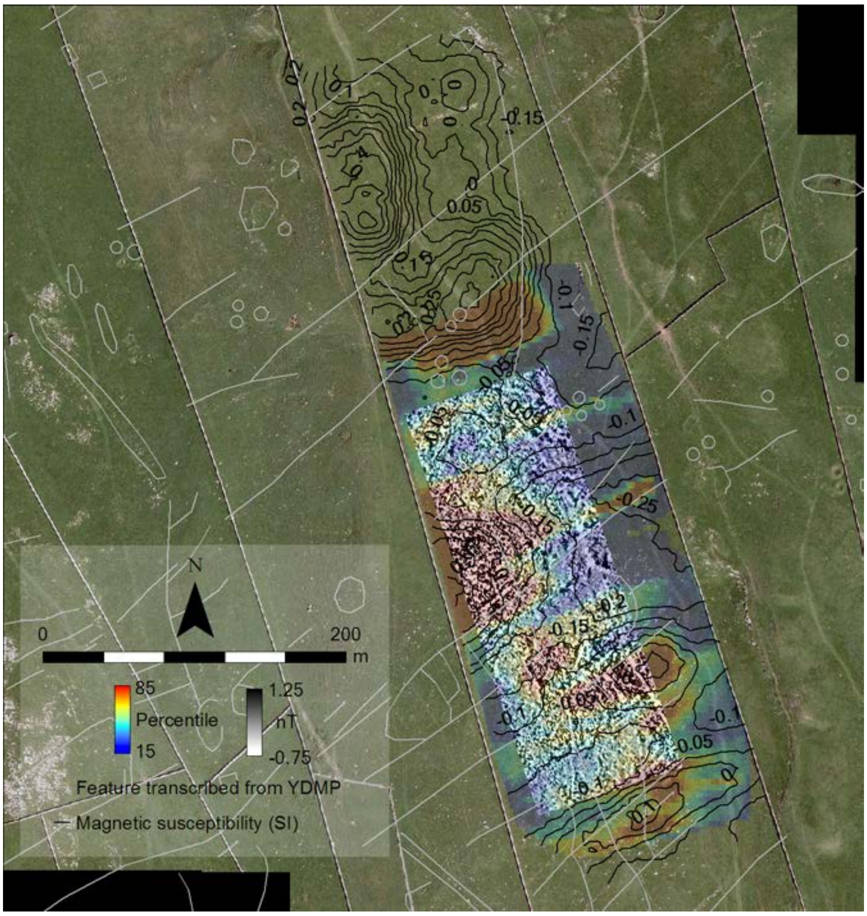

Fig. 2 YDMP transcriptions, magnetic susceptibility survey, EMI survey and magnetic survey, north of High Pasture, Grassington (aerial imagery (c) Google 2014).

Because of the size of this field system, the work focused on developing methods to rapidly assess and characterise the features within it, building upon existing information from the Yorkshire Dales Mapping Project (YDMP), during which the RCHME transcribed thousands of aerial photographs (see Horne and MacLeod 2001, 2004). Kite aerial photography, walkover survey, broad scale magnetic susceptibility survey, broad scale EMI survey and gridded magnetic survey were all employed with varying degrees of success. Magnetic susceptibility survey and magnetic survey were of most use, particularly when combined with the YDMP transcriptions or low-level aerial imagery (e.g. Google). Walkover survey proved extremely time consuming but was invaluable in the characterisation and interpretation of the extant features. The broad zones of increased response identified by the magnetic susceptibility survey could be contextualised by comparison with the YDMP transcriptions, indicating a somewhat unexpected, high degree of zonality across the field system. Magnetic survey, although not without practical difficulties, was far more successful than anticipated and was both able to more accurately map the existing features, while at the same time refining and delimiting the activity zones identified by the magnetic susceptibility survey.

Although this work covered only a tiny percentage of the Yorkshire Dales later prehistoric field systems, it served to prove the value of a multi-faceted approach to survey in this kind of environment. Because there are many practical issues involved in working in upland and marginal locations and because the nature of the archaeology often differs from that found in the lowlands, perhaps a reconsideration of our whole approach to working in these areas is necessary. The go-to method of archaeological assessment, walkover survey, relies on the presence of partially extant surface features and the effective integration these remains with the other layers of existing data, has to be central in the development of any revised geophysical methodology. The scale and scope of work is also of key importance because in many cases the terrain found in marginal and upland areas precludes the use of standard geophysical techniques and in cases where the 'norm' is not appropriate, we must ensure we do not completely write off these methods.

Because we have additional layers of information in many of these locations, we are in the enviable position of being able to pose much more developed research questions and by addressing these with a tailored, perhaps non-standard approach, can begin to better understand and characterise these upland and marginal landscapes.

This project is one of two AHRC Collaborative Doctoral Awards between the University of Bradford and Dr Roger Martlew at Dales Landscape Heritage and Robert White at the Yorkshire Dales National Park Authority. The projects are based around the later prehistoric landscapes of the Yorkshire Dales, the first utilising GIS to study the area within a European context and this, the second, looking more closely at the nature and development of the field systems themselves, through the use of a variety of fieldwork and remote-sensing approaches.

Bibliography

Horne P and MacLeod D (2001) Unravelling a Wharfedale Landscape: A Case study in field enhanced aerial survey. *Landscapes* 2: 65 – 82

Horne PD and MacLeod D (2004) The RCHME's Yorkshire Dales Mapping Project in White RF and Wilson PR (eds) *Archaeology and historical landscapes of the Yorkshire Dales.* Yorks. Arch. Soc. Occ. Papers 2: 15 – 24

Jordon D (2009) How effective is geophysical survey? A regional review. *Archaeol. Prospect.* 16(2): 77 – 90

Rippon S (2007) Historic Landscape Characterisation: Its Role in Contemporary British Archaeology and Landscape History. *Landscapes* 8(2): 1 – 14

Rippon S (2013) Historic Landscape Character and Sense of Place. *Landscape Research.* 38(2): 179–202

MAGNETIC SUSCEPTIBILITY MAPPING WITH THE GEONICS EM38B ELECTROMAGNETIC SUSCEPTIBILITY / CONDUCTIVITY METER TO LOCATE AND MAP ARCHAEOLOGICAL SITES

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Many years ago Tabbagh (1986) suggested that short-spacing, dipole-dipole electromagnetic instrumentation, such as the EM38B, could be effectively used to rapidly map prospective archaeological sites. Moreover, such instruments have advantages over the more commonly used vertical-gradient magnetometers.

For example, gradiometers respond to local variations in the regional, *essentially uniform* earth's magnetic field caused by local variations in terrain magnetic susceptibility. Uniform magnetic excitation over the entire survey area means that this technique is relatively insensitive to variations in the thickness and susceptibility of extended horizontal thin layers of susceptible material, a model that often applies to archaeologically interesting targets.

Conversely, at every survey measurement location, dipole-dipole instruments, such as the EM38B, *selectively energize only that part of the survey area* whose susceptibility is to be measured, resulting in a more highly resolved profile of local amplitude and spatial variations of the magnetic susceptibility. Such measurement is a much better indicator of actual target shape, greatly improving target interpretation.

Other advantages are that survey data interpretation does not vary with geomagnetic latitude. Moreover, since target response does not exhibit large changes in the sign of the response, spatial response tends to be better than gradiometers. All fluctuations in measured susceptibility reflect changes in target susceptibility or size, with the result that there is a large amount of useful data in the survey data *profiles*, every bit of which provide useful information.

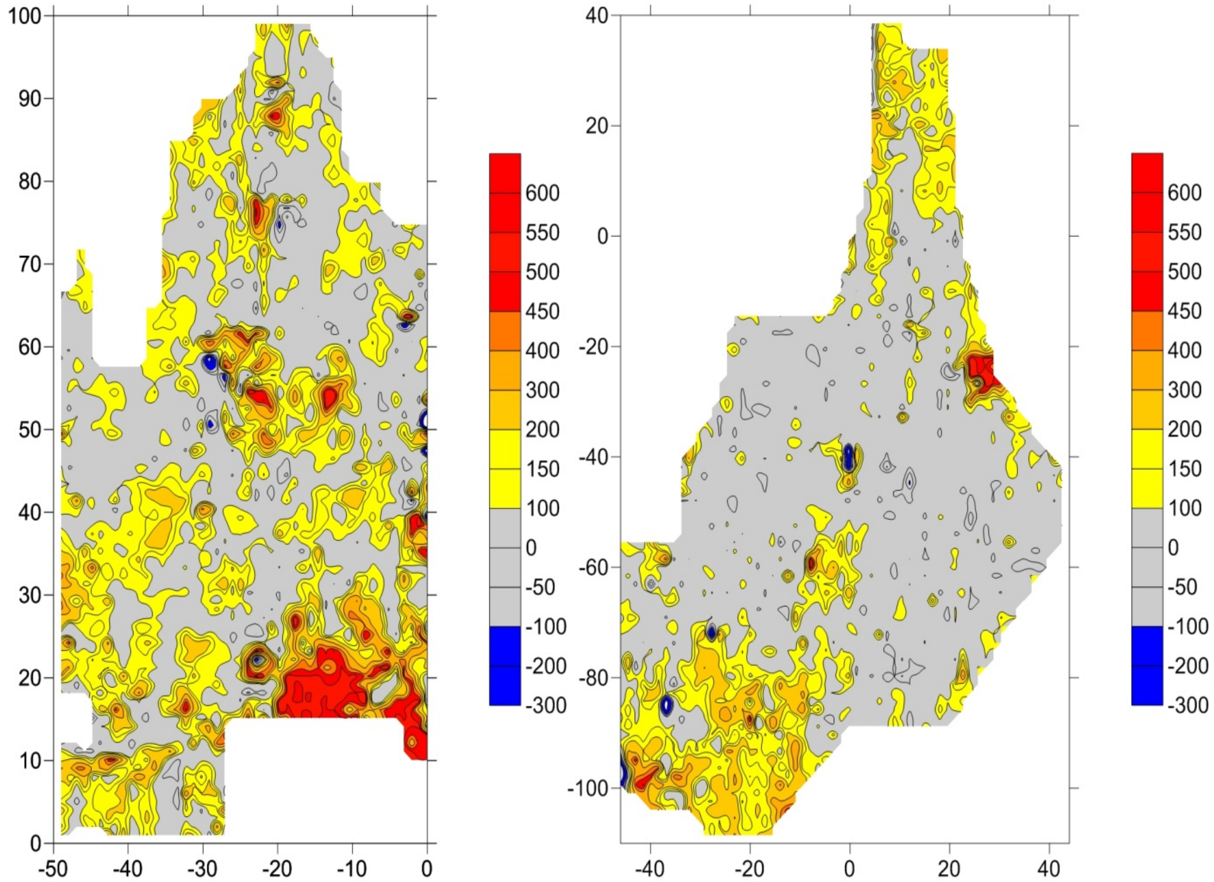
Since the technique does not respond to remnant magnetization, less interference is encountered in areas cluttered with metallic iron targets (although the technique does respond to ferrous targets via their increased susceptibility). Furthermore since the technique also responds to electrical conductivity, non-ferrous metallic targets are also detected. Both ferrous and non-ferrous metallic targets are usually easily distinguished by their characteristic signatures.

Depth of exploration is of the order of one-half metre, useful in a great variety of archaeological environments.

Most importantly, these instruments simultaneously and independently measure terrain electrical conductivity, in addition to magnetic susceptibility, providing a completely complementary picture of the survey environment and area. Conductivity provides useful information as to changes in soil types, soil moisture patterns, differences in underlying geology, and also enhances interpretability of metallic responses.

And finally, by measuring both the in phase (susceptibility) and quadrature-phase components (conductivity) of the terrain response it appears that the ratio of these two responses will prove to be useful in deciding (in the same sense as does the percent frequency-effect in magnetometry) whether the magnetic grains causing the target susceptibility response are of super-paramagnetic or stable single-domain size).

Following a brief description of the measurement technique, this paper provides a selection of EM38B survey case histories carried out over the past decade over a variety of archaeological sites in Eastern North America, and illustrating all of the above features. In some cases complementary gradiometer data is also presented or discussed (not all sites had magnetometry data).



The case-history shown above (details of which will be discussed in the paper) was taken over two days at St. Croix Island on the Canadian/USA border. The left plot is of the north half of the island, right is of the south half. Colour scale bars are of apparent magnetic susceptibility in parts-per-million (ppm), distances are in metres (note that the distance scales are different for each half of the island), and interline spacing was one metre.

It was on this very small island (of area two and half hectares) in June, 1604, that Samuel Champlain and a company of 75 men attempted to establish a settlement in North America. During the following bitterly cold winter, 34 members of the company died from scurvy and were interred in an earlier Indian burial site situated at the south end of the island. The following year the survivors, along with some of the wooden buildings, were removed to Port Royal in the Bay of Fundy where they established the well-known 'Habitation'. The remaining buildings were left, to be burned ten years later by visiting New Englanders. (Assistance of Steven R. Pendery, University of Massachusetts, Amherst, and the United States National Park Service in carrying out this survey is gratefully acknowledged).

THE CANTERBURY HINTERLAND PROJECT: MULTI-METHOD GEOPHYSICAL INVESTIGATION OF A ROMAN ENCLOSURE AT BOURNE PARK (WITH THE EMPHASIS ON THE GPR SURVEY)

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In 2011, a pilot fluxgate gradiometer survey was conducted at Bourne Park, Bishopsbourne, Kent, where crop marks representing a probable Roman building had been observed by Mr Chris Blair-Myers in aerial photographs of 1990, and by Dr Ben Croxford in a Google Earth image from 2003 (Wallace and Johnson 2012). Furthermore, metal detectorists had recovered Iron Age, Roman and Saxon coins and brooches between 1986 and 2002. The promising results of the 2011 survey warranted further geophysical and topographical investigations. In three seasons of survey (2012-2014), *c.* 47 ha were surveyed with magnetometry at Bourne Park. From 2014 onwards, in addition to Bourne Park, three other sites are investigated with geophysical techniques within the Canterbury Hinterland Project (a rectilinear enclosure at Patrixbourne, a farmstead at Petham and a Roman-period structural complex at Ickham). More details can be found at http://www.arch.cam.ac.uk/research/projects/canterbury-hinterland

Bourne Park is an area of open parkland between the villages of Bishopsbourne to the south and Bridge to the north, *c.* 6 km southeast of the centre of Canterbury. It lies in a valley shaped by the Nailbourne Stream, which is now only seasonal. The valley slopes up to the north-east, towards the line of the Roman road between Canterbury and Dover. The British Geological Survey records the local geology as White Chalk (Wallace *et al.* 2013). The primary objective of the survey at Bourne Park is to investigate the probable Roman structures, the landscape surrounding them, and their relationship with the Roman town at Canterbury and the Canterbury-Dover road with the many burials along it (Wallace *et al.* 2014b).

The fluxgate gradiometer survey was conducted using a Bartington Instruments Grad 601-2 Dual Sensor magnetometer. Readings were taken at 0.25 m intervals along traverses of 0.5 m spacing. The site exhibited a good response to the gradiometer and buried features show clearly against the geological background: positive readings appear to result from ditches or pits, whereas negative magnetic responses are interpreted as walls. Several enclosures were detected, most of which lie approximately parallel to the Roman road. Moreover, an Anglo-Saxon cemetery, partially excavated previously, and probable Iron Age structures were found.

The focus of this contribution is on an enclosure of *c.* 100 m × 110 m, bounded by linear ditches on three sides, and with at least two large buildings within it (hereafter referred to as western and southern building). These are clear in the magnetometry, although the northern part of the western building, visible in the aerial photographs, is absent (Wallace 2013). An earth resistance survey was undertaken over the western building in March 2013 with a Geoscan Research RM15, at spatial resolutions of 0.5 m × 0.5 m and 0.5 m × 1 m, using a 0.5 m and 1 m twin-probe configuration, respectively. It shows the walls in more detail than the magnetometry (Wallace *et al.* 2014a).

In August 2013, a ground-penetrating radar (GPR) survey of *c.* 0.6 ha was conducted over the western and southern buildings, using a Sensors & Software Spidar network comprising five single 500 MHz antennas mounted in parallel and towed behind an all-terrain vehicle (Verdonck *et al.* 2013). The inline sample interval was 0.05 m, the transect spacing 0.125 m. After dewow and time zero alignment, the same gain function was applied to all traces to enhance later arrivals and preserve relative amplitudes. A low-pass frequency filter (1 GHz) was applied. Also after background removal, there were slight variations in the amplitudes recorded by the different channels in the network, visible as stripes in the time-slices. The amplitudes were equalised using an average for each channel, computed over the entire profile length. Migration velocity analysis was performed both on profiles and horizontal slices extracted from data cubes 3-D migrated with different velocities, and resulted in a velocity of 0.07 m/ns showing little lateral or vertical variation. After 3-D migration, the data were converted from time to depth.

On the basis of the GPR data, the western building seems to consist of a long corridor of 37 m × 5 m, and two 13 m × 6 m large rooms, projecting in SW direction at the extremities of the corridor (Figure 1).

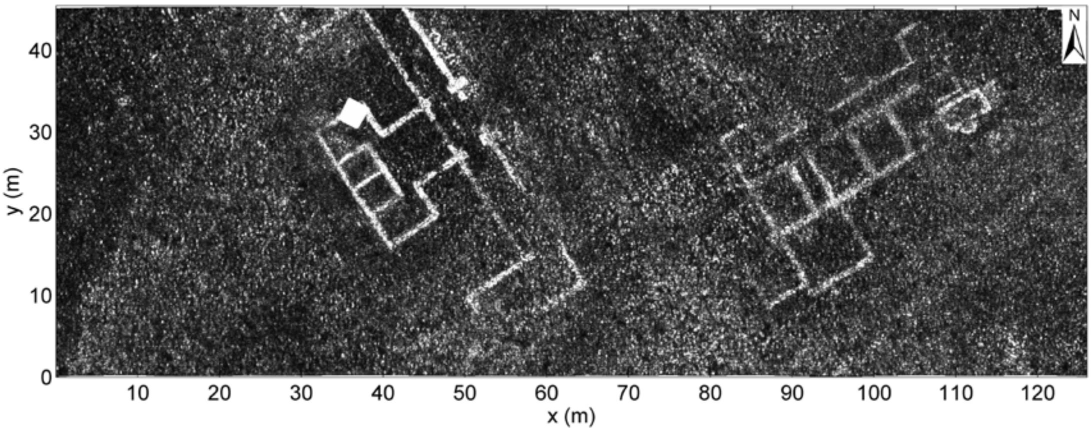

Fig 1

The 4.5 m wide entrance in the middle of the corridor opens onto a T-shaped addition, 13 m deep SW of the corridor, and with a maximum width of 17 m. Whereas the function of this western building is unclear, the plan of the southern building resembles the villas with *porticus* and two projecting pavilions, found elsewhere in Roman Britain and in other provinces of the western Roman Empire (Smith 1997). Remarkably, the *porticus* is not situated in between the two pavilions (as is often the case), but extends over the whole length of the building (*c.* 28 m) and separates the pavilions from the core building. The latter consists of at least four rooms, *c*. 7 m deep and 4.5 - 6 m wide, and a narrow room, probably a corridor. Two more rooms are visible to the south, and a room with apse on the eastern corner could be interpreted as baths (Figure 1).

Beside the western and southern building, a possible third wing in the northern part of the enclosure is indicated by an area of less clear magnetic anomalies. Neither the earth resistance survey nor the GPR prospection of this area in August 2014 were able to reveal clear structures, suggesting a poor state of preservation.

References

Smith, J.T. 1997. *Roman villas. A study in social structure.* Routledge: London-New York.

Verdonck, L., Vermeulen, F., Docter, R., Meyer, C. and Kniess, R. 2013. 2D and 3D ground-penetrating radar surveys with a modular system: data processing strategies and results from archaeological field tests. *Near Surface Geophysics* 11: 239–252.

Wallace, L. 2013. The Canterbury Hinterland Project: Phase I. *The Bulletin of the Association for Roman Archaeology* 29: 18–20.

Wallace, L. and Johnson, P. 2012. *Bourne Park (Bishopsbourne) Geophysical Survey, 2011 Results*. Unpublished archive report. Kent Historic Environment Record. http://www.arch.cam.ac.uk/research/projects/canterbury-hinterland/chp-images/bpk11-report-mar-2012-reduced.pdf [accessed 25 September 2014].

Wallace, L., Johnson, P. and Strutt, K. 2013. *Bourne Park (Bishopsbourne) Geophysical Survey, 2012 Results*. Unpublished archive report. Kent Historic Environment Record. http://www.arch.cam.ac.uk/research/projects/canterbury-hinterland/chp-images/bpk12-report-jan-2013-smaller.pdf [accessed 25 September 2014].

Wallace, L., Johnson, P. and Mullen, A. 2014a. *Bourne Park (Bishopsbourne) Geophysical Survey, 2013 Results*. Unpublished archive report. Kent Historic Environment Record.

Wallace, L., Johnson, P., Strutt, K. and Mullen, A. 2014b. Archaeological Investigations of a Major Building, Probably Roman, and Related Landscape Features at Bourne Park, Bishopsbourne, 2011-12. *Archaeologia Cantiana* 134: 187-203.

Acknowledgement

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RECENT SURVEYS AT SARUQ AL-HADID, DUBAI, UNITED ARAB EMIRATES

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The archaeological site of Saruq al-Hadidin the Emirate of Dubai was first discovered from the air in 2002 by Sheikh Mohammed bin Rashid al-Maktoum, who noticed a large spread of dark material in the dunes as he flew overhead. Further inspection determined that the material was metal-working slag on the dune surface, interspersed with metal artefacts, ceramics and other cultural material. The main slag-covered mound extended over more than 1ha, though associated activities could extend the wider site to over 1km^2.

Fig. 1 Aerial image of the study area (courtesy of Google Earth)

Investigations have now determined that the site started as a campsite for nomadic pastoralists in the mid-third millennium BC, became a ritual focus for a snake cult in the first millennium BC and subsequently a major production centre for gold, copper, bronze and iron artefacts in the later Iron Age. In recent years, excavations have revealed a wealth of artefacts including diagnostic ceramics, stone vessels, beads and some 10,000 metal artefacts including swords, daggers, intricately decorated gold objects, arrowheads, tweezers, axe heads, fish-hooks, models of snakes, bracelets, rings, pins, knives, spouted bowls, incense burners and jewellery items, for example. Many of the ceramic and metal artefacts incorporate a snake motif.

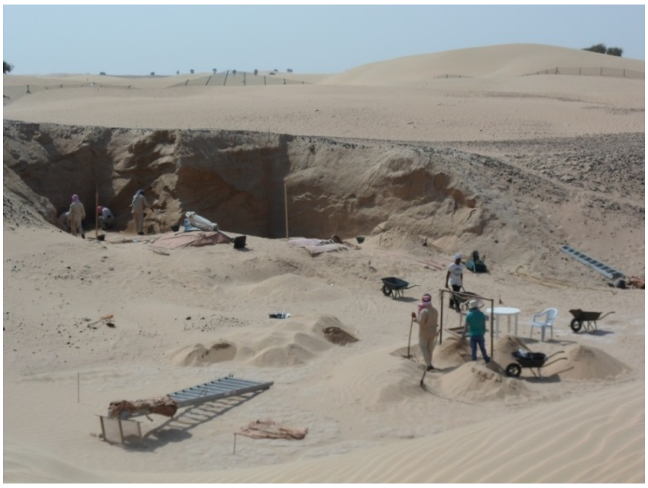

Fig. 2 Excavation in progress

Perhaps the greatest enigma regarding the site is its location, approximately 70km south of Dubai city and 40km west of al Faqa, in the eastern part of the Rub' al Khali ('Empty Quarter'), the largest continuous sand desert in the world. There are no known sources of mineral ore, fuel or water within 60-100km. Another enigma is the fact that, during the metal-working phases, there is no evidence for any furnaces, buildings or any other structures, nor any evidence for cut features such as pits, ditches or burials.

The specific aims of the geomagnetic survey were therefore to map the sub-surface extent of slag concentrations across the site, and, if possible, to identify potential furnace locations and any evidence for settlement or other features. Eight areas totalling approximately 12 hectares were surveyed. In addition to the main fenced site area, surveys were also undertaken to the north, south, east and west of the site.

All the surveys were undertaken in an active dune field. Some of the dunes along the north and south edges of the compound were approximately 10m high; within the compound they measured up to 7m in height. Although only a few metres in height, the dunes provided particularly challenging terrain for data collection, especially in temperatures over 40^{0}C.

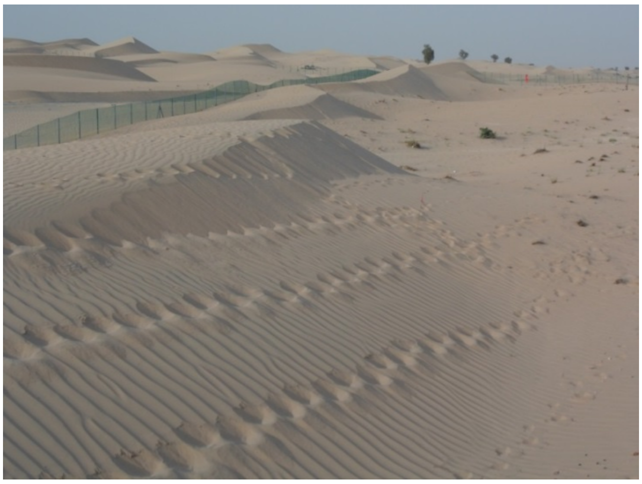

Fig. 3 Part of the main site compound

The surveys proved effective at detecting spreads of metal-working slag, which extended considerable distances beyond what could be seen on the surface. The largest concentration corresponds to a scatter of metal-working debris around the east end of the current excavation. Three small clusters of surface slag have been shown to be surface expressions of much larger sub-surface concentrations.

Possible sub-surface arrangements of limestone blocks were detected in two areas, which could potentially reflect the foundations for buildings or other structures. Both possible structures are in areas where slag and other cultural materials are present, as well as other larger possible features. There do not appear to be spreads of limestone, as might be expected from collapsed walls, and so perhaps limestone blocks were used as foundations for more temporary superstructures.

Large, weak dipolar magnetic anomalies were detected throughout the site, though concentrated around the main site compound. The cause of these anomalies remains uncertain. They could reflect ferrous or fired clay materials which are deeply buried, or perhaps burnt areas or hearths nearer the surface. Blocks of tabular limestone were present on the surface in several places; some of these blocks showed signs of having been burnt. If rudimentary furnaces or kilns at the site used limestone in their construction, rather than clay/mudbrick, then these weaker dipolar anomalies could perhaps reflect such furnaces. Trial excavation of selected anomalies could determine the depths at which different materials were detected and might inform the interpretation of many more anomalies across the site. This would be very useful for determining any further survey or excavation strategy.

Several weak, curvilinear, positive magnetic anomalies were detected across the site. In this case the anomalies correspond to the accumulation of iron-rich particles on the windward crests of dune ridges. In some instances there are also accompanying weak negative magnetic anomalies to the south or south-west, at the top of the steep, leeward side of a dune.

Several small, low mounds of gravel were present at the site, generally close to the concentrations of metal-working debris. It has been suggested that these could reflect the remains of small mudbrick structures after erosion of the clay component

(Derek Kennet pers. comm.). It was anticipated that areas of enhanced magnetism might be detected over these mounds, however, no corresponding anomalies were detected and the nature of these mounds remains uncertain.

Acknowledgements

Archaeological Services Durham University is grateful to Dubai Municipality (DM) for commissioning and facilitating this research. Further on-site support and information was kindly provided by the on-going excavation director Dr Hussein Qandil (Dubai Department of Archaeology). Dr Derek Kennet of Durham University is gratefully acknowledged for his role in facilitating the survey and providing support and discussion.

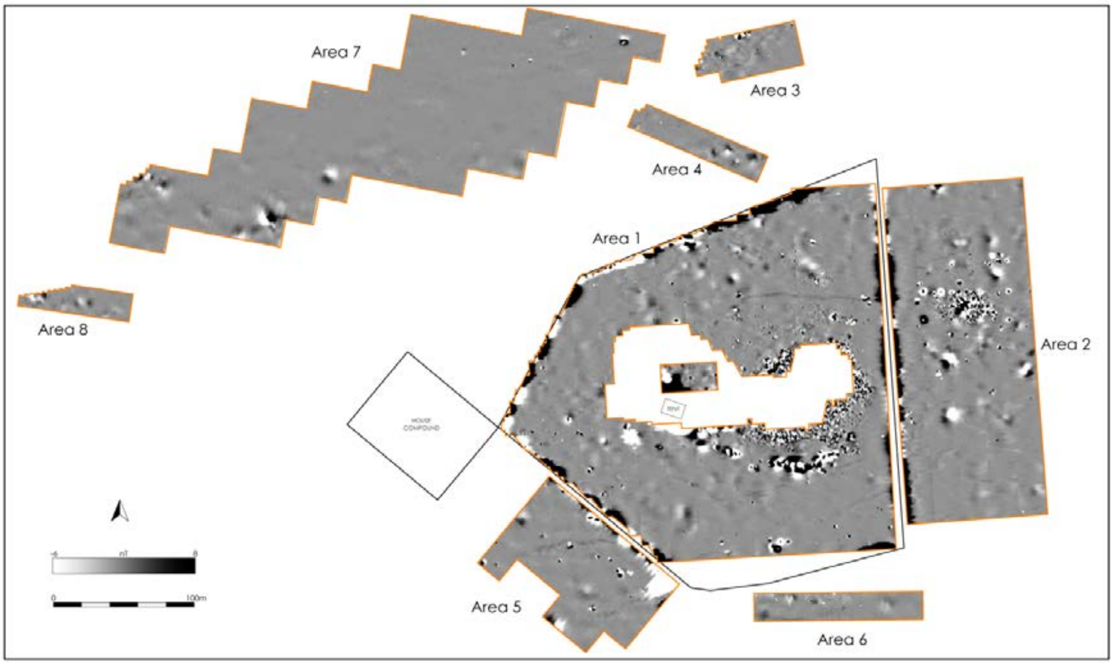

Fig. 4 Geomagnetic survey results

MARY, MARY, QUITE UNWARY, WHAT COULD YOUR GARDEN GEOPHYSICAL SURVEY SHOW?

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Dowsers regularly undertake surveys of historic gardens, including those of National Trust properties (e.g. Peter Golding Dowsing 2014, The Independent 1992). Taken that the value of dowsing for garden features has yet to be scientifically verified in controlled experiments, this could suggest that in some quarters there may be perceived deficiencies or limitations in the subsurface information that is provided by conventional archaeological geophysical survey approaches. This view may result from the sometimes relatively limited results that geophysical survey can often produce as will be demonstrated in the examples provided below. Therefore, the question that must be addressed is, "are we doing such surveys to the best standard?" The EH geophysical survey in archaeological field evaluation guidelines (English Heritage 2008) understandably do not specifically address standards for historic garden geophysics. Unfortunately neither, to the knowledge of the author, does anyone else. This paper will focus on a number of case studies that illustrate some limitations of more traditional methodological approaches employed when undertaking garden geophysical survey. It will argue that perhaps different or more novel approaches need to be taken to ensure that the most appropriate data is obtained, even if this takes much more work on the part of the survey team. If such an approach is taken then far better results are likely on many sites.

The first case study is the geophysical of the site of Court Green, Bere Regis (Dorset, UK). An initial geoelectrical survey using a 0.5m mobile electrode separation twin array taking readings at 1m interval along and 1m between traverses, undertaken in the autumn, produced extremely poor results, whereas the same area surveyed in the spring with a 4 x 0.25m mobile probe separation MPET (multiple potential electrode twin) array developed by the author (Cheetham 2001) employed at a 0.5m interval along and between traverses, undertaken in January (fig. 2), produced outstanding results. The results demonstrate that not only do such surveys need to be undertaken when ground conditions are favourable, but also that a higher resolution is required to do this site justice. The obvious danger here is that results from examples like the first survey that show limited archaeological potential may lead onto potentially erroneous heritage management decisions.

The second case study to be presented is from Kingston Lacy House, near Wimborne (Dorset, UK). This time three geoelectrical surveys have been conducted, one in July 2013 using a standard 0.5m separation twin at a 1x1m interval, the second in July2014 and again in October 2014 using the 4x0.25 MPET array. In this instance the work was supplemented by high frequency high resolution GPR (800MHz) to provide essential depth information. Here the potential issue is again surveying under favourable ground conditions and again employing a high survey resolution and the high resolving characteristics of the MPET array.

The third is at Clifton Maybank, near Sherborne (Dorset, UK) (Andrews and Cheetham 2014) where there is clear evidence that the 0.25m MPET array outperformed the standard 0.5m twin array in defining ephemeral garden features, the former arguably detecting the first instance of the remains of a turf bench *exedra* discovered by geophysical means, a anomaly/feature that was invisible in a survey employing the 0.5m twin array configuration.

The conclusions that can be drawn are that in respect of techniques that are affected by changes in ground moisture contrasts, for garden surveys multiple season surveys and high resolution surveys should be regarded as essential – anything less is likely to lead to a poor level of detection and delineation of all but the larger garden features. As a consequence, in light of these results it may be that many previously surveyed gardens will need to be resurveyed in order to establish the existence and true extent of the more ephemeral, but surviving, archaeological garden features. As is always the case, further comparative surveys will be needed to more fully evaluate this issue and the author strongly suggests that additional surveys are undertaken before decisions that are based on or will affect the archaeology are taken.

Sources Cited

Andrews, A. and Cheetham, P., 2014. 'Clifton Maybank: a case for geophysical investigations', in *The Association of Gardens Trusts 2014 Yearbook*. The Association of Gardens Trusts: London.

Cheetham, P.N., 2001. 'A symmetrical response, high resolution and reduced near-surface noise multiple potential electrode earth resistivity array for archaeological area survey', in Doneus, M., Edler-Hinterleitner, A. and Neubauer, W. (eds.), *Archaeological Prospection: Fourth international conference on archaeological prospection*, Austrian Academy of Sciences, Vienna: 79-80

English Heritage, 2008.*Geophysical Survey in Archaeological Field Evaluation*, 2nd Edition.

The Independent,Wednesday 05 August 1992. *A dowser explains the twitch's spell: National Trust experts have taken unusual advice on tracing 'lost' buildings. Michael Leapman reports.* Available from: http://www.independent.co.uk/news/uk/a-dowser-explains-the-twitchs-spell-national-trust-experts-have-taken-unusual-advice-on-tracing-lost-buildings-michael-leapman-reports-1538166.htmlm [accessed 08/08/14]

Peter Golding Dowsing, 2012.*SLIMBRIDGE DOWSING GROUP REPORTS: Woodchester Park*. Available from: http://www.petergolding.net/HTML/Woodchester_park2.html [accessed 08/08/14]

POSTER ABSTRACTS

PROSPECTING THE LOCATION OF THE GESSEL HOARD – THE BRONZE AGE GOLD DISCOVERY FROM SYKE, LOWER SAXONY, GERMANY

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Introduction

The excavations along the route of the Northern European Gas Pipeline (NEL) represent the largest archaeological project in Lower Saxony. The NEL-Pipeline was built in 2011 and 2012 in order to transport Siberian natural gas via the Baltic Sea Pipeline to the West European gas supply network. On the approximately 200 kilometer-long stretch from the river Elbe to the gas landing point in Rehden more than 150 largely unknown settlements and cemeteries were uncovered. Before the construction of the pipeline experts of the Lower Saxony State Service for Cultural Heritage (NLD) did a thorough archaeological investigation on an area of more than seven million square meters, the largest excavation section ever done in Lower Saxony. The highlight of the recent discoveries is the Gessel Hoard find near Syke, Gessel, about 18 km south of Bremen. With a weight of 1.7 kilos it is one of the largest Bronze Age gold treasures ever found on the old continent (Fig.1, 2). It had been buried in the 14th century B.C. and was excavated on the NEL-route in April 2011.

At the end of 2011 the NLD started a research program to investigate the possible archaeological context of the Gold Hoard which may have been buried near a Bronze Age settlement, stored by the wayside or deposited at a pronounced topographical location. The program consisted of high resolution caesium-magnetometry with a Scintrex SMARTMAG SM 4/4G, air borne laser scanning and analysis of historical maps.

Geophysical Prospection and Interpretation

In December 2011and April 2013 the vicinity of the Gessel Hoard location was magnetically prospected by Schweitzer-GPI, Burgwedel, Germany,with six surveys totaling 10ha and spread over an area of 550m by 550m (Fig.1). The objective was to search for subsurface remains of a bronze-age hamlet typical for that timei n northern Germany with wooden buildings and supply and firepits, possibly surrounded by enclosing ditches.The investigation area is located in the low relief topography of the Syker Geest formed during the Saalian glaciation period in the middle Pleistocene stage. Theglacial subsoil with clay and sand deposits contain erratic boulders and polygonal ice wedges of permafrost soils. Experience shows that archaeological prospecting is intricate in this geological environment due to low magnetization of the subsoil. Post-holes, pits and ditches are therefore difficult to detect due to their small mass and low magnetization contrast. A successful interpretation requires a thorough understanding of the magnetic image from the near-surface geology.

For the interpretation of the magnetograms the following approach has been chosen. All magnetic anomalies have been mapped and classified to categories such as small and large pits, linear, polygonial or rectangular structures, recent iron scrap, strong magnetized magmatic rocks, i.e. erratic boulders (Fig.3). The interpretation next to the NEL-steel pipeline in the magnetically highly disturbed area could be improved by the application of a special ‘desloping’-processing. The high resolution height model gained from LiDAR data of airborne laser scanning aerial survey has helped to understand the nature of the features at the flanks of the Heidberg (ground moraine). The areal distribution of the categorized anomalies has been analyzed and compared with the topography and excavation map from the site. The interpretation of the subsurface geology shows relics of crack polygons typical for permafrost soils prevailing on the western plateau area of the Heidberg and the southern foot of the hill. Erratic boulders are mainly present in the eastern plateau. Areas of sand deposits are distributed over the plateau area and in trenches down the flanks. The interpretation of man-made findings shows large and small pits all over the investigation area. In the eastern Heidberg plateau rectangular shaped and north-south oriented structures may indicate an old settlement, probably of medieval age.
The excavation plan shows few remains from the pre-Roman Iron Age but no finds from Bronze Age.

The interpretation of the magnetograms has revealed so far no geophysical indications for the existence of a hamlet of Bronze Age near the location of the Gessel Hoard.

Study of historical maps

Alternatively, it was checked whether the gold Hoard could have been deposited by the wayside. At first glance the possibility seems to be unlikely because the find-spot of the hoard is now located on open farmland. But it is worth studying the historical road system from the Cartographic Survey of Kurhannover (Kurhannoversche Landesaufnahme) from the 18th century (Fig. 4). This map shows the old road network which was later partially destroyed and reshaped due to the comprehensive agrarian reform ("Verkoppelung") accomplished in the 19th Century and the land consolidation and reparcelling in the 1960’s and 1970’s (‘Flurbereinigung’). Projecting the find-spot into the historical map it turns out that the Gessel Hoard lies at the old route from Syke to Leerssum. This could indicate that the Gessel Hoard had been buried by the wayside. Although the age of this old route remains unknown we know that old roads and traffic connections have existed since pre-historical time.

Summary

It will be always a challenge to unravel events and activities which happened in the Bronze Age. So we can only speculate under which circumstances the Gold Hoard from Gessel was buried at the place where it was discovered 3400 years later. The recent investigations initiated and financed by the Lower Saxony State Service for

Cultural Heritage(NLD) comprising magnetometer-prospection, air borne Laser scanning and the study of historical maps suggest that the Gessel Hoard might have been deposited at the wayside. The existence of a Bronze Age hamlet could not been proven neither by geophysics nor by the excavation along the NEL-stretch. Future studiesof the trade routes of the Middle Bronze Agein this part of Northwest Germany should pay special attention to the old way from Syke to Leerssen and ascertain whether it fits into the Bronze Age route network.

References

Haßmann Henning, Tina Heintges, Bernd Rasink, Stefan Winghart, Friedrich-Wilhelm Wulf: Der bronzezeitliche Hortfund von Gessel, Stadt Syke, Landkreis Diepholz. In: Berichte zur Denkmalpflege in Niedersachsen. Hameln 2012,1, S. 28.

Wikipedia: Goldhort von Gessel, http://de.wikipedia.org/wiki/Goldhort_von_Gessel

Figures

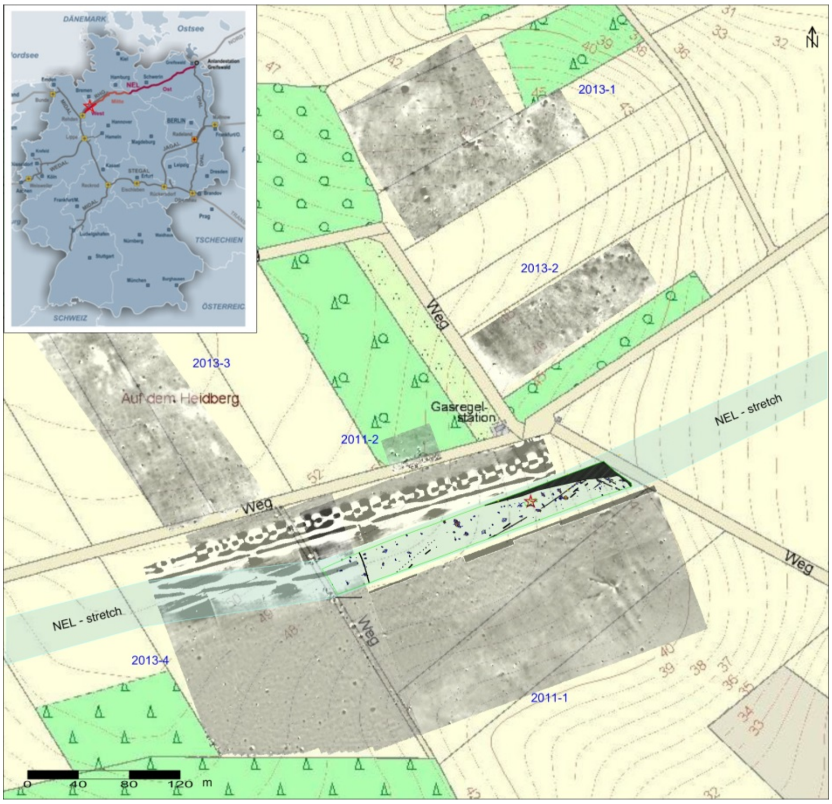

Fig. 1 The area of interest with the NEL-pipeline crossing the Heidberg hill and the find-spot of the Gessel Hoard (red star) embedded in the excavation area (outlined in green).Six magnetometer-surveys are from December 2011 and April 2013. Inlet: the NEL-pipeline infrastructure.

Fig. 2 GESSEL HOARD's 117 artifacts unpacked from earth: a fibula adorned with sun symbols, a bracelet, aspiralring-type torque, and numerous coils of varying sizes, joined to form chains of ten links each. Hoard dated to the 14th century BC, the Middle Bronze Age. (Foto: Volker Minkus,Lower Saxony State Service for Cultural Heritage (NLD), Hannover, Germany).

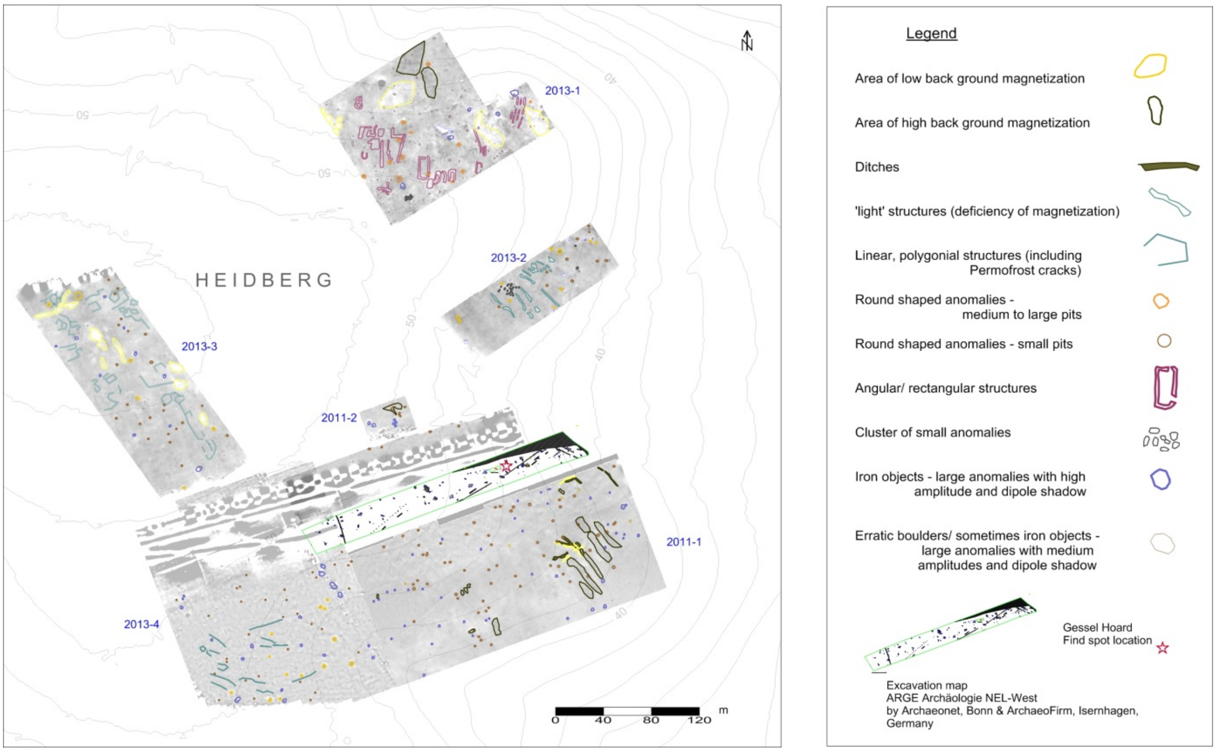

Fig. 3 Interpreted magnetometer-surveys in the vicinity of the Gessel Hoard

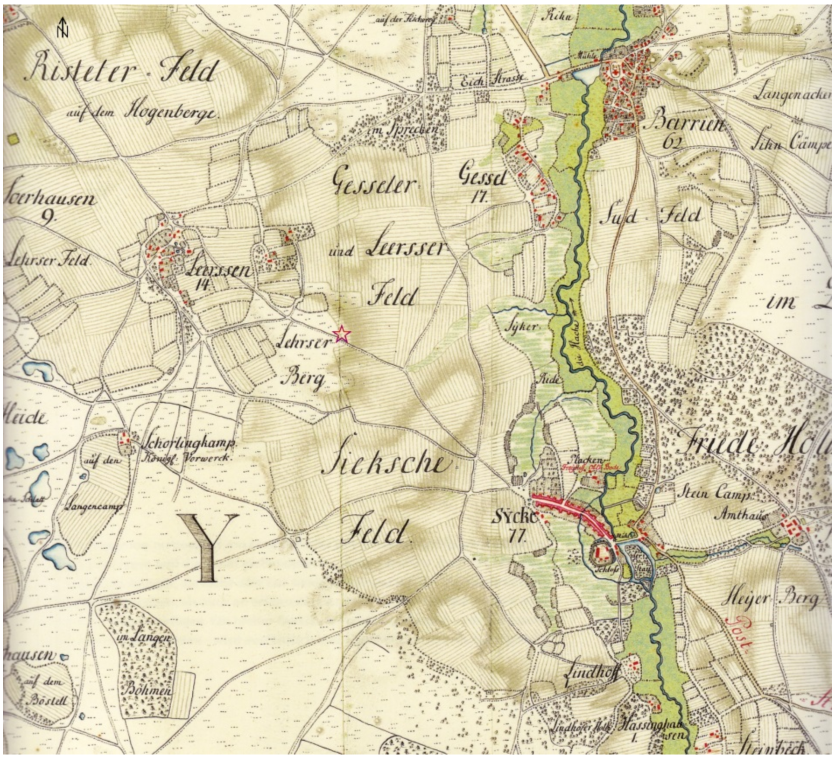

Fig. 4 Location of the Gessel Hoard by the wayside from Gessel to Leerssen (marked by red star)- Cartographic Survey 18th century (Kurhannoversche Landesaufnahme)

THE SAME OLD SEASONAL ISSUE? A TIME-LAPSE INVESTIGATION INTO THE CHANGING RESISTIVITY OF ARCHAEOLOGICAL SOILS *IN-SITU*

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Electrical methods of geophysical survey are known to produce inconsistent results at different times of the year, and under differing weather conditions. This is a problem which can lead to misinterpretation of archaeological features under investigation. The dynamic relationship between a 'natural' soil matrix and an archaeological feature is a complex one, which greatly affects the success of the feature's detection when using active electrical methods of geophysical survey. This study has monitored the gradual variation of resistivity over a selection of study areas. By targeting difficult to find, and often 'missing' electrical anomalies of known archaeological features, this study has increased the understanding of both the detection and interpretation capabilities of such geophysical surveys.

A 16 month time-lapse study over 4 archaeological features has taken place to investigate the aforementioned detection problem across different soils and environments. In addition to the commonly used Twin-Probe earth resistance survey, electrical resistivity imaging (ERI) and quadrature electro-magnetic induction (EMI) were also utilised to explore the problem. Statistical analyses have provided a novel interpretation, which has yielded new insights into how the detection of archaeological features is influenced by the relationship between the target feature and the surrounding 'natural' soils.

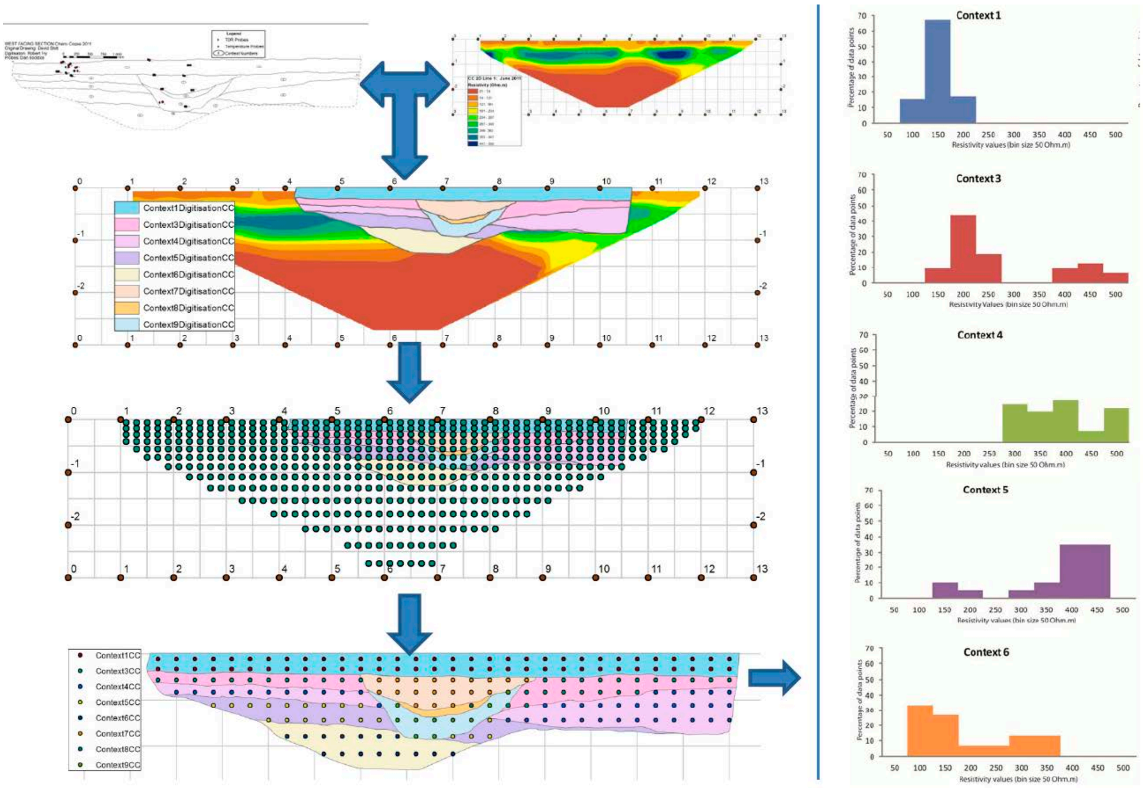

Fig. 1 Extraction of resistivity data from ERI profiles into separate archaeological contexts

Detection test:

$$U = R\,\frac{n(n+1)}{2} \qquad Z = \frac{\bar{U}}{\sigma_U} \qquad r = \frac{Z}{\sqrt{N}} \qquad f(r) = \begin{cases} r & \text{if } r = \geq 0.4 \\ 0 & \text{if } r = < 0.4 \end{cases}$$

Magnitude test:

$$\text{SPMF} = \frac{\bar{x}\rho_{background} - \bar{x}\rho_{archaeology}}{\bar{x}\rho_{backaround} \times 100}$$

$$\text{Contrast Factor} = \text{Detection}\,[f(r)] * \text{Magnitude}\,[(\text{SPMF})]$$

Fig. 2 The creation of a new calculation for a contrast factor (bottom)

The study has highlighted both the complexity and previous misconceptions around the predictability of the electrical methods. The analysis has confirmed that each site provides an individual and nuanced situation, the variation clearly relating to the composition of the soils (particularly pore size) and the local weather history. The wide range of reasons behind survey success at each specific study site has been revealed. The outcomes have shown that a simplistic model of seasonality is not universally applicable to the electrical detection of archaeological features. This has led to the development of a method for quantifying survey success, enabling a deeper understanding of the unique way in which each site is affected by the interaction of local environmental and geological conditions.

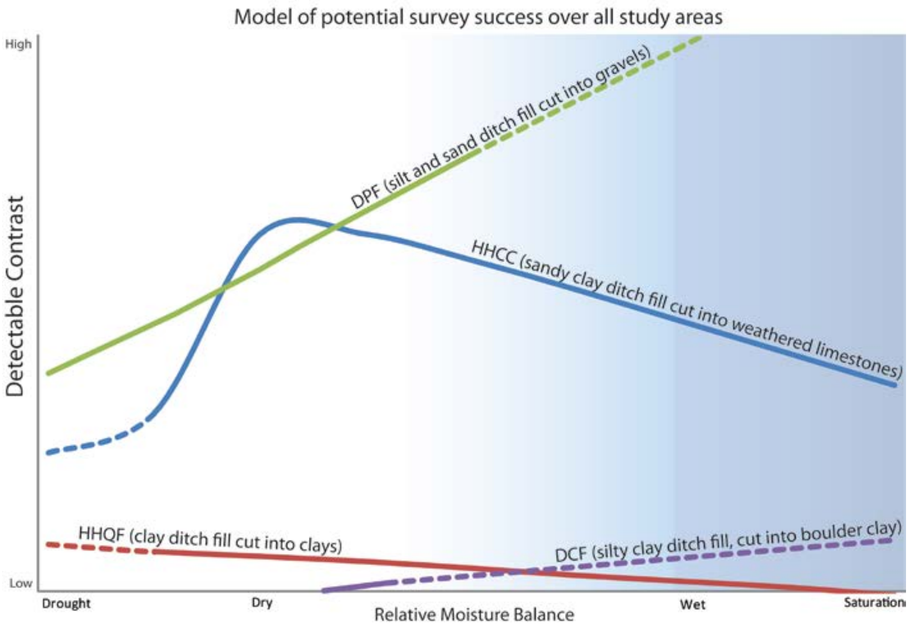

Fig. 3 Detecting ditches with electrical resistivity – A very different success-rate over each site

THE ROMAN COUNTRYSIDE OF NORTHWESTERN NORICUM

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The process of Romanization of the countryside in the Roman province of Noricum appears to have progressed much earlier and slower than in the other northwestern provinces. Recent work has focused on geophysical prospection and is now giving us a much greater understanding of the density and continuity of occupation of the Roman countryside. Earlier excavations, surface collection and aerial photography only gave an incoherent slight impression on this research topic. The geophysical surveys of the project “Roman *villae rusticae* in Bavarian part of ancient Noricum” show many significant results that give us an idea of how the countryside of this area in Roman times appeared to be. The results from the 2013/14 field seasons suggest that our knowledge of this archaeological landscape increased to a level of understanding, with the integration of remote sensing.

Geophysical prospection in Weildorf

One of the newest results is from Weildorf, where Roman buildings are mentioned since the beginning of the 19th century, but no structures were excavated. The magnetometer prospection showed some anomalies which indicated roman buildings in the north-eastern area, but also some farming structures in the western part. The Radar prospection verified buildings in the supposed area.

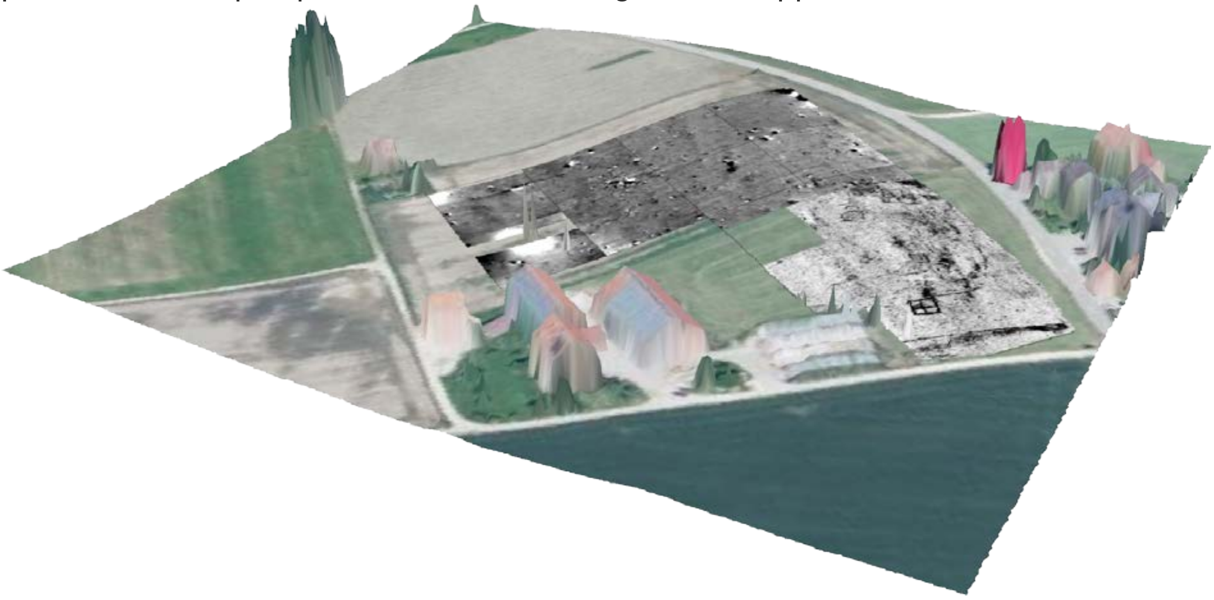

Fig. 1 Weildorf. Cäsium-Magnetometer Smartmag SM4G-Special, Duo-Sensor-configuration. sensitivity +-10pT, 0,50 m x 0,25 m sampling interval, interpolated to 0,125 x 0,125 m, 40-m-grid. Radargram depth slice 40 - 60 cm, GSSI SIR-3000 with 400 MHz-antenna, prospected area 109 x 80 m. sampling interval 2 x 25 cm (BLfD, Archiv-Nr. 8142/073_1).

Unfortunately the biggest building shown in the results is the least well preserved, so we cannot answer whether we have discovered a residential building, or, if there really is no interior division, it may be a kind of kiln. As we are quite near the Roman town Iuvavum there was a suggestion that farms here maybe don’t need a big residence building for the landowner, but there must have been some kind of accommodation. The most substantial argument against this proposal is the existence of such a large thermal bath. Relating to the bath, another rare discovery was made. We could verify the water supply by the canals, coming from a branch stream in the north, leading to the bath building and a building in the south with unknown function.

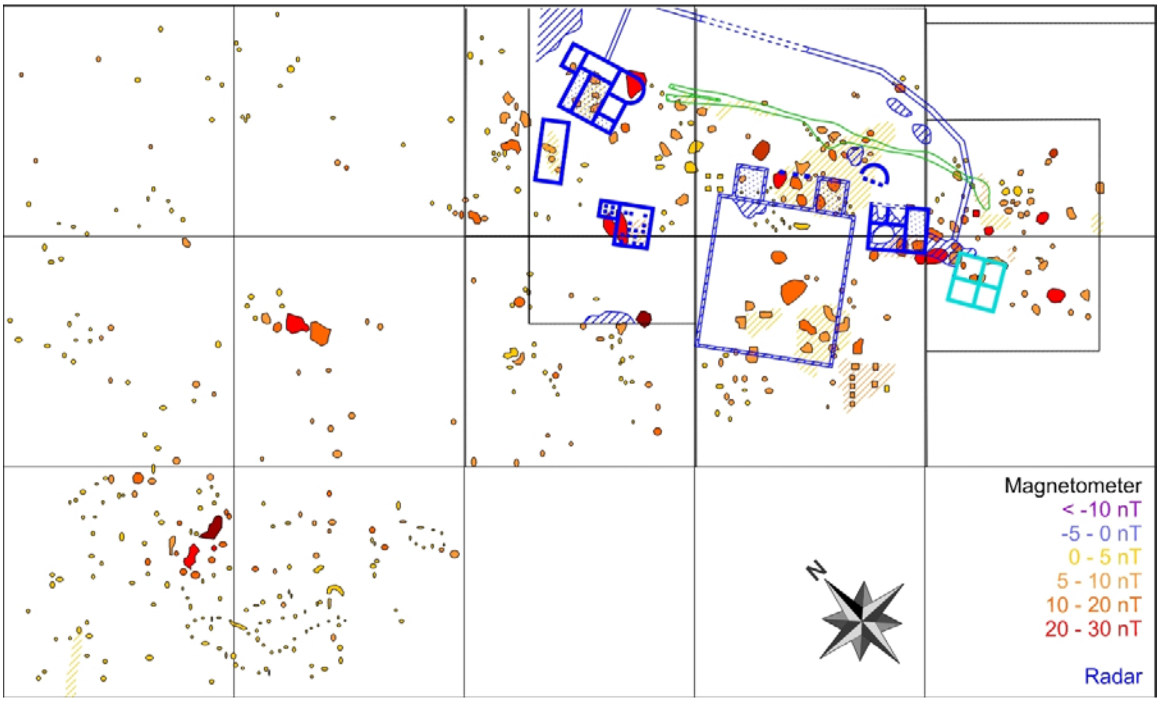

Fig. 2 Digital plan of the Interpretation from the magnetometer and GRP prospection in Weildorf. (L. Kühne, R. Linck, BLfD, AutoCAD-Plan Nr. 8142/073_1).

LIDAR Analysis

Aside from the documentation of the villas themselves with geophysical prospection, an approach to landscape archaeology is made by analysing two large areas with LIDAR data. In the first area we know the locations of some Roman villas, so we could analyse the site selection and try to identify the appending territory and traces of field systems. Knowledge of suitable conditions for the presence of archaeological sites gained from the prospection and analysis of the first area, will hopefully enable the detection of new archaeological sites in the second area, if conditions for their existence are favourable, even though presently no roman villas are known.

Through the geophysical results, LIDAR-Data-Analysis and other research we could get a much more differentiated view of the composition and organisation in the Roman countryside. Embedded in the information we have about the roads, street stations, cemeteries, sanctuaries and environmental information we can try to create an approximate reconstruction of the area in Roman times.

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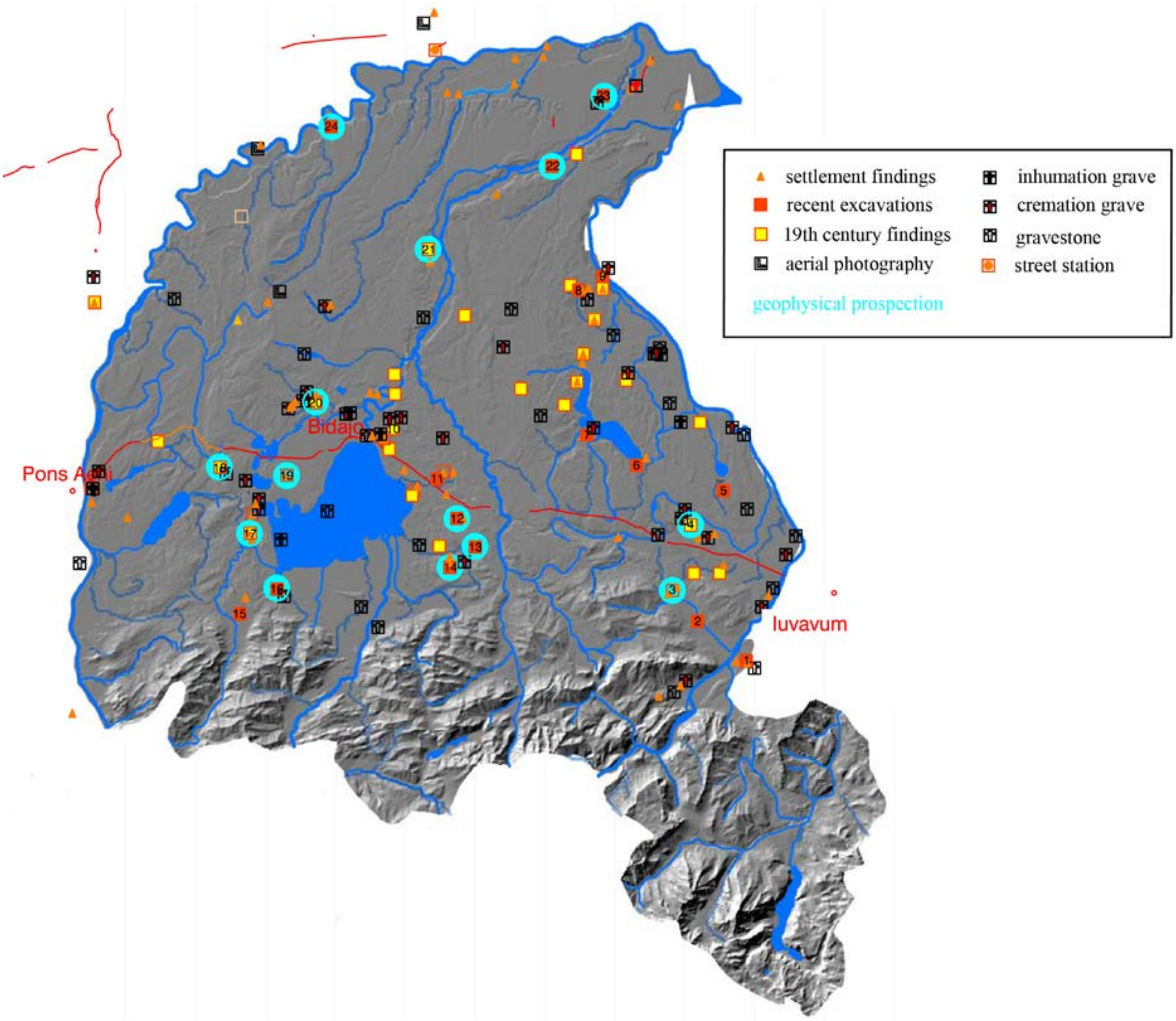

References

Kühne, L. 2014. Römische Villen im bayerischen Noricum. Verwendung naturwissenschaftlicher Prospektionsmethoden zur Erschließung forschungsgeschichtlich problematischer Befunde, in: COLLOQUIUM IUVAVUM 2012, Archäologie in Salzburg Bd. 8, Jahresschrift des Salzburg Museum Bd. 56, Das municipium Claudium Iuvavum und sein Umland, Bestandsaufnahme und Forschungsstrategien, 203-213.

Traxler, S.; Kastler, R. 2010. Römische Guts- und Bauernhöfe in Nordwest-Noricum. Gehöftsstrukturen, Wohn- und Badegebäude, in: K. Schmotz et al. (Hrsg.), Fines Transire, Jahrgang 19, Archäologische Arbeitsgemeinschaft Ostbayern/West- und Südböhmen/Oberösterreich, Rahden, S.233-252.

Czysz, W.; Dietz, K.; Fischer, T. Kellner, H.-J. 1995 Die Römer in Bayern, Theiss Verlag, Stuttgart

Fischer, T. 1994. Römische Landwirtschaft in Bayern, in: H. Bender, H. Wolff (Hrsg.), Ländliche Besiedlung und Landwirtschaft in den Rhein – Donau – Provinzen des Römischen Reiches, Bd. 2 Espelkamp, S. 267-300.

SEARCHING FOR SCANDINAVIANS: A MULTIDISCIPLINARY INVESTIGATION AT TORKSEY, LINCOLNSHIRE

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The *Anglo-Saxon Chronicle* records that in 872-3 the Viking Great Army - which had been prowling Britain for 7 years - took winter quarters at Torksey, now a small village on the River Trent in Lincolnshire, UK. The exact location, however, has only recently been determined, as a result of increasingly intensive metal detecting in the area. The Torksey Project, collaboration between the Universities of Sheffield and York with the British Museum, is now examining the nature and circumstances of the Viking occupation as well as its impact on the development of the existing Anglo-Saxon settlement. Research incorporates geophysical survey, geomorphological investigation, analysis of metal detected finds, existing archaeological and historical evidence, field walking and targeted excavation to illuminate the evolution of this landscape and the Scandinavian influence on it. This poster presents some of the geophysical research that has been carried out on the site.

The project has been working with a number of local metal detectorists to catalogue their finds and record their locations using handheld GPS. Over 1500 metal finds have been recorded from the site, over three-quarters of which are of early medieval date (and many more have been removed without being recorded). These include unusual concentrations of characteristically Viking items, such as hack gold and silver, Arabic *dirhams*, Northumbrian *stycas*, bullion weights and gaming pieces; the deposition of many of these can be closely dated to the early 870s.

Magnetometer survey of the camp site
Based on the distribution of the metal detected finds, a total of 29ha of magnetometer survey has been conducted over the site (to the north of the modern village), using a Bartington Instruments Grad-601 fluxgate gradiometer, in order to locate and characterize any detectable archaeology (see fig. 1). Despite difficult field conditions - including heavy ploughing and very sandy soil - survey was very successful in some respects. For example, a series of rectilinear enclosures with associated positive magnetic responses have been detected; these have been interpreted as deriving from a previously unknown Romano-British farmstead. This interpretation is strengthened when the locations of metal-detected and field-walked finds of Roman date are considered alongside the magnetometer results.

Fig. 1 Magnetometer survey results to the north of modern Torksey (superimposed on lidar data). The slightly raised ground forms a very obvious 'island' in the low-lying landscape, with a steep cliff down to the river on the left of the image.

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Magnetometer survey of the kiln field

Magnetometer survey to the south of the modern village (fig. 2), where previous excavation has located early medieval pottery kilns and associated features, has deepened our knowledge of the pottery industry through the detection of strong anomalies interpreted, in association with field walking finds of sherds and wasters, as further kilns. Amongst other anomalies, a distinct enclosure boundary is visible; human bone found within this area during field walking has been carbon-14 dated and suggests the boundary is that of a medieval cemetery. This has interesting implications for the growth of the medieval village following Viking occupation as a number of burial sites and ecclesiastical institutions are known within a small area.

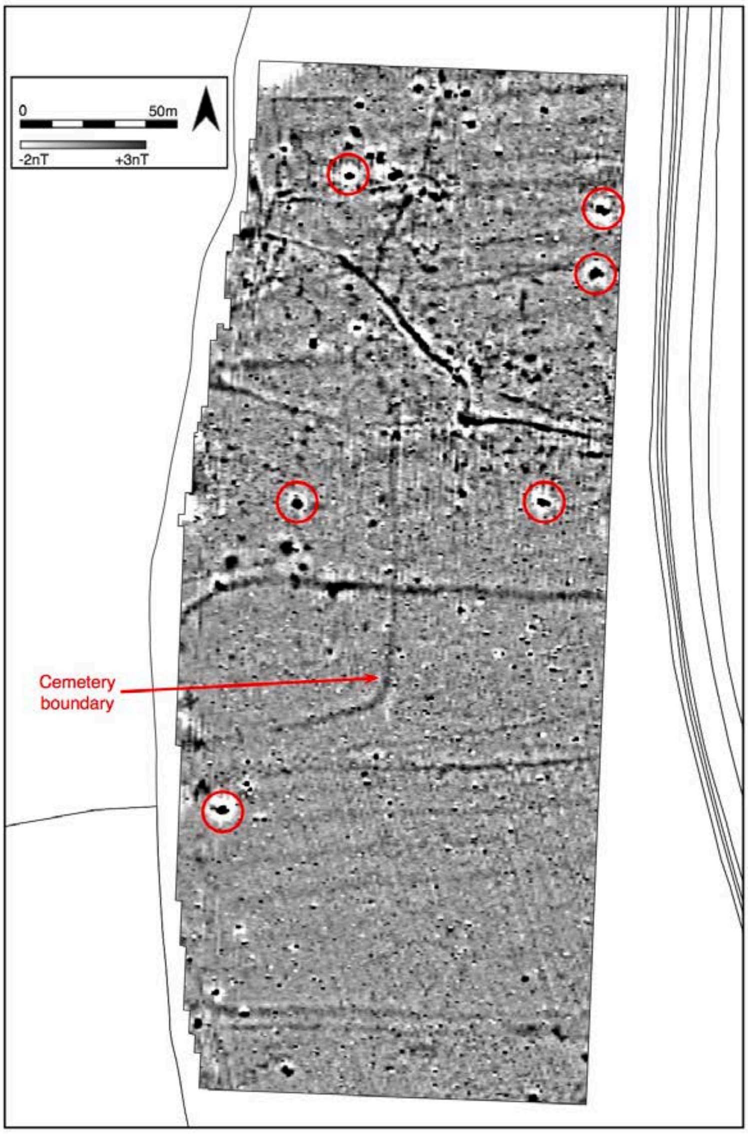

Fig. 2 Magnetometer survey results to the south of modern Torksey, over the known location of the early medieval pottery industry site. The probable cemetery boundary is marked.

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Electro-magnetic survey

In other respects magnetometer survey has proved frustrating, not least because of a lack of comparable geophysical surveys from similar sites, in addition to the difficulties of searching for such ephemeral occupation evidence. The winter camp site itself is located on a natural island of slightly higher ground, overlooking the flood plain. At the highest point, the near-vertical cliff drops away several metres to the river; this area offers the most topographically suggestive location for the camp itself, particularly given that many of the characteristically Viking metal finds have been found here. The magnetometer data, however, provided little coherent evidence of archaeology. This was concluded to be due to an excessive depth of windblown sand, a deposit found across the site in greater or lesser quantities (and confirmed by auger survey as being up to 1.5m deep in places). Subsequent field tests using a GF Instruments CMD Mini-Explorer, however, suggest the presence of archaeology below this deposit (fig. 3). The geophysical results have therefore begun to shed light on the local landscape and, alongside other research strands, will inform further geophysical and archaeological fieldwork in the future.

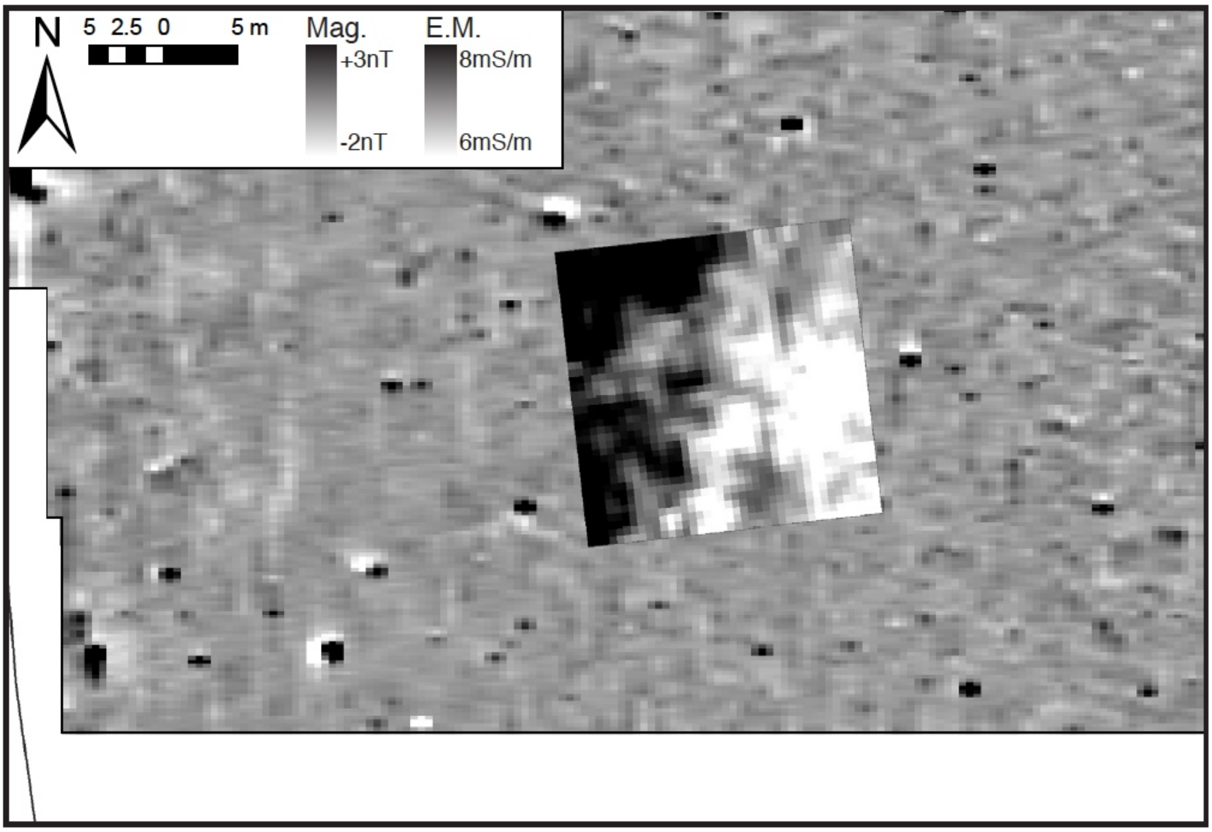

Fig. 3 Superimposition of CMD data (middle depth conductivity data) on the magnetometer data in the area of the Viking winter camp.

LOCATING AND DELIMITING IRON AGE AND EARLY MEDIEVAL SETTLEMENT SITES IN NORWAY BY MAPPING TOPSOIL MAGNETIC SUSCEPTIBILITY

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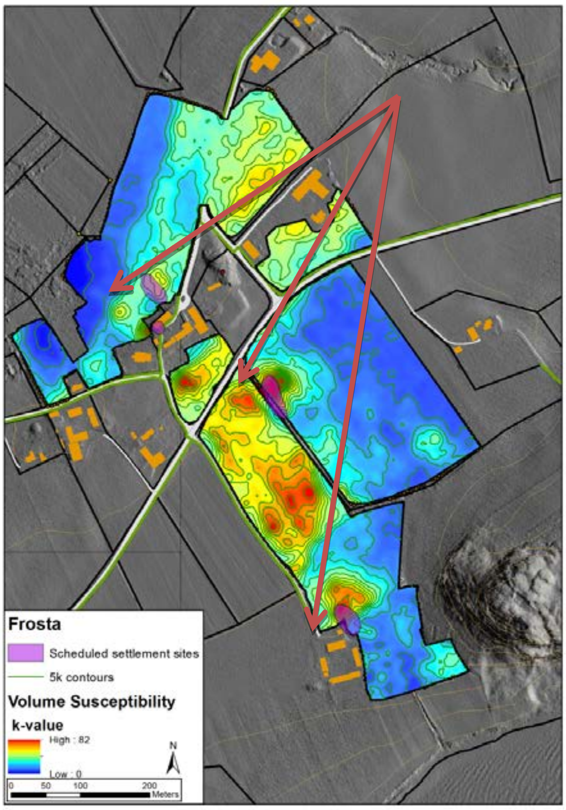
Topsoil Magnetic Susceptibility has been mapped on several Iron Age settlement and activity sites as part of a PhD-project concerning the application of magnetic geophysical prospection methods on archaeological settlements in Norway. On several sites, this sort of geophysical mapping has proven to be a highly successful way to locate, delimit and/or characterise the archaeological activity, while on other sites the results were more unclear. It is therefore possible to extract some experiences on the potential and constraints that lies within such an application of topsoil magnetic susceptibility.

For this project, a Bartington MS2-D field loop was utilized for measuring the volume susceptibility. Each measurement was logged with an RTK or CPOS GPS. Other analyses such as mass susceptibility, fractional conversion or other more detailed analyses of magnetic properties of the soil were not conducted at this stage. Gradiometer surveys and consecutive archaeological excavations were performed on some sites.

Examples:

Logtun and Logstein – Frosta municipality:



At this site, we have rich evidence of occupation through finds of burnt stone, associated with brewing of beer and/or cooking, as well as scattered archaeological objects at several locations (see arrows). In the yard of the Logtun farm, just east of the church in the centre of the map, medieval cultural layers have previously been found. The topsoil magnetic susceptibility mapping has increased our knowledge of the location, size and layout of the human occupation on the landscape.

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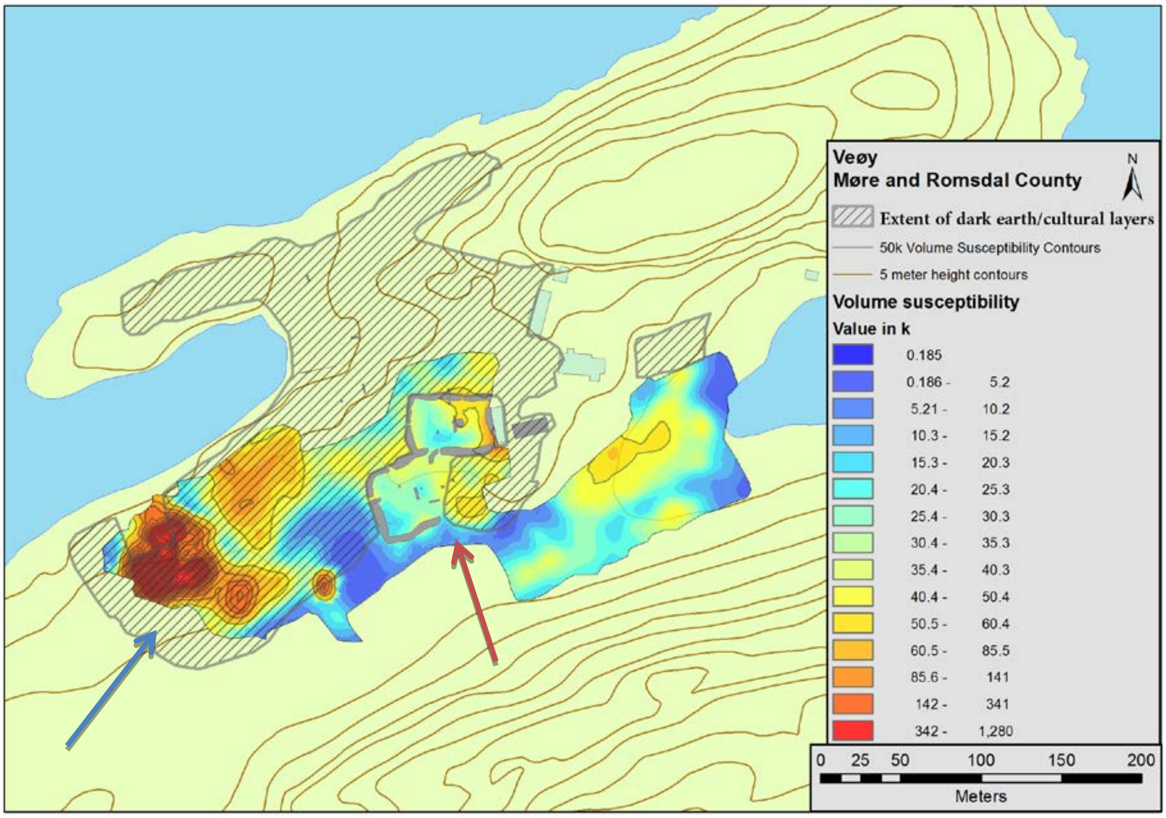
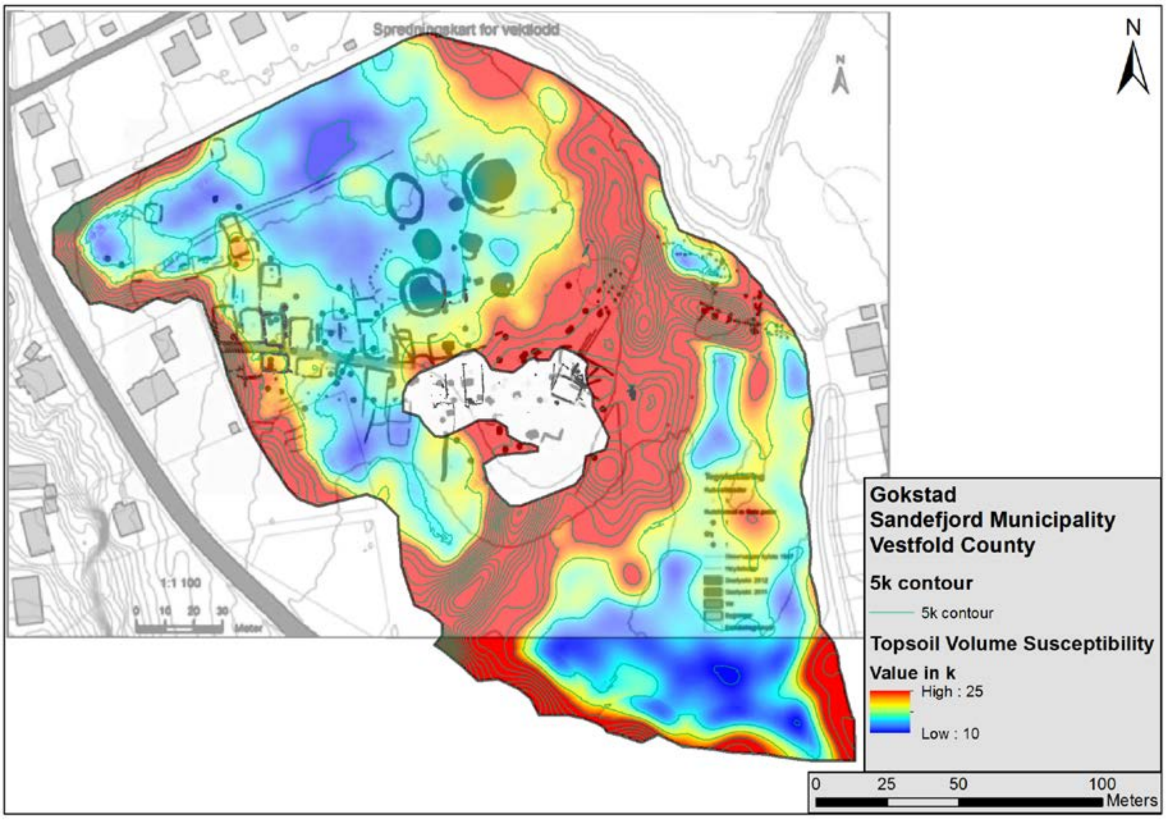


Veøy, Molde Municipality, MøreogRomsdal County

At Veøy, we have some of the earliest known Christian burial grounds in Norway from the 10th century, as well as evidence for some of the earliest Stave Churches found in Norway known through excavations and geophysical evidence. The Island was a marketplace which resembled an early town in structure and layout, and was settled from around the 10th century until the black death arrived in the mid-14th century . By augering, archaeologists have mapped an area of about 4 hectares of black earth/cultural layers. Parts of the stone built churchyard wall still exist, but the eastern part of the southern enclosure is missing. Also, a smithy was excavated in the 1950s in the southwestern part of the site. The extent of the churchyard and area of metal working was therefore unknown. The topsoil susceptibility mapping revealed the extent eastwards of the churchyard (red arrow), and the size of the area of metalworking (blue Arrow). The metalworking at Veøy covered an area of approximately 0.6 hectares, equal to about 15% of the size of the marketplace.



Heimdal, Sandefjord Municipality, Vestfold County

At the farm called Heimdal, close to the famous Gokstad burial mound, which once contained the famous Viking ship with the same name, the Ludwig Boltzmann Institute in collaboration with the Museum of Cultural History in Oslo and the Vestfold Municipality carried out a geophysical survey. This led to the identification of a Viking-age trading site and market place, with a clear layout of parcels neatly ordered along a road, close to the previous water edge. A systematic metal detecting survey revealed rich finds of silver dirhem coins, precious metals, weights, and slags. The site have been dated to mid-9th century, and seem to have gone out of use sometimes in the end of the 10th century. At Heimdal, the topsoil magnetic susceptibility did not clearly delimit the house parcels and the activity known to have been on the site. The edges along the present day roads and settlements seem to have increased k-values, as well as an area east of the settlements – possibly connected the digging of a pipe through the edge of the site. The variability of the measurements are low, indicating a low MS-contrast between anthropogenically influenced soil and the background geology.

CARTEASY^N – MOVING FROM 2D TILES TO THREE-DIMENSIONAL DATA COLLECTION AND ANALYSIS IN MAGNETOMETRY

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The majority (78%) (GSB, 2014) of archaeological surveys conducted in the UK consist solely of 'detailed' magnetometry, as defined by the English Heritage and IFA guidelines (David et al., 2008). These are usually conducted using Bartington Grad-601 fluxgate gradiometers. The key differences between the current Bartington Grad-601 and earlier systems, such as the Plessey gradiometer (Philpot, 1972), are increased ease of data logging and the ability to carry multiple sensors simultaneously. These improvements facilitate a more rapid survey speed, but the fundamental instrumentation of magnetometers has remained unchanged; efforts to develop novel sensors and data collection systems (Gaffney et al., 2008; Leech and Hill, 2008) can suffer from mobility or precision issues. Compared to the innovation for the development of complementary techniques, such as resistivity (Dabas, 2009) and GPR (Trinks et al., 2010), magnetometry methods have remained comparatively static.

Bartington Grad-601 measurements are typically collected over20m or 30m grids with readings collected approximating 0.25m x 1m, located by time (Bartington and Chapman, 2004). Data collected in this way suffers from systematic location errors associated with the conversion from time to position and user walking error.

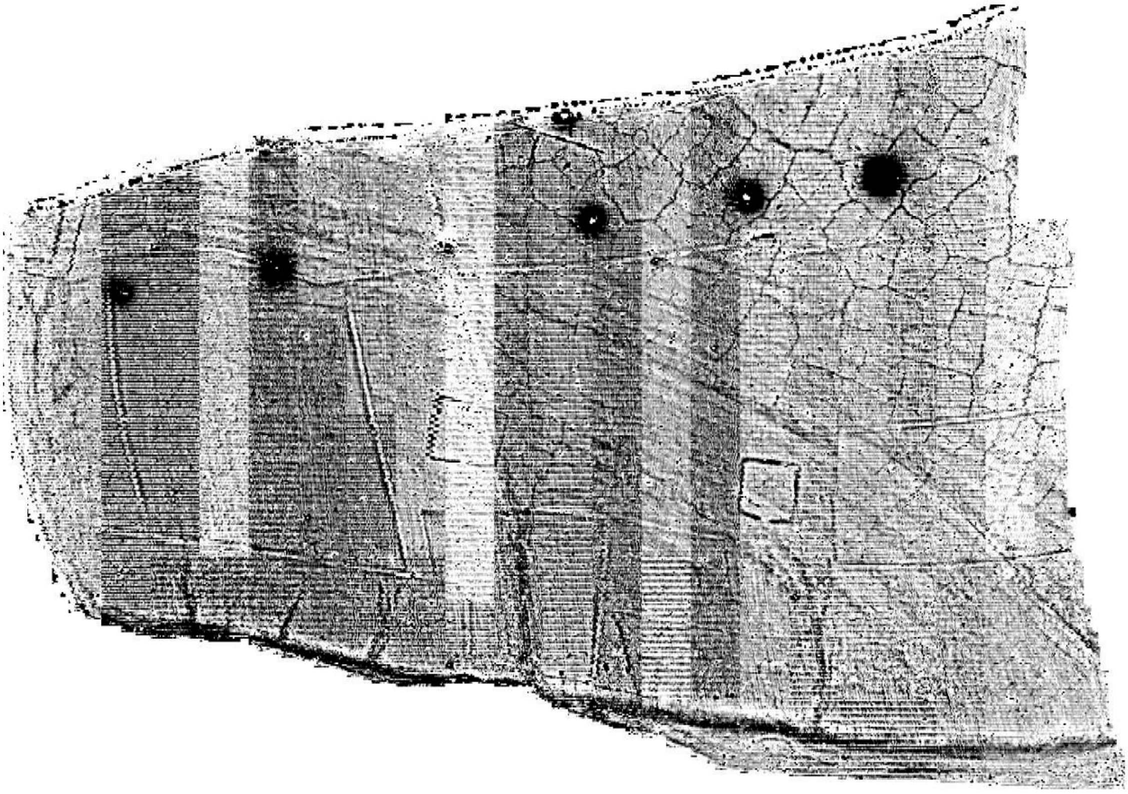
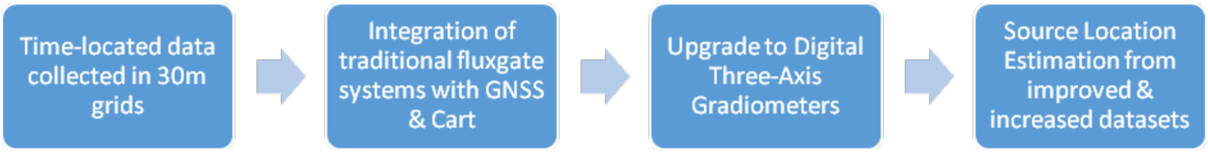


Fig. 1 Raw Bartington Grad-601 datasets indicating typical systematic errors.

Grids are subsequently combined into composite Data plots (Figure 1) and processed to produce an interpretable image. Standard processing steps include correcting spurious readings, manually adjusting poorly or incorrectly referenced measurements into the correct position, and statistical analysis to balance the backgrounds of each traverse (Walker, 2004).

While these processing steps can be useful for producing a more interpretable image, they are time consuming and can sometimes produce undesirable side effects, such as obscuring or removing archaeological anomalies. As a result, the produced image may not be an accurate representation of subsurface magnetic properties, reducing the confidence and reliability in the interpretation of results.

Due to magnetometry's importance for archaeological geophysics, as a rapid and therefore cost-effective strategy, magnetic survey warrants further improvements. As a result, GSB have designed a custom system to facilitate a more effective and accurate magnetic survey method. To bring about the changes as quickly as possible, GSB outline the multi-stepped development approach:



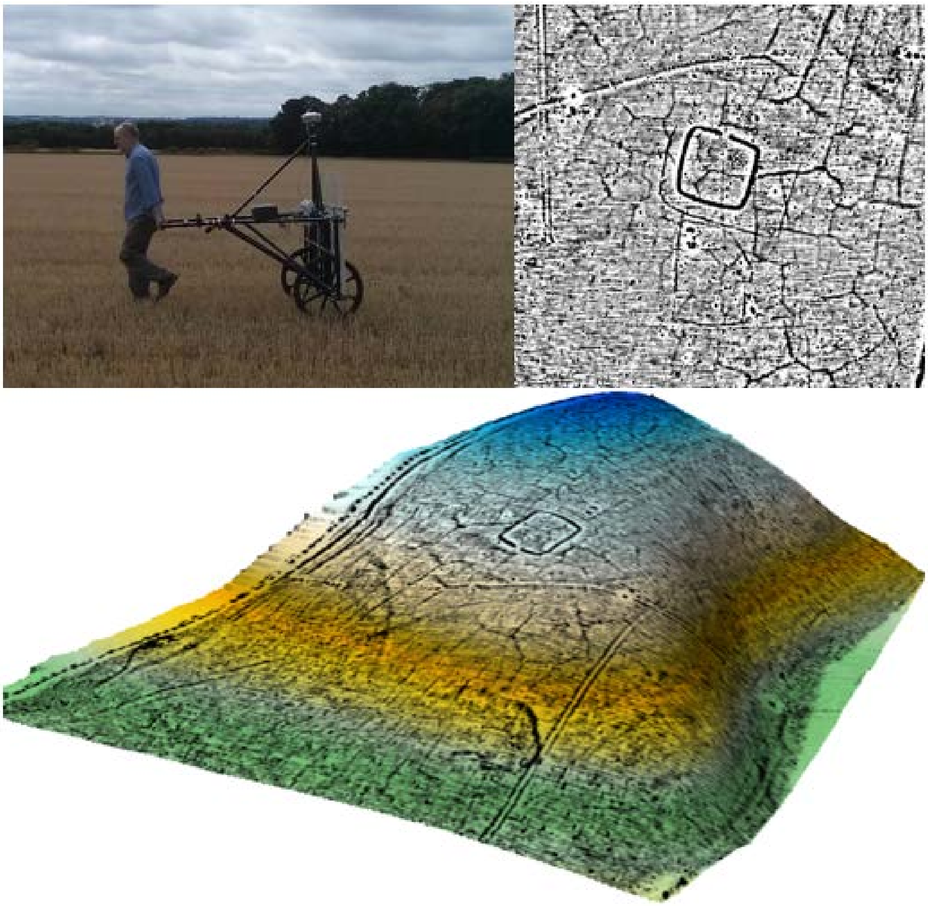


Fig. 2 Clockwise: CartEasyN collection system, Minimally processed greyscale of CartEasyN data, CartEasyN data overlaying topographic model

During phase one of the development programme, GSB initially tested Bartington 1000L sensors on a custom frame (figure-2). The 1000L cart utilises sensors at 0.75m collecting data at ~10Hz (Pope-Carter and Attwood, 2014). Readings are positioned using an RTK GNSS system, utilising a pseudo-Kalman filter to compensate for variations in cart speed and rotation. Furthermore, the RTK GNSS system can be used to create a three-dimensional surface plot, which allows the geophysical data to be viewed in context with the topographical information.

This system is a major improvement over traditional gridded data collection. While coverage rates are only marginally faster, the reduction in data processing time and increased resolution of the data, are key advantages.

The development path's second phase requires the upgrade of the 1000L sensors to Bartington Grad-13 Sensors. While currently in development, delivery of these sensors is expected soon. The Grad-13 digital three axis gradiometer comprises dual three-axis fluxgate sensors with a 1m sensor separation. The sensor housing also contains three-axis accelerometers and temperature sensors to improve positional information and calibrate for temperature variations.

Initially three-axis data will be collected and analyzed as gradiometer and individual sensor data. This will allow a greater comparison between near surface data, predominantly affecting the lower sensor, and geological variations affecting both sensors. By phasing the improvements, upgrading the data collections systems can be achieved rapidly allowing for further infield testing and analysis whilst implementing the final, third, stage of development.

The third phase will involve moving from analyzing images to utilising the three-axis components of the Grad-13 sensors for a better understanding of subsurface features. Initial work will focus on calibrating the three-axis components of the gradiometers, which will allow for the calculation of total field data and remove the need to run linear filters to mitigate for discrepancies in vertical sensor alignment (Munschy et al., 2007).

Ongoing work will concentrate on source analysis, building upon work done to detect and characterise dipole anomalies arising from UXO sources. (Foss and McKenzie, 2009; Kumar et al., 2004; Luo and Foss, 2013).

The third phase of this development process and ongoing source analysis work comprises the majority of this authors PhD research at the University of Bradford.

Bibliography

Bartington, G., Chapman, C.E., 2004. A high-stability fluxgate magnetic gradiometer for shallow geophysical survey applications. Archaeol. Prospect. 11, 19–34. doi:10.1002/arp.219

Dabas, M., 2009. Theory and practice of the new fast electrical imaging system ARP., in: Campana, S., Piro, S. (Eds.), Seeing the Unseen: Geophysisc and Landscape Archaeology. Taylor & Francis Group, London, pp. 105–128.

David, A., N. Linford & P. Linford (2008) *Geophysical Survey in Archaeological Field Evaluation* (2nd edn). Swindon: English Heritage.

Foss, C., McKenzie, K.B., 2009 Strategies to invert a suite of magnetic field anomalies due to remanent magnetization: an example from the Georgetown area of Queensland. ASEG Ext. Abstr. 2009, 1–18.

Gaffney, C., Gaffney, V., Cuttler, R., Yorston, R., 2008. Initial results using GPS navigation with the Foerster magnetometer system at the World Heritage site of Cyrene, Libya. Archaeol. Prospect. 15, 151–156. doi:10.1002/arp.330

GSB, 2009. Internal database of tenders and surveys conducted.

Kumar, S., Perry, A.R., Moeller, C.R., Skvoretz, D.C., Ebbert, M.J., Ostrom, R.K., Bennett, S.L., Czipott, P.A., 2004. Real-time tracking magnetic gradiometer for underwater mine detection, in: OCEANS'04. MTTS/IEEE TECHNO-OCEAN'04. IEEE, pp. 874–878.

Leech, C., Hill, I., 2008. Development of a multi-sensor exploration equipment platform for shallow geophysical applications. First Break 26.

Luo, X., Foss, C., 2013. Inverse of magnetic dipole field using a reversible jump Markov chain Monte Carlo. ArXiv Prepr. ArXiv13100915.

Munschy, M., Boulanger, D., Ulrich, P., Bouiflane, M., 2007. Magnetic mapping for the detection and characterization of UXO: Use of multi-sensor fluxgate 3-axis magnetometers and methods of interpretation. J. Appl. Geophys. 61, 168–183. doi:10.1016/j.jappgeo.2006.06.004

Philpot, F.., 1972. An improved fluxgate gradiometer for archaeological surveys. Prospezioni Archaeol. 7-8, 99–106.

Pope-Carter, F., Attwood, G., 2014. Are we doing enough? How increased sampling density and alternative techniques can increase our understanding of buried archaeology. Presented at the Commercial Archaeological Geophysics Seminar 2014, University of Bradford, p. 16.

Trinks, I., Johansson, B., Gustafsson, J., Emilsson, J., Friborg, J., Gustafsson, C., Nissen, J., Hinterleitner, A., 2010. Efficient, large-scale archaeological prospection using a true three-dimensional ground-penetrating Radar Array system. Archaeol. Prospect. 17, 175–186. doi:10.1002/arp.381

Walker, R., 2004. 6 - Data Processing, in: Geoplot Instruction Manual.

GPR APPROACHES IN REVEALING THE URBAN PLANNING OF ANCIENT MANTINEA

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Introduction

A geophysical survey was conducted to explore the structure and urban development of the classical Greek city of Mantinea in the Peloponnese through an intensive geophysical fieldwork campaign carried out by the Laboratory of

Geophysical, Satellite Remote Sensing and Archaeoenvironment of the Institute for Mediterranean Studies (FORTH). For this task the GPR Noggin smart cart system of Sensors & Software (Fig. 1a) was employed equipped with a 250MHz antenna. Ground Penetrating Radar (GPR) is a non-destructive electromagnetic (EM) geophysical method that uses radio waves to map the subsurface. GPR has been successfully used in archaeological prospection for mapping buried relics and foundations (Papadopoulos et al., 2009; Spanoudakis et al., 2011). In this study the results obtained from GPR for mapping the urban center of ancient Mantinea are presented and discussed.

Fig. 1 Noggin Smart Cart equipped with 250MHz antenna.

Historical Background

Mantinea was established within a level flood basin of northeastern Arcadia in the Peloponnese before the middle of the 5th century BCE. Due to the lack of archaeological and literary evidence up to the present, the foundation date remains unknown. At 385 BCE the city was destroyed by a Spartan invasion and its citizens were forced to depopulate. For 15 years Mantinea was abandoned until it was reestablished in 370 BCE after Sparta’s defeat in the Battle of Leuctra. The city played a prominent role in the activities of the newly established Arcadian League during the 4th century BCE, and, along with Megalopolis and Tegea, continued to be an influential regional presence in Arcadia and the Peloponnese for several centuries.

The known archaeological features at Mantinea include the well-preserved elliptical fortification walls, approximately 4 km in circumference, and the agora and theatre at the centre (Hodkinson and Hodkinson, 1981; Winter, 1987, 1989) but very little of the remaining urban area inside the fortification walls (~120 hectares) has been explored. A geophysical survey through the use of soil resistivity and magnetic methods was conducted by the University of Patras (Greece) from 1988-91 northwest of the theatre (Sarris, 1992). The target area was limited to 1 hectare, but the survey revealed evidence for subsurface streets arranged at right angles together with various buildings, possibly domestic in nature.

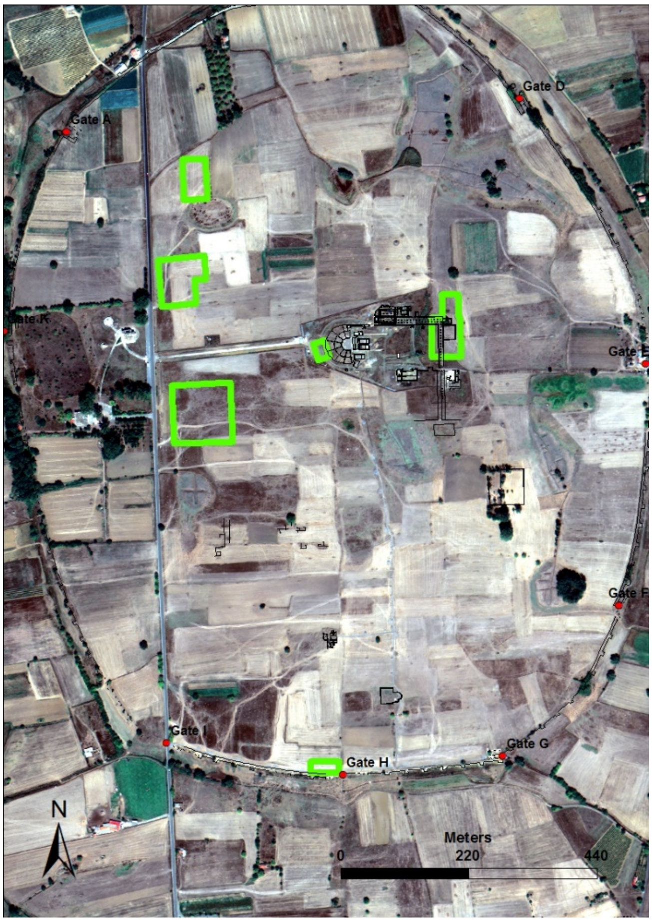

Fig. 2 The area covered with GPR.

Survey Results

The purpose of the fieldwork was to identify near-surface features of archaeological interest relevant to the organization of urban space and its use and development over time. An area of 2.45ha was covered with GPR using 0.5m spacing between each transect. The data were processed in order to enhance the anomalies related to buried antiquities and slices were extracted. The filters and correction applied in order were: trace reposition, time zero correction, dewow filter, SEC gain, background removal, bandpass filtering and migration.

The most interesting results derived from the area located at the eastern side of agora (Fig. 3) and the area located at the southwest of the agora (Fig. 4). Figure 3 illustrates the slice at 0.6-0.7m depth, where public buildings including a long stoa with columns appear as strong anomalies with high detail. Similarly in Figure 4, the depth slice at 0.6-0.7m reveals residential buildings and streets. Those structures appear as strong linear anomalies.

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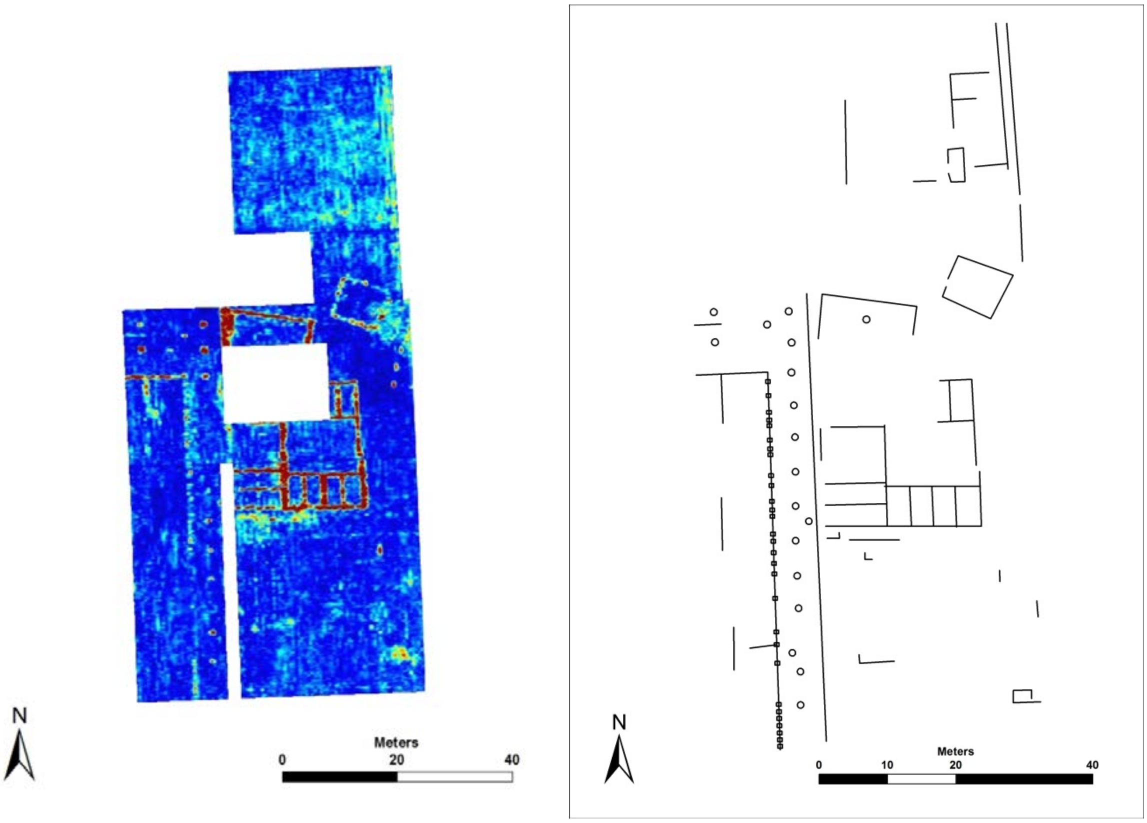

Fig. 3 GPR results and interpretation from the eastern side of the agora at Mantinea.

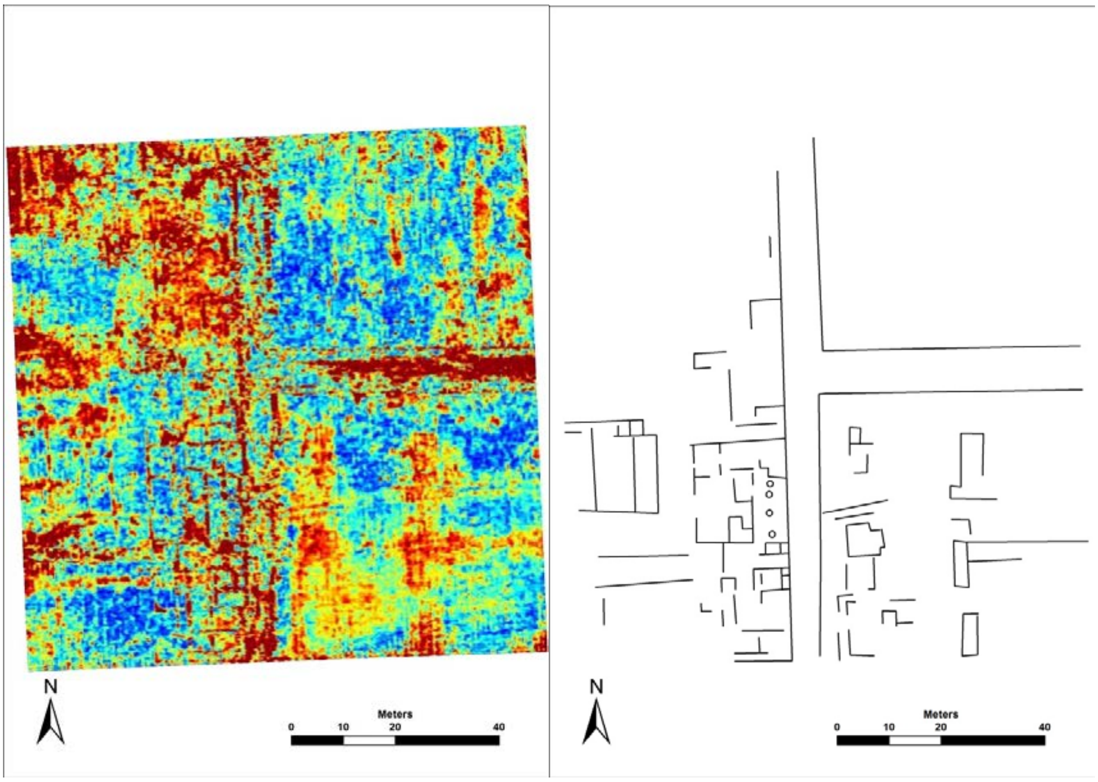

Fig. 4 GPR results and interpretation from the region southwest of the agora at Mantinea

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Conclusions

The GPR survey at Mantinea was successful in revealing the organization and the urban planning near the region of the agora. Many of the identified anomalies define organized streets and city blocks, mostly because of their frequency, ordered arrangement and metrology. Additionally, the results derived from the eastern side of agora show that the structures are oriented at a diagonal angle which is a new distinct characteristic that was not present on the existing plans of the agora made by the French School at Athens that excavated the site from 1887-89 (Fougères 1898). Compared to the rest of the methods applied (multifrequency EM and multisensory magnetics), GPR data provided much more detail of the structural remains.

Overall, the geophysical prospection has shown that Mantinea was a planned settlement with regular streets and city-blocks but further research needs to be done by covering more areas. Ongoing investigations by the 39th Ephorate of Prehistoric and Classical Antiquities in the agora may prove decisive, since the position of the public square and the alignment of its buildings appear to coordinate with the urban street system. If not contemporary with the orthogonal street system, these buildings reveal an inclination toward the rational organization of public space and place Mantinea squarely within established traditions of Greek city planning in the ancient Mediterranean.

References

Fougères, G. 1898. *Mantinée et l'Arcadie orientale*. Paris: A. Fontemoing.

Hodkinson, S., and Hodkinson, H. (1981). Mantineia and the Mantinike: Settlement and Society in a Greek Polis. Annu. Br. Sch. Athens *76*, 239–296.

Papadopoulos, N., Sarris, A., Yi, M., and Kim, J. (2009). Urban archaeological investigations using surface 3D Ground Penetrating Radar and Electrical Resistivity Tomography methods. Explor. Geophys. *40*, 56–68.

Sarris, A. (1992). Shallow Depth Geophysical Investigation Through the Application of Magnetic and Electric Resistance Techniques: An Evaluation Study of the Responses of Magnetic and Electric Resistance Techniques to Archaeogeophysical Prospection Surveys in Greece and Cyprus. Thesis PHD-- Univ. Neb. - Linc. 1992Source Diss. Abstr. Int. Vol. 53-08 Sect. B Page 4002.
Spanoudakis, N.S., Manataki, M., Niniou-Kindeli, V., and Vafidis, A.P. (2011). GPR Imaging at Aptera Archaeological Site.

Winter, F.E. (1987). Arkadian Notes I: Identification of the Agora Buildings at Orchomenos and Mantinea. EchCl *31*, 235–246.

Winter, F.E. (1989). Arkadian Notes II: the Walls of Mantinea, Orchomenos and Kleitor. EchCl Ns *8*, 192–196.

GEOPHYSICAL SURVEY AT PUNA PAU, RAPA NUI (EASTER ISLAND)

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Introduction

This research focuses on the application of geophysical survey at Puna Pau, Rapa Nui (Easter Island) (Figure 1). The work presented here forms part of a larger Arts and Humanities Research Council funded project, *Rapa Nui: Landscapes of Construction.*

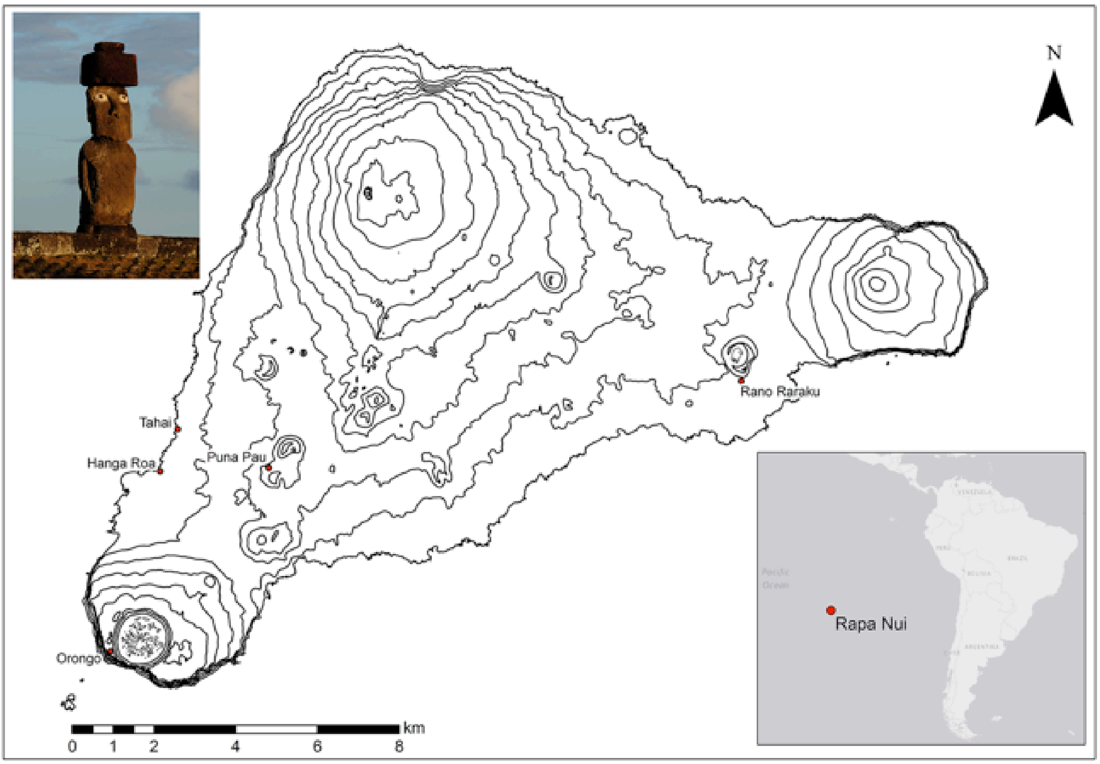

Fig. 1 Location map of Rapa Nui (Easter Island). Inset of moai (statue) with pukao (topknot) at the reconstructed Ahu Tahai (Photo: Adam Stanford, Aerial-Cam).

Located within a small volcanic crater Puna Pau was the site of a red scoria quarry, the main source of the pukao that are associated with a number of the moai found over the rest of the island (Figure 2). Several pukao remain at the site, located both on the inside and outside of the crater (Figure 2). Movement of both moai and pukao across the Island is thought to be via a series of ara (roads) (Lipo and Hunt 2005).

Fig. 2 Puna Pau. A: Looking south-west, downhill from the top of the crater edge. B: Looking north towards Puna Pau with the top of the crater visible. C: Looking north-west into the crater (Photos: Adam Stanford, Aerial-Cam).

Aims and Methods

Geophysical survey was conducted at Puna Pau in an attempt to determine the presence of any ara pukao. Electromagnetic (Geonics EM38B conductivity meter) and fluxgate magnetometer (Bartington 601) survey were conducted within the quarry over the crater base and sides where the slope allowed. The data obtained

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were then confirmed via excavation in subsequent field seasons. This latter activity enabled access for an additional magnetic susceptibility survey (Bartington MS2 Surface Scanning Probe) within the open trench.

Results and Conclusions

The fluxgate magnetometer and in-phase and quadrature data from the electromagnetic survey all indicate the presence of a possible ara pukao running north-west to south-east along the bottom of the crater. This is seen to run directly alongside an extant pukao left in-situ (Figure 3), and excavation of a cross-section of the linear anomaly at this point confirmed the presence of a route-way, with compacted layers of sediment that gave a high magnetic susceptibility response directly over the road surface (Figure 3). In the south, it is likely that the route would have joined with an existing ara pukao running down the outside of the crater (see photos A and B in Figure 2). In the south-west, the position of two pukao on the top lip of the crater give the suggestion of an additional 'back exit' to the quarry, but it is not possible to determine from these data whether this is likely to have been the case.

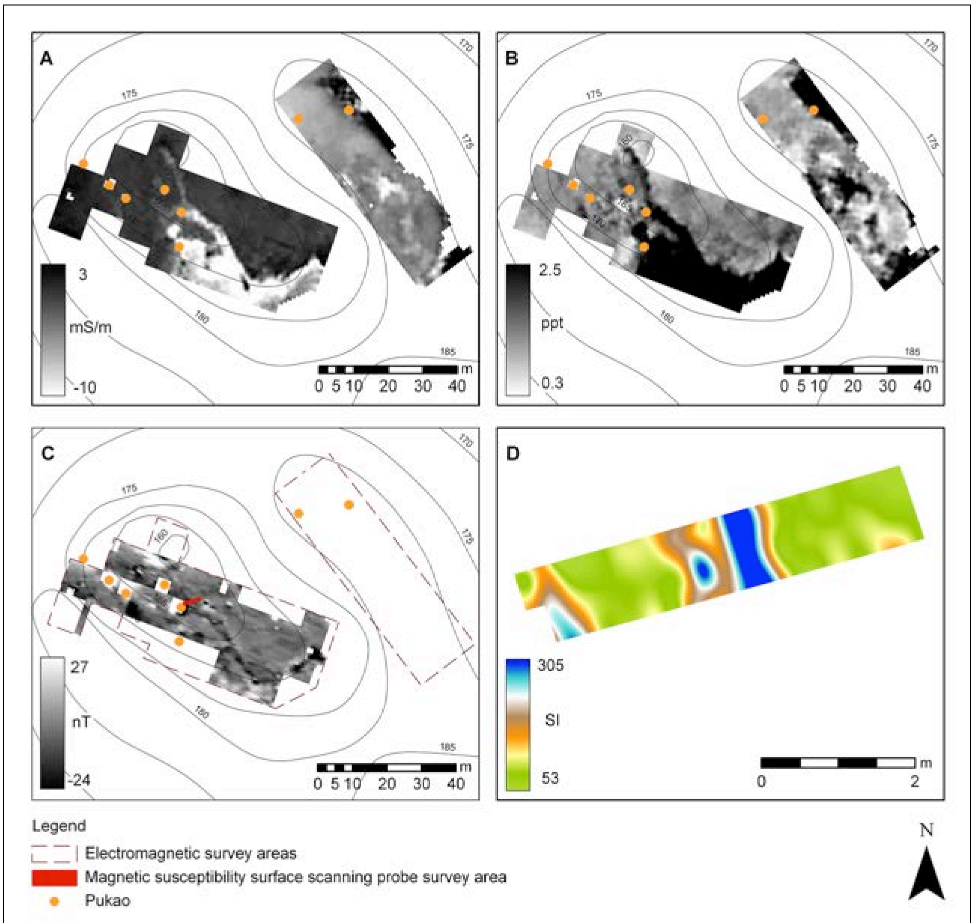

Fig. 3 Results of the geophysical survey at Puna Pau. A: Enhanced quadrature data (vertical magnetic dipole mode, edge matched, clipped and interpolated). B: Enhanced in-phase data (vertical

magnetic dipole mode, edge matched, de-sloped, clipped and interpolated). C: Enhanced fluxgate magnetometer data (de-striped, clipped and interpolated). D: Enhanced magnetic susceptibility data from within the excavated area (clipped and interpolated).

References

Lipo, C. P. and Hunt, T. L. 2005. Mapping prehistoric statue roads on Easter Island. *Antiquity* 79: 158-68.

THE ABSENT LINE OF SIGHT AND OTHER SURVEY LESSONS FROM WESTMINSTER ABBEY – A FINAL CHAPTER IN A COMPREHENSIVE CHURCH SURVEY

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A comprehensive programme of GPR surveys has been carried out in Westminster Abbey since 2004. The initial surveys were in connection with the repair, cleaning and conservation of the 12th Century mosaics in the Sanctuary and in the Shrine Chapel to the East of the Sanctuary (Utsi,2006; Utsi, 2012). Since 2009, attention has turned to the main floor of the Abbey Church, comprising the Nave, the Choir, the Transepts, the Crossing and finally the Ambulatory, the various chapels being too crowded with monuments for a systematic survey.

The survey brief was to provide a comprehensive plan of all subsurface monuments and, in particular, the graves for which previously commissioned surveys had provided very limited evidence. The survey of the Cosmati Pavement in the Sanctuary had revealed the presence of two tombs for which it was possible to image the contents in some detail because both were within 12cm of the mosaic surface and a very high frequency radar could therefore be used (see Figure 1).

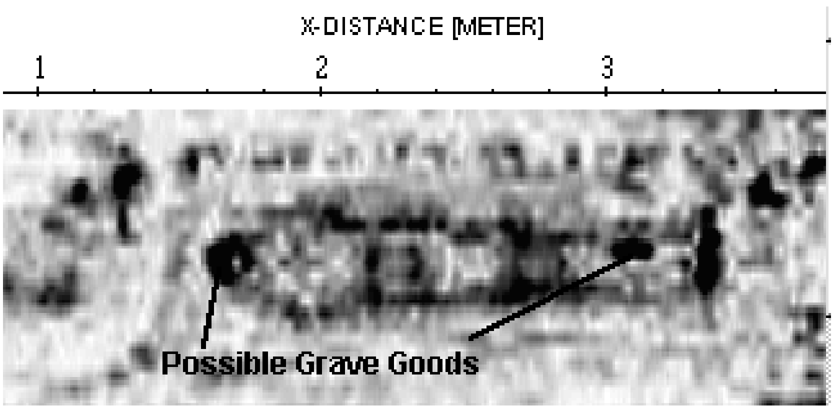

Fig. 1 Grave goods within the Northern Tomb in the Sanctuary

One interesting lesson from trialling different antenna frequencies on the mosaic was that better results were obtained from a 4GHz antenna relative to a 1GHz antenna. Although this theoretically flies in the face of the accepted wisdom of signal losses being linear with frequency, in fact, this is only true of electrical losses. Magnetic losses peak close to 1GHz and thereafter decline, making the very high frequency antenna a relatively powerful tool.

Continuing this work in the Shrine Chapel revealed that the tombs set into the floor in a more traditional manner were mostly beyond the reach of the 4GHz antenna used in the Sanctuary survey and better results were obtained using a 400MHz antenna and close transect spacing conforming to the Nyquist sampling requirement. The strategy of using a minimal sampling interval along the line of travel of the radar (c 15mm) together with a 25cm transect spacing has revealed a comprehensive floor plan for all of the main floor subsurface (see Figure 2).

Total floor coverage was an important feature of the survey, simply because sampling would have been ineffective in terms of understanding the subsurface structures and understanding the structural integrity of the floor itself. All of the areas investigated, with the exception of the Ambulatory, were susceptible to grid survey. The Ambulatory, being an inverted U in shape and also

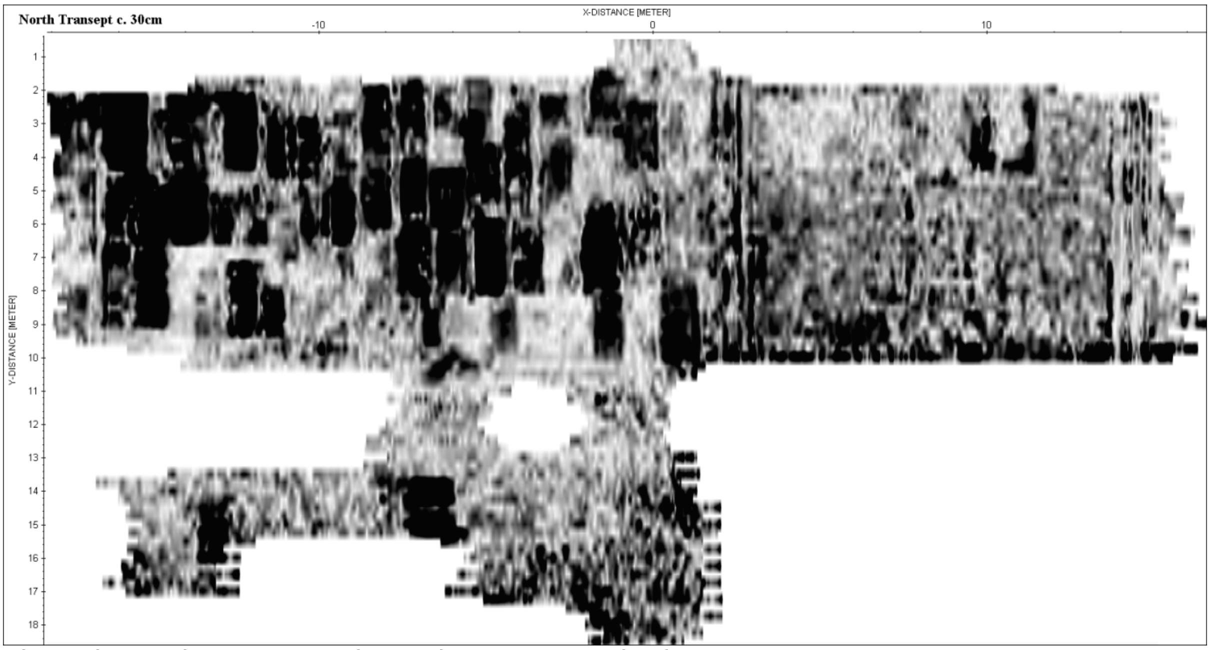

Fig. 2 The North Transept and Crossing at c. 30cm depth

containing a large number of monuments was potentially a difficult proposition (Figure 3). Although in theory at least, it would have been possible to use a total station, this also relies on line of sight and it would have been necessary to complete the survey in a number of sections. Not only does this add to the time taken, potentially it can reduce the coherence of the results. The approach taken was to develop a dual wheel odometer in order to give a continuous x and y position relative to a common start point. In order to ensure that errors did not build up, the Ambulatory was divided into two (slightly overlapping) sections, North and South which were surveyed independently. Since it is not possible to use an encoder wheel to guide the operator, marks were placed on the floor of the Ambulatory at 5 or 6 pre-defined positions, starting from the centre line and at 25cm intervals thereafter to each side. This allowed the systematic collection of data and also a reference check for the odometer positions.

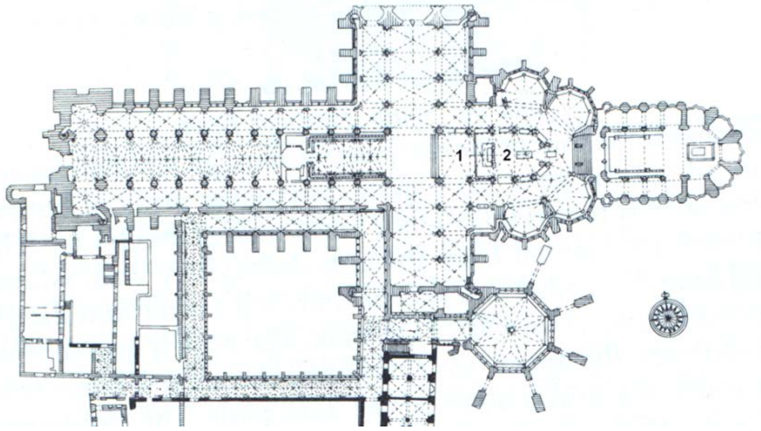

Fig.3 Plan of Westminster Abbey: the Ambulatory is the U shaped corridor surrounding the Sanctuary (1) and the Shrine Chapel (2).

As with other areas of the Abbey, the results reveal a very high density of tombs as well as a number of other structures and some unexplained objects (Figure 4).

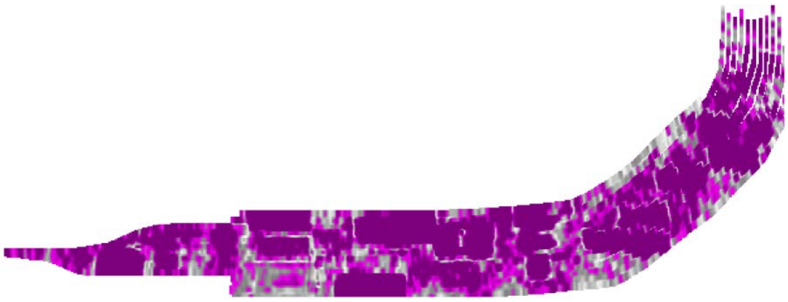

Fig. 4 Time Slice from c. 22cm depth showing a high density of tombs and other structural material Survey data produced using a dual (x, y) encoder wheel and starting from a common point.

One of the objections frequently lodged against both total area coverage and also close spacing to comply with Nyquist is the amount of time necessitated. This is not necessarily true. GPRs vary widely in their characteristics and data collection does not have to be slow. The time taken for the surveys in the Abbey ranges from a half day for two surveys of the mosaic in the Sanctuary (400MHz at 25cm and 4GHz at 5cm transect spacings) to a maximum of 2 evenings for the Nave and Choir (400MHz, 25cm). All surveys were completed using single channel systems, not arrays, because of the large quantities of immovable furniture and fittings.

The same is true of the observation that church furniture results in above ground reflections on the data. Screening is another variable characteristic and the only air signals from this series of investigations are from the interior of subsurface tombs and from continuing over the edge of an altar step (cfTsokas et al, 2007).

The principal lesson from this series of surveys is, however, that both antenna frequency and data density, basically fulfilling the Nyquist requirement, is absolutely essential to understanding the features contained in the subsurface. It is no longer acceptable to complete a few lines at wide spacing on the grounds of time available and interpret all strong amplitude returns as graves when it is possible to produce a detailed plan both horizontally and vertically without expending excessive resources.

References

English Heritage, “Geophysical Survey in Archaeological Field Evaluation”, English Heritage Publishing, 2008, p32.

Tsokas, G. N., Stampolidis, A., Mertzanidis, I., Tsourlos, P., Hamza, R., Chrisafis, C., Ambonis, D., and Tavlakis, I. Geophysical Exploration in the Church of Protaton at Karyes of Mount Athos (Holy Mountain) in Northern Greece in Archaeological Prospection 14 (2), pp 75 -86, 2007.

Utsi, E., "Improving definition: GPR investigations at Westminster Abbey", in Daniels, J.J., & Chen, C.C. (eds), Proceedings of GPR 2006, the 11th International Conference on Ground Penetrating Radar, State University of Ohio, Columbus, Ohio, USA, 2006.

Utsi, E., "The Shrine of Edward the Confessor: a study in multi-frequency GPR Investigation" in Near Surface Geophysics, Vol 10 No1, pp 65-75, 2012.

ELECTRICAL RESISTIVITY TOMOGRAPHIES IN SHALLOW WATER MARINE ENVIRONMENT FOR DETECTING ARCHAEOLOGICAL TARGETS

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Introduction – Theory

Electrical resistivity tomography (ERT) is a well-established method used for onshore archaeological prospection (Papadopoulos et al 2011). Recently, there is a tendency in incorporating this technique within offshore geophysical surveys, especially in marine environments close to the coast line. Comparing with other geophysical methods like seismic tomography, ERT has lower resolving ability but it can be effective if it is applied in relatively shallow water environments.

The imaging of geological structures beneath water-covered areas has been in great demand because of numerous tunnel and bridge construction projects on river or lake sites. An electrical resistivity survey can be effective in such a situation because it provides a subsurface image of faults or weak zones beneath the water layer (Kwon et al., 2005). Furthermore, the electrical resistivity imaging can be useful for the characterization of waterbed sediments (Orlando, 2013). It has proved its usefulness in the geological mapping or ground water studying (Rucker et al., 2007; Rucker et al., 2011). The application of the method doesn't require a specific instrumentation since the existing resistivity equipment can be used for this purpose. Data acquisition can be carried out by using either submerged (Kim et al., 2002) or floating electrodes in conjunction with continuous resistivity profiling.

The present study focus on examining the most appropriate electrode array that is able to handle successfully this type of measurements. The problem is further approached in terms of the effect that the thickness of the water column and the conductivity of the sea water can have on the ERT measurements. Numerous tests with synthetic data and numerical models simulating real cases scenarios of a shallow marine ERT archaeological survey were made in order to address these questions

Synthetic Model

The applicability of the ERT marine measurements for shallow sea water is tested using synthetic numerical data. The synthetic models were created using the 2D modeling and inversion software “DC2DPro” (Kim and Yi, 2010). One of the models that was tested is shown in Figure 1. Specifically, a 2D ERT line was assumed with 48 electrodes equally spaced every 1 meter (a=1m). The thickness and the resistivity of the water layer were set to 1 meter and 0.2 Ohm-m respectively. The subsurface below the water layer consists of two horizontal layers. The overburden layer is 0.5 thick with resistivity 5 Ohm-m. A resistive target (500 Ohm-m) with dimensions 5m by 2m was placed inside the second subsurface layer 0.5m below the overburden. The dipole-dipole (DD), pole-dipole (PD) and gradient (GRAD) electrode arrays, that are suitable for multichannel resistivity instrumentations, were used to create specific measuring ERT protocols.

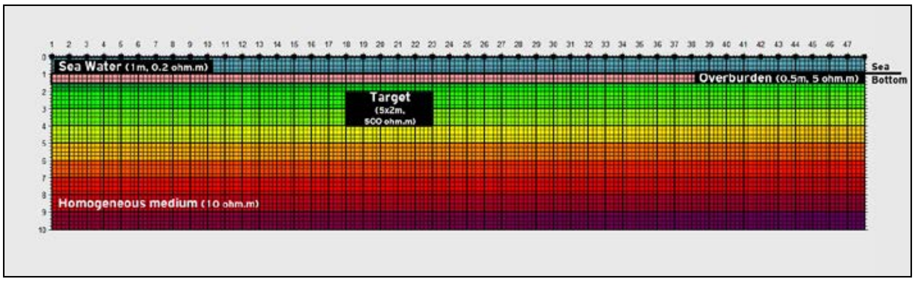

Fig. 1 Synthetic model for ERT marine for shallow sea water measurements. A target (500 ohm.m) is embedded in a homogeneous medium (10 ohm.m), 0.5m below an overburden layer (5 ohm.m). Sea water column is set to 0.5 m (resistivity 0.2 ohm.m).

Testing – Inversion Results

Synthetic modeling was at first implemented in order to compare the inversion results and the reconstructed models employing different electrode arrays. Figure 2 (left side) shows the resistivity inversion models for DD, PD and GRAD where the electrodes are placed on the surface of the water layer (floating electrodes) and no constraints were imposed into the inversion procedure. Generally all the arrays are able to reconstruct the overburden and the sea water layers. Additionally, DD and GRAD seem to have superior results with respect to PD in locating the resistive target.

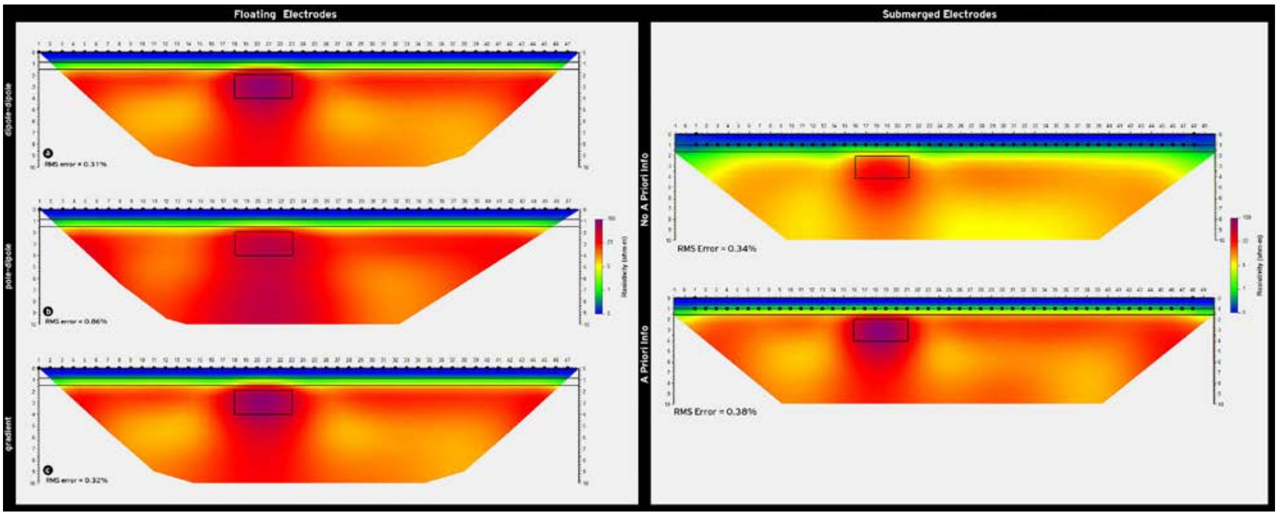

Fig. 2 Inversion results between protocols (a) dipole-dipole, (b) pole-dipole and (c) gradient, using floating electrodes (left side) and using submerged electrodes position with (d) or without (e) a priori information (right side). Black dots indicate electrode position.

An extra scenario involves the case of placing the electrodes on the bottom of the sea (submerged). As shown in Figure 2 (left side), for a sea water column of 1m thickness it is possible to detect the target if the electrodes are placed on the sea surface. If the electrodes are situated on the sea bottom Figure 2d (right side) the results are not promising, but it can be if a priori information (Kim et al., 2014) is taken into consideration during the inversion procedure (Figure 2e). It should be noted that although the a priori information is useful, it should not be used in case of lack of knowledge, cause it will lead to erroneous results if used.

Further testing involved the compilation of optimized protocols where a small subset of measurements in relation to an original comprehensive data set is extracted without compromising the quality and resolution of the inversion results. The optimization procedure was based on the Jacobian matrix method (Athanasiou, 2009), where only the measurements that exhibit the highest resolving capability are chosen during an optimization algorithm. Figure 3 compares the results of the original and the optimized protocols. The inversion models show comparable accuracy despite the fact that the optimized protocol uses only 34% of the measurement of the original entire protocol.

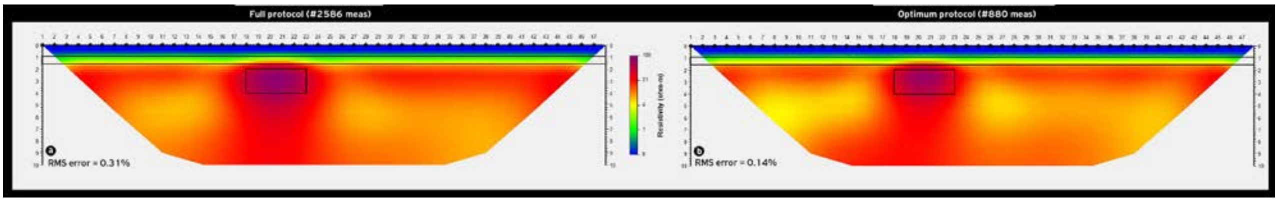

Fig. 3 Inversion results comparing (a) full protocol (#2586 measurements) and (b) optimum protocol (#880 measurements).

Conclusions – Future Work

The numerical modeling results of this study shows that ERT has a potential and could be used for detecting archaeological remains in shallow marine environments. Among the basic array protocols, dipole-dipole and gradient seems to give the most optimum results. The outcomes of this survey also show that it is possible to have satisfactory results by placing the electrodes inside the sea bottom as long as a priori information about the resistivity and the thickness of the sea water layer are known. Optimization of the initial measurement protocol can yield to equally reconstructed resistivity models minimizing at the same the actual field time for data collection.

References

Athanasiou H., (2009), Algorithm Development for Optimum Measurements of ERT data, PhD Thesis.

Kim, J.-H., Tsourlos, P., Yi, M.-J., Karmis, P., (2014), Inversion of ERT data with a priori information using variable weighting factors, Journal of Applied Geophysics, 105, 1-9.

Kim, J-H, Yi, M-J., (2010), 'DC3D_PRO', Geoelectrical Modeling and Inversion, User's Manual, KIGAM, Korea.

Kim, J.-H., Yi, M.-J., Song, Y., Cho, S.-J., Chung, S.-H., Kim, K.-S., (2002), DC Resitivity Survey to Image Faults Beneath a Riverbed, SAGEEP, Las Vegas, 13IDA10.

Kwon, H.S., Kim, J.H., Ahn, H.Y., Yoon, J.S., Kim, K.S., Jung, C.K., Lee, S.B., Uchida T., (2005), Delineation of a fault zone beneath a riverbed by an electrical resistivity survey using a floating streamer cable, Exploration Geophysics,35, 50-58.

Orlando, L., (2013), Some considerations on electrical resistivity imaging for characterization of waterbed sediments, Journal of Applied Geophysics, 95, 77-89.

Papadopoulos, N.G, P. Tsourlos, C. Papazachos, G.N. Tsokas, A. Sarris and J. H. Kim (2011), An Algorithm for the Fast 3-D Resistivity Inversion of Surface Electrical Resistivity Data: Application on Imaging Buried Antiquities. Geophysical Prospection, 59, 557-575.

Rucker D.F., Noonan G.E., Greenwood W.JW,(2011), Electrical resistivity in support of geological mapping along the Panama Canal Engineering Geology, 117, 121-133.

Rucker D.F., Fink J.B. (2007), Inorganic Plume Delineation using Surface High-Resolution Electrical Resistivity at the BC Cribs and Trenches site, Hanford, Vadose Zone J., 6, 946-958.

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GEOPHYSICAL EXPLORATIONS AT ANCIENT ONCHESTOS, BOEOTIA, CENTRAL GREECE

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The ancient settlement of Onchestos and the sanctuary of Poseidon are located towards the southeast part of Kopais lake (central Greece), on a low relief between the valley of Thebes to the east and the city of Aliartosto the west (Fig. 1). The area of Onchestos exhibits a diachronic occupation since prehistoric times. The sanctuary, in particular, was famous in antiquity, because it functioned as the political and religious centre of the Boeotian Federation (*koinon*). Literary references to the sanctuary of Poseidon and its overall significance within the Boeotian territory are mainly found in the works of Homer, Pindar, Strabo, and Pausanias. The Homeric Hymn to Apollo describes a specific ritual that was probably used to choose the most appropriate young horses to drag chariots. Scholarship has suggested that this ritual might date back to Mycenaean times, when chariots were used in the battle-field. Thus the sanctuary of Poseidon could have had a significant role in the traditions of the Mycenaean elite in Boeotia.

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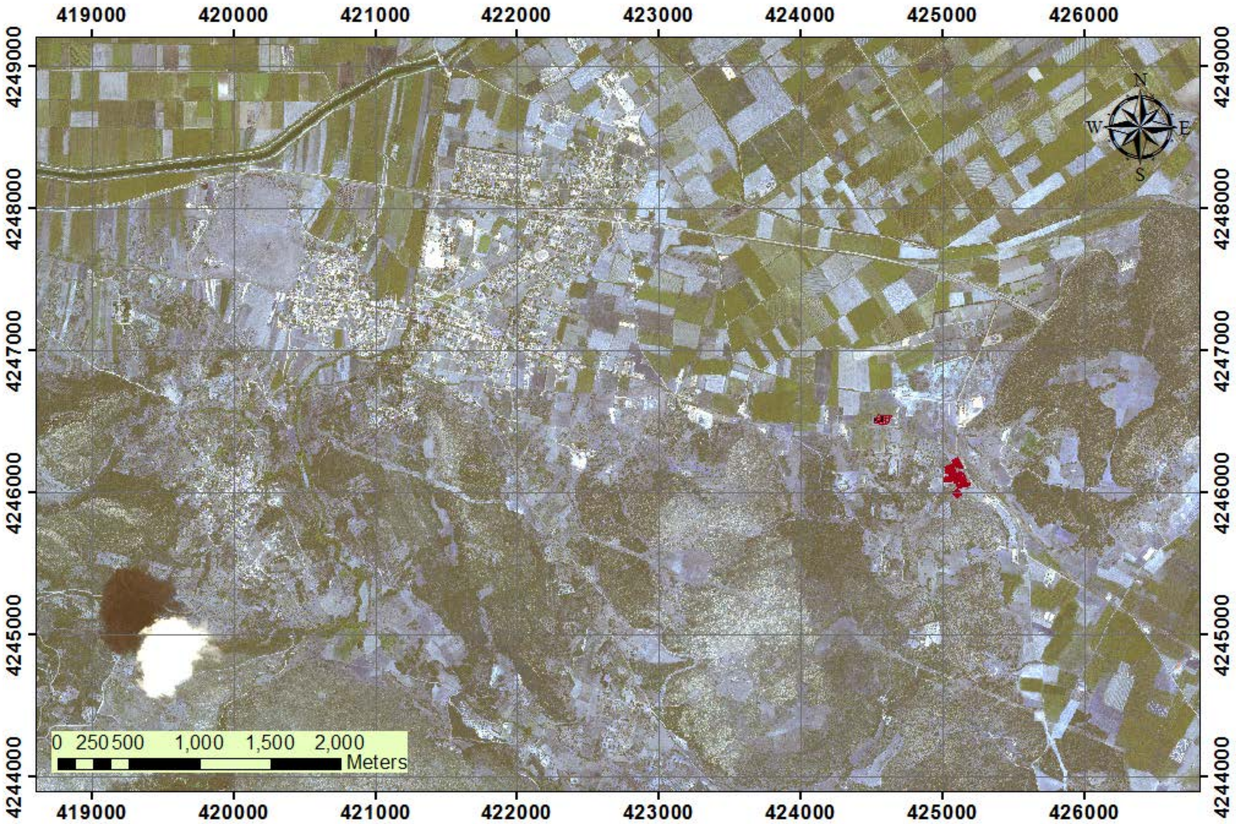


Fig. 1 (up) Google Earth satellite images showing the location of ancient Onchestos in central Boeotia. (down)World View 2 satellite image (Acquisition Date: August 2nd, 2010) of the wider areaof Onchestos; the city of Aliartos is shown to the west. The red polygons indicate the locations of Area A (east) and Area B (west) where the geophysical survey was focused.

Despite the importance of the sanctuary, the first systematic excavation campaign was conducted in the early 70s, although Area A (along the 91st kilometre of the national road Thebes-Livadia, Fig. 2) was identified as the sanctuary of Poseidon already in 1964 after the accidental discovery of inscriptions during farming activity. The excavation brought to light the temple and a large rectangular building that was thought to be an “early” bouleuterion. Further excavations in the early 70s as well as in the mid-90s in an area only 1 km west of the sanctuary (Area B) brought to light a long building with 18 or 19 rooms that is probably a stoa dating to the 4th century B.C. (Fig. 2). Furthermore, the discovery of two bronze votes at the site linked Area B with the Pan-Boeotian sanctuary of Poseidon as well.

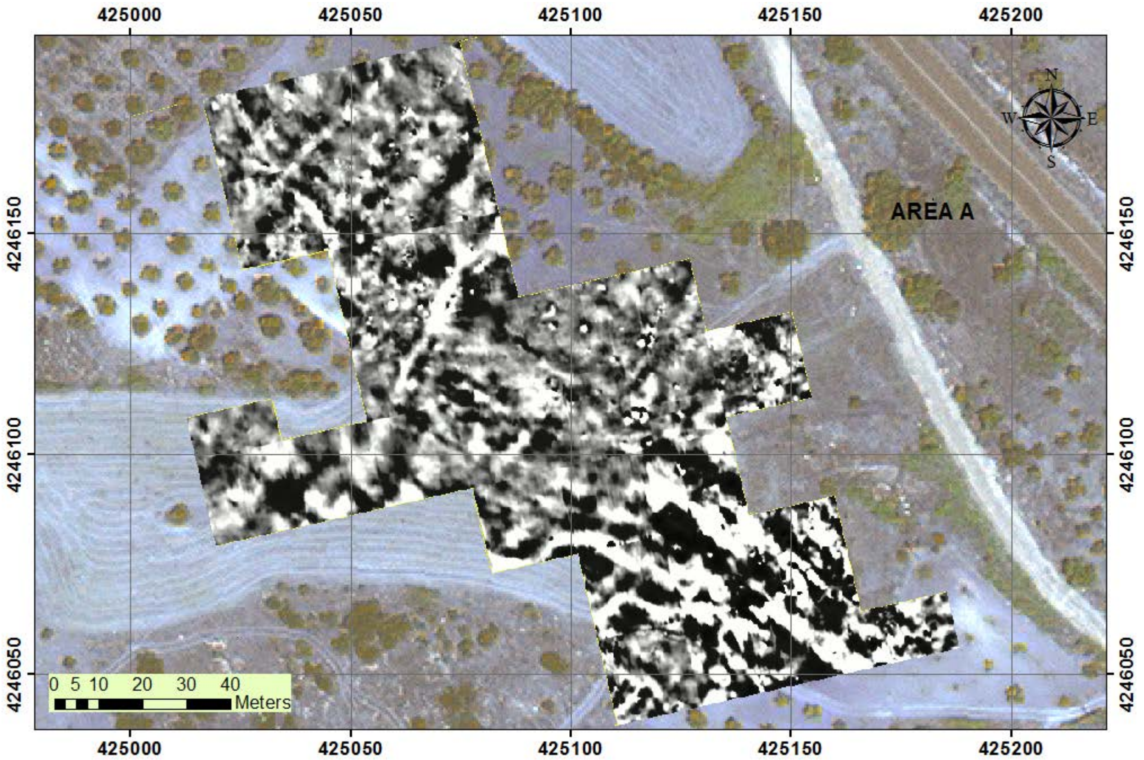
 View of Area A-Section 1 from the SW	 View of the Sanctuary of Poseidon from the south
 View of Area B from North West	 Visible architectural relics at the west of Area B

Fig. 2 Details from areas A and B of the archaeological site of Onchestosthat were surveyed during the geophysical campaign in 2014.

Under the auspices of the Archaeology Society at Athens, Columbia University in the City of New York has recently initiated the “Columbia-Greek excavation at Boeotian Onchestos” project in collaboration with the 9th Ephorate of Prehistoric and Classical Antiquities. In the summer of 2014, the Laboratory of Geophysical Satellite Remote Sensing and Archaeoenvironment conducted the geophysical mapping of the site in order to investigate and map possible architectural structures that are related with the sanctuary of Poseidon.

Magnetic gradiometry, ground penetrating radar (GPR) and electrical resistance mapping techniques were all used in a complementary way for the prospection of various sectors of the archaeological site. More than 2 hectares were covered with a single geophysical method, while about 1 hectare was overlapped with at least two different geophysical mapping techniques. Magnetic and resistivity data were subject to standard signal processing. Despiking filters were used to isolate the extreme values due to metal fragments or poor electrode contacts. Grid and line equalization algorithms accounted for balancing the measurements between the different grid units and individual lines. Regarding GPR, the first peak was determined in order to define the initial useful signal from each line. Then, different filters (AGC, Dewow and DCshift) were applied in order to enhance the recorded signal. The final geophysical maps were rectified and imported in a GIS platform for the purposes of a possible interpretation.

Area A is located around the temple of Poseidon. The magnetic map (Fig. 3) shows some magnetic dipoles scattered mainly towards the north, east and west of the surveyed area that are caused by buried or visible metal fragments. It should be noted that the site was proven to be rich in metal finds. The bedrock outcrop, the different modern terraces, and the backfill soil material from previous excavation activities at the temple area resulted in high magnetic gradients. Despite these interferences the magnetic survey managed to outline three long linear anomalies at the northwest of the temple that form a rectangular structure probably related to architectural remains, buried no more than 1.5-2 metres in depth. The specific structure is oriented along the SE-NW direction and its dimensions are 52m by 34m. It also seems to enclose three other architectural parts signifying either different construction phases or the existence of smaller structures surrounded by a peribolos wall. Further to the north, the magnetic data clearly show the southern part of a linear structure as positive magnetic gradients. The structure runs for about 34 meters along the SW-NE direction. The eastern and western parts of this feature seem to continue further to the north entering a field with olive trees. Moreover, at the central part of the investigated area the GPR maps managed to outline the shape of a rectangular building (8x12m) as strong reflectors. The building has a SE-NW orientation and shows good preservation. The western wall of the building is further extended to the north correlating quite well with the corresponding linear magnetic anomaly at the specific location.



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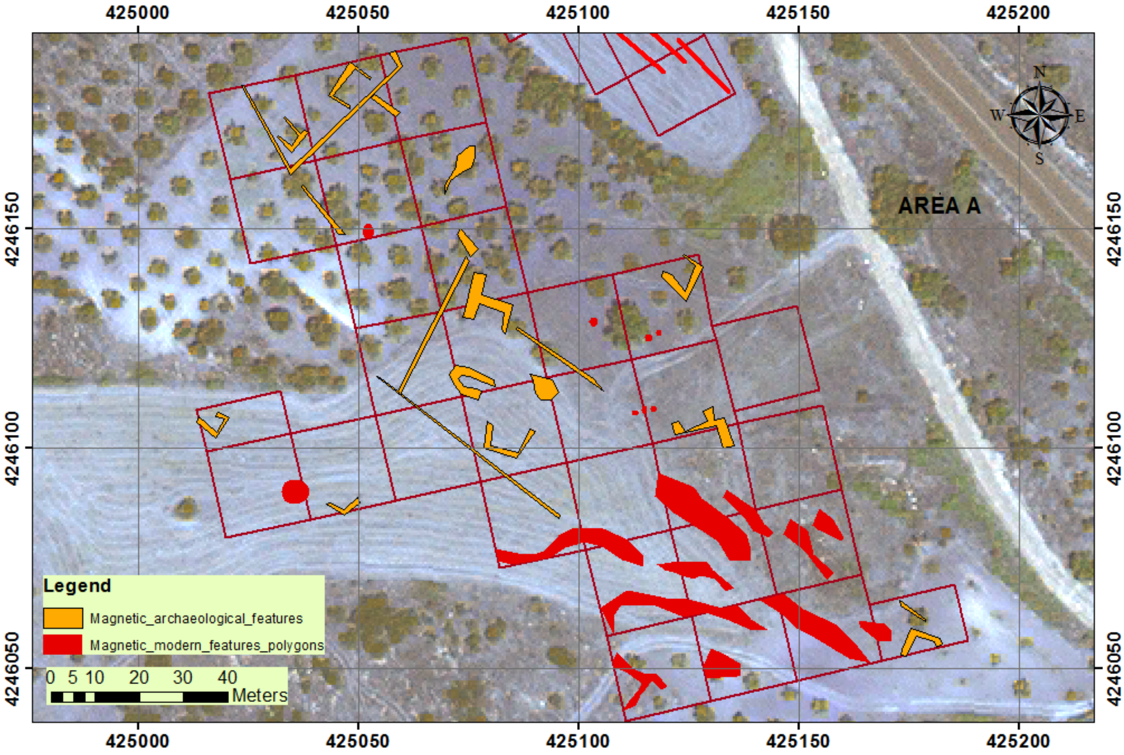

Fig. 3 Overlay of magnetic gradiometry map from Area A on the satellite image of the site and diagrammatic interpretation of the magnetic anomalies. Negative gradients are shown with black. Dynamic range -/+45 nT/m.

The magnetic map in Area B (Fig. 4) is extremely revealing, especially at the eastern part of the investigated area. The data clearly outline the foundations of four almost square rooms with negative magnetic gradients. They are situated next to each other along the south-north direction and measure 5.3m by 5 m. To the south of the last room, a larger rectangular building (22x23m) is visible. The northern and the western part of this large building seem to appear with double parallel walls. The circular negative magnetic anomaly that crosses the interior part of this large building is still under consideration for further archaeological investigation. As we move to the western part of the area, the older excavation trenches have masked the data by disturbing the magnetic gradiometry readings around them. Modern visible and buried metal fragments caused the scattered dipoles all over this part of the area. The south edge of the area next to the highway is also extremely disturbed because of thrown garbage.

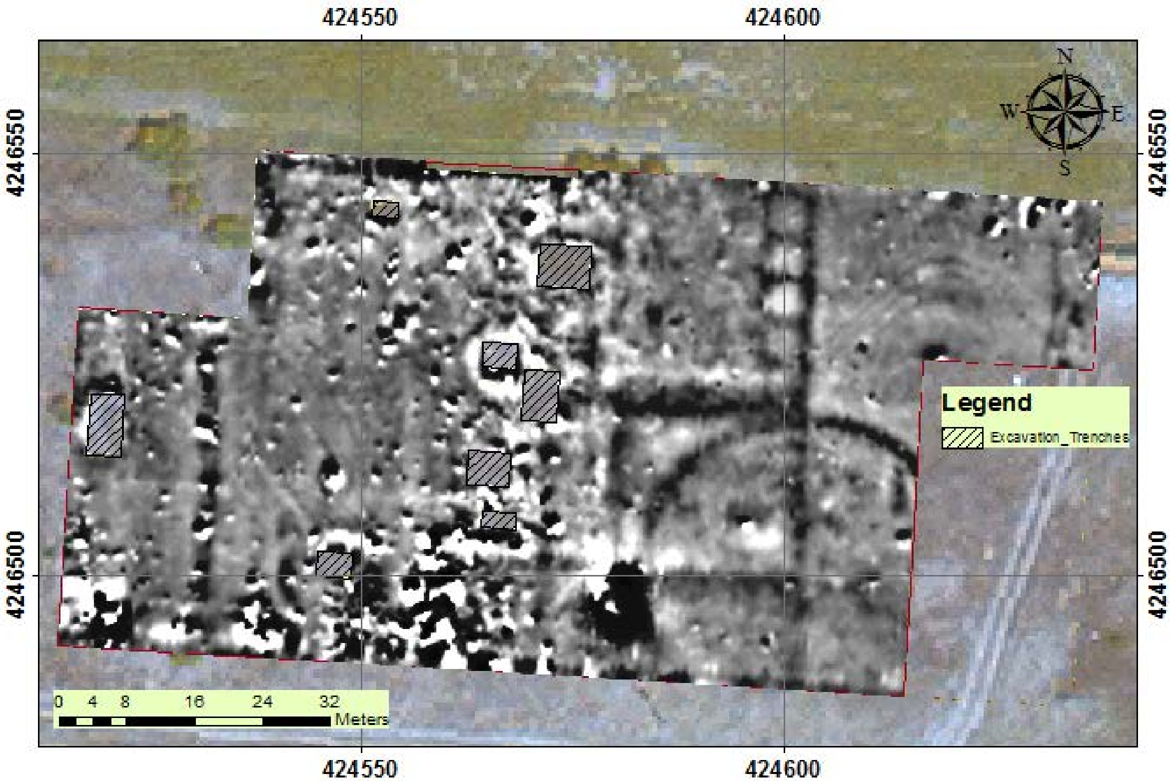

Fig. 4 Magnetic gradiometry map from Area B at Onchestos. Negative gradients are shown with black. Dynamic range -/+60 nT/m.

The geophysical results clearly demonstrate the importance of the manifold geophysical strategy to survey the area of Onchestos. Each one of the methods applied has been able to suggest specific targets in terms of the physical quantity measured and the properties of the subsurface.The different methods used for the scanning of the site were invaluable, since they provided complementary information and thus helped a more accurate delineation of the most significant architectural features. The magnetic gradiometry method proved to be the most suitable for reconstructing the topography of the area. On the contrary, resistivity and GPR data were severely affected by the geological and local environmental setting of the site.

MALA "MINI" MIRA (MALA IMAGING RADAR ARRAY) EXPERIENCES

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Multi-channel GPR systems are now offered by many manufacturers including the 3d-Radar Geoscope, GSSI DF, IDS StreamX, MALÅ MIRA, Radarteam Cobra, Sensors & Software SPIDAR and Utsi Groundvue3 Multi-channel. These instruments offer simultaneous collection of multiple frequencies, offsets, polarisations or even a combination of these.

MALÅ Geoscience (Sweden) have concentrated on producing a single-frequency multi-channel system where the antenna units are arranged in an “array”. Rather than use this term to generically describe antennas collecting data simultaneously, MALÅ ascribe a very specific set of parameters to the term (MALÅ 2014):

1) individual channel spacing less than 1/4 of the centre wavelength in the transmitting media;
2) any combination of receiver/transmitter elements should be achievable, i.e. shooting from any transmitter to any receiver(s);
3) all antennas in the array must produce near-identical response signatures;
4) the positioning system must provide an accuracy of at least half the channel spacing.

By having offset, overlapping banks of transmitters and receivers, and firing diagonally between them, very close line spacings are achievable, producing genuine 3D datasets. This allows identification of subtle features and also generation of radargrams in any direction, following any course, regardless of survey direction.

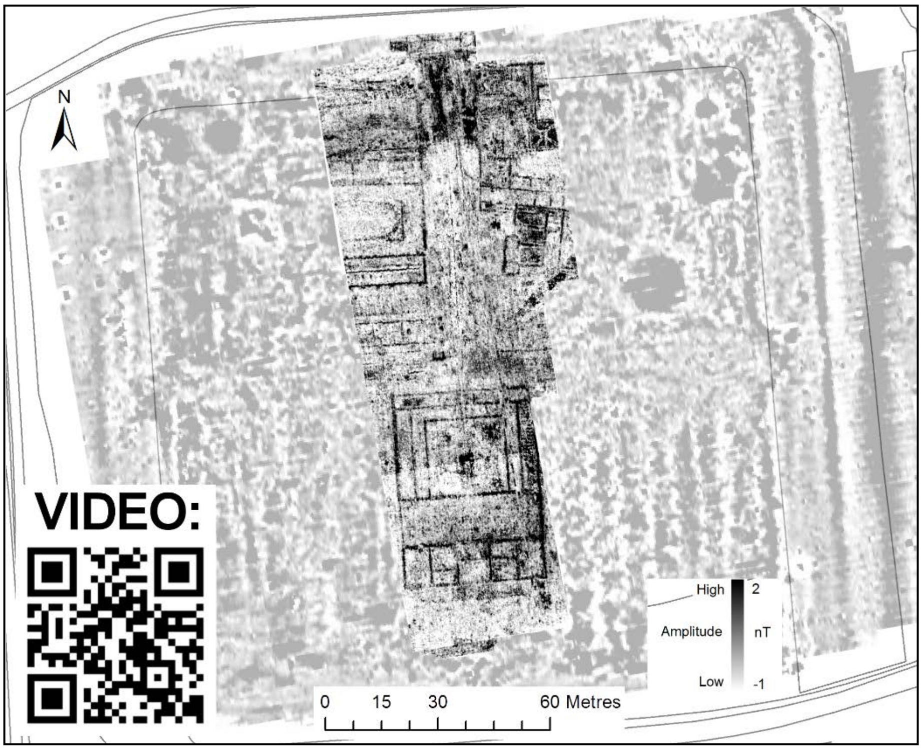
The systems are modular (up to 31 channels) and can be built to suit customers' needs. Being designed around individual transmitter and receiver antennas, anyone can be swapped out, should a fault develop, with minimal disruption. The “standard” configuration is 400MHz, 16 channels (from 9 transmitters, 8receivers), producing 0.08m line spacing. Early archaeological work was carried out in Scandinavia (Trinks 2006) whilst the first system in Britain was operated by LTU Ltd, who assisted GSB with surveys for Time Team during 2009, representing the first use of a MIRA on an archaeological site in the UK. Another of these 16-channel arrays, operated by the Ludwig Boltzmann Institute and their partners has produced excellent results (Neubauer et al. 2013) including recent high profile surveys at Stonehenge with the University of Birmingham (Gaffney et al 2012).

As good as the standard configuration is, the needs of GSB (and the wider SUMO Group) necessitated comprise between a desire to survey quickly and the need to often work within relatively confined spaces. On archaeological sites survey might be around or within standing monuments whilst our utility colleagues often need to undertake pavement survey or work around areas busy with street furniture. The 8-channel variant (5 transmitters, 4 receivers) can be towed when on large open areas, providing rapid data collection (0.75ha – 1.0ha per day) but, importantly, can also be broken down and hand-operated for smaller or more congested sites.

Over the past 2 years the 8-channel system has been deployed on a number of sites ranging from urban redevelopment projects and large multi-property estates to more straightforward open areas. This paper looks at some notable case studies:

Prehistoric– survey was conducted over part of a ploughed-out barrow on Salisbury Plain. With no topographic evidence remaining in the field and only a weak magnetic signature, the state of preservation was uncertain. MIRA clearly defined the ditch extents, showing obvious variation within the backfill and highlighted the depth of deposits that remained; these were found to be shallower on one side than the other. Natural bands within the chalk could be seen advancing across the survey area with increasing depth.

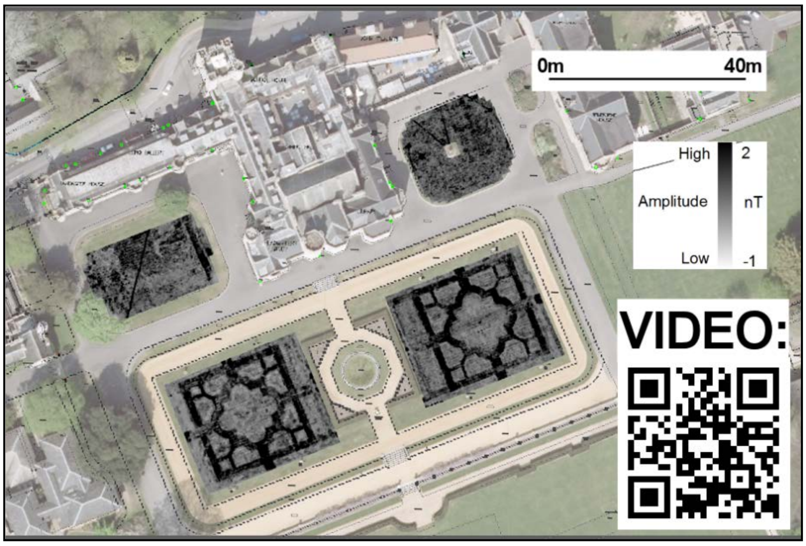
Roman – no presentation on GPR would be complete without a Roman site… Whilst there was a high likelihood of success (Brancaster, Norfolk - a relatively untouched, greenfield site) the clarity of results obtained from this small survey were still a pleasant surprise. The clear building outlines and construction details such as hypocaust systems, buttresses and pillar bases, as well as evidence of phasing, almost negated the need for an interpretation diagram.



Post-Medieval– originally surveyed using a traditional single channel GPR system, the results had been good but a network of utilities and complex stratigraphy complicated interpretation. The improved resolution and ability to define radargrams in any direction, allowed for better visibility and interpretation of the underlying archaeological features through the “windows” between utilities.

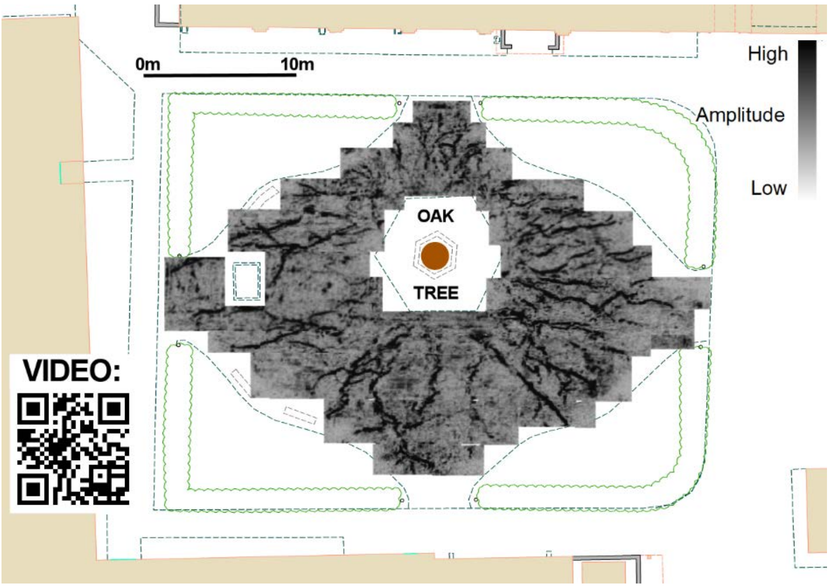
Garden Archaeology–increasingly becoming an area of research, former garden layouts are well within the scope of the MIRA system. Just 0.2m below the surface of two well-kept but otherwise non-descript grass lawns, the pattern of an intricate formal garden was obvious. Despite the last phase having been recorded on early

Ordnance Survey mapping, the exact position and level of preservation of this once great garden were unknown to the present custodians.



Natural World– although not archaeological, the high-resolution set-up of the MIRA can provide valuable information on the root systems of mature trees. In this instance, a courtyard garden with a sizeable oak at its centre was surveyed to determine where the primary root structures lay in order to inform upon, and direct, subsequent intrusive works. Previous efforts to map root systems undertaken using single channel arrays have been labour-intensive and technically challenging to achieve good results (Novo 2008); this survey took around an hour from setting-up to packing the van and required minimal data processing to arrive at these results.

As alluded to in the last example, the MALÅ software (Rslicer) is designed specifically to operate with the MIRA system; this means that the workflow is streamlined and data can be processed very simply and quickly by anyone with a reasonable knowledge of GPR theory. The only potential bottleneck in the process is the specification of the operator’s computer, with file sizes and processing time increasing dramatically with increasing survey area. But that does, at least, give you an opportunity to make a well-earned cup of tea.



References

Gaffney, C., Gaffney, V., Neubauer, W., Baldwin, E., Chapman, H., Garwood, P., Moulden, H., Sparrow, T., Bates, R., Löcker, K., Hinterleitner, A., Trinks, I., Nau, E., Zitz, T., Floery, S., Verhoeven, G., Doneus, M. (2012): *The Stonehenge Hidden*

Landscapes Project. Archaeological Prospection. Volume 19, Issue 2, April/June 2012, Pages: 147-155.

Novo, A.,Grasmueck, M., Viggiano, D., Lorenzo, H. (2008):*3D GPR in Archaeology: What can be gained from dense Data Acquisition and Processing?* in Proceedings 12th International Conference on Ground Penetrating Radar (GPR 2008), Birmingham, UK , June 16-19, 2008:5.

Neubauer, W., Flöry S., Trinks, I., Hinterleitner, A., Löcker, K.,Seren, S. (2013): *High-resolution multi-channel GPR survey of the Roman town FlaviaSolva in Austria.* In Proceedings of the 10th International Conference on Archaeological Prospection (AP2013), Wien, Austria, May 29 – June 02, 2013: 171–172.

MALÅ Geoscience. 2014. MALÅ MIRA (MALÅ Imaging Radar Array) System. [ONLINE] Available at: http://www.malags.com/products/mala-imaging-radar-array-(mira)-system. [Accessed 26 September 14].

Trinks, I., Johansson, B., Gustafsson, J., Emilsson, J., Friborg, J., Gustafsson, C., Nissen, J. and Hinterleitner, A. (2010): *Efficient, large-scale archaeological prospection using a true three-dimensional ground-penetrating Radar Array system.* Archaeological Prospection, 17: 175–186.

NEW FINDINGS FOLLOWING THE MAGNETIC SURVEY OF THE PORT CITY OF BERENIKE ON THE RED SEA COAST IN EGYPT (PCMA UW – UNIVERSITY OF DELAWARE PROJECT)

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The Berenike Project magnetic prospection is nearing completion, providing a practically full and promising map of the ancient city remains. In previous years, the survey provided data on the surroundings of the southwestern bay, which has long been considered as the main harbor of the Hellenistic fortified settlement (3rd century BC) and the early Roman emporium (1st century BC/1st century AD through 3rd century AD). The mapping results also contributed significantly to the discovery and tracing of the Hellenistic fort and defense walls that surrounded the early settlement. Work over the last two seasons on the site of the main Ptolemaic and Roman town (from the 2nd century BC to the early 6th century AD) has produced a surprisingly lucid image of the urban layout of the town as well as of the architecture of individual buildings, presumably from the latest phase of the city (4th–6th century AD), enhancing the topography that could be traced on the ground. It also contributed surprising new elements to what had been believed to be a full plan. Based on the newest results, archaeologists have traced a structure that has all the appearances of a four-way gate (tetrapylon) at the crossing of two main streets in the town and a large complex at the northern end of the presumed cardo of the Roman town, which could well be the early Roman administrative and possibly religious official complex of the harbor, tantalizing evidence of which has been suggested by the continuous stream of official records on ostraka found at the site from the start of regular excavations by first the American–Dutch (in 1994–2001) and now (since 2008) the American–Polish team. The results of the magnetic prospection have been verified archaeologically over recent seasons, contributing not only to knowledge of the Berenike harbor and to the current archaeological investigations, but also to enhanced understanding of magnetic survey results in the specific environmental conditions of the Red Sea coastal desert zone.

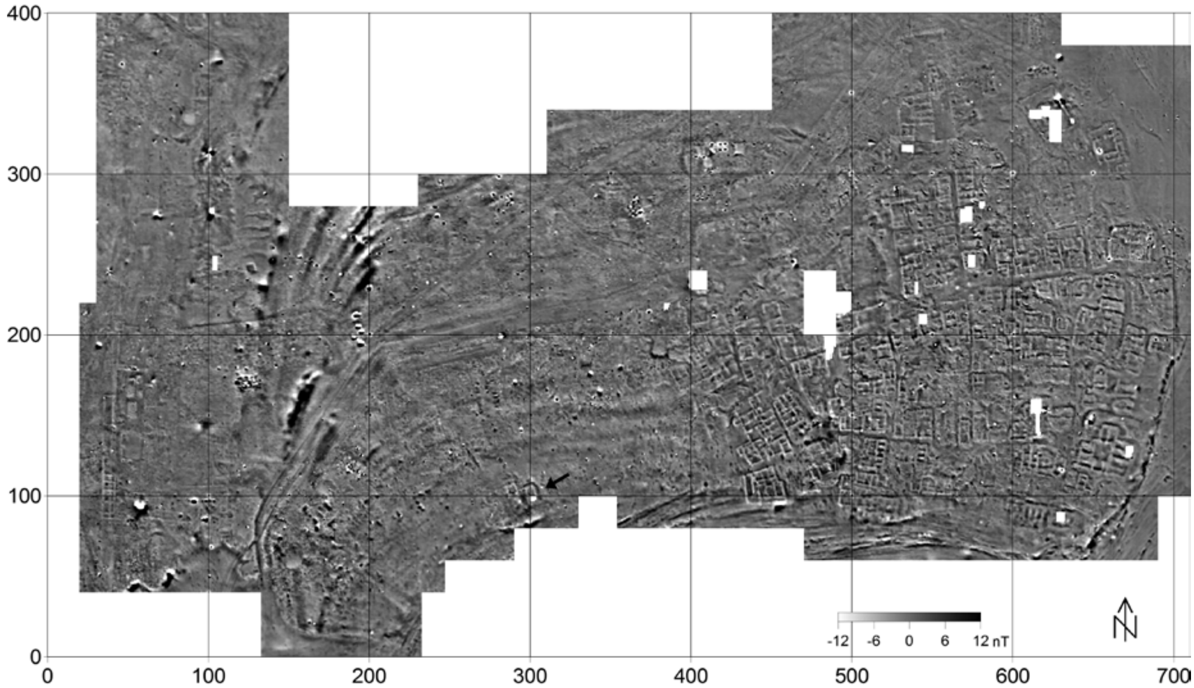

Fig. 1 Magnetic map. Geoscan Research FM36, FM256. Sampling grid 0.50 x 0.25 m. Arrow marks a temple (see fig.3)

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Fig. 2 Remains of the Roman period town.

Fig. 3 Remains of the Roman period temple.

LEA MAX – FROM NOW ON A MULTI-SENSOR ARRAY FOR DIVERSE TYPES OF MAGNETIC GRADIOMETERS

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During the past few years Eastern Atlas has been engaged in the development of high-end multi-sensor arrays with focus on greatest possible flexibility. Several multi-channel systems have been costumized so far. Both commercial contractors and institutional clients draw on them. Of course, Eastern Atlas is also carrying out its own magnetic measurements for archaeological purposes using these arrays. During the last two years the development works have been enlarged in order to integrate other fluxgate gradiometers. As a result the LEA D2 data logger was adapted to control Bartington Grad601 sensors. The special features of the Bartington probes required several eletronic changes. However, the main characteristics of the LEA system could be retained.

The system consists of three modules: The digitiser LEA D2, the non-magnetic cart and the field computer. An adaption of almost all commercial GNSS receivers is possible by means of an digitiser NMEA interface. Naturally, the heart of the system is the digitiser LEA D2. It can be manufactured with up to 10 channels. The casing can be changed in order to create space for even more channels. Each channel employs a separate 24 bit ADC.

The data, both magnetic field data and GPS data is transfered to the field computer via USB interface. Time sensitivity is guaranteed by including the PPS signal. The control program for data collection runs in a Linux environment. Data decoding and first processing is already possible in field by use of script-based routines. The ea-software routines analyse GPS data and eliminate corrupt position data. Offset compensation and gridding of magnetic data is possible by use of either scripts or quick access. Furthermore the software is linked with Quantum GIS for instant generation of both, track maps and georeferenced magnetic maps.

The non-magnetic cart is freely configurable for the required number of probes. It can be pulled by an ATV or pushed by an operator when the terrain impedes the use of vehicles. Even a ten-probe cart can be dismantled so that it can be transported in an estate car.

The extension of the LEA multi-channel systems to other sensor types opens new horizons for owners and users of these gradiometers. The upgrade from single or dual sensor systems to large wheeled arrays with is now possible. Compared to purchasing complete systems the expenses for that stay within reason.

STAMP COLLECTING OR DIAGNOSTIC ADVANCEMENT? A VISION FOR LANDSCAPE SURVEY

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The last 5 years have seen a real boom in the advancement of data collection methodologies used for archaeological geophysics. Whether it is by sledge (as below) or cart systems, both research and commercial sectors are striving forward towards ever larger (and faster) area coverage, at greater spatial resolution (and by implication, data quality) than was previously considered. This is especially true with magnetic survey systems, upon which much of the industry is still heavily dependent. With so much new data available, and with such an ever increasing emphasis on landscape scale survey, should we also be adapting the way we look at, analyse and interpret our data? Are we just interested in 'sites' (whatever they are, foci?) or do we want to extract more diagnostic information about the landscape in which these sit? This presentation is not intended to provide the answers!

Fig. 1 Sledge systems such as ArchaeoPhysica's 'Blackbird' can achieve over 20ha of Cs magnetometer and EMI survey coverage a day, at greater resolution and data quality than walked survey

Pressure on the commercial sector in the UK has resulted in magnetic surveys conducted at what many now consider as sub-optimum spatial resolutions. Such surveys can be great at detecting 'sites' (again, whatever they are) but maybe less capable of providing the level of detail needed to understand the intra-site landscape. A key talking point of a recent commercial geophysics conference (CAGS

2014) revolved around the issues of area versus resolution. Many agreed that greater spatial resolution was needed, however, some supported surveying only 60% of an area as compensation for a perceived extra cost. Ignoring 40% of a landscape when 100% survey at higher resolution is already attainable is clearly nonsense and lacks any geophysical justification. Regardless of commercial pressure the industry should be seeking to maximise information return and that means optimal spatial resolution *and* full coverage.

At the same time, survey must not become an exercise in 'stamp collecting', to quote Irwin Scollar (AP Vienna, 2001) because landscape scale survey needs to support understanding the evolution of landscape. With such survey, the definition of a site becomes less clear as the environment within which such activity foci becomes more apparent. Where are the 'edges' of a site? Are there fields and how might these have been used? Were these on slopes and does colluvium from these still exist? Did land use correlate with soil type? Were there woodlands and streams, in other words, what was the geographical context of the past foci and how did this change?

We propose that the use of multiple geophysical techniques in combination, combined with the collection of higher resolution data, can provide a proxy for some classes of soil data and in combination with geographical information can thus allow the development of landscape to be better understood. It should be possible, for example, to map former stream systems and thus their interaction with settlement and communications. The 'habitation' effect, rather than being an inconvenient limit on magnetic performance away from sites, could be exploited to better understand land use around these. Can areas of woodland or scrub be identified? In short, we are proposing that geophysical survey develops into a primary tool for landscape investigation and not just a means of locating sites.

More work is needed to develop techniques and understanding, but the potential is there. There will need to be greater analytical treatment of data and improved means of extracting meaning from multi-method datasets, but this would ideally be happening anyway. So, the challenge is set: academia must lead the way and produce the tools to support this new geophysical approach!

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EVIDENCING THE PART OF DIELECTRIC PERMITTIVITY IN THE IN-PHASE EMI RESPONSE: AN EXAMPLE IN BAHRAIN

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The island of Bahrain, located in the Arabian/Persian Gulf is well known for the important necropoles from the Dilmun period until the Hellenistic period which have been discovered. The burial mounds are so numerous that until the 20th century, Bahrain was considered as a "necropolis island" without permanent settlement. Archaeologists finally proved that a brilliant and original civilization had spread up the Gulf, particularly during the Dilmun period, and played an important role as a crossroad for the commercial traffic in the Gulf (Bibby 1973, Lombard 1999).

Since 2011, in collaboration with the French archaeological mission directed by Pierre Lombard (CNRS, UMR 5133 Archéorient), a set of geophysical tests have been undertaken on different sites on the island to evaluate the most relevant methods in different archaeological contexts. Some of these tests concerned the site of Qal'at al-Bahrain, located on the northern coast. The site is a tell of 17 ha with an almost continuous occupation from the second half of the third millennium BC until the 17th centuryA.D. A part of the site is now dominated by a Portuguese fort from the 16th century but the excavations carried out since 1954 revealed an important settlement from the Dilmun period including a palace of settlers from Kassite Babylonia (15th c. B.C.) with cuneiform archive. The continuous stratigraphy is also a fundamental reference for the history of the island of which Qal'at al-Bahrain was a major settlement, and probably the capital during the Dilmun period. The environmental context is a very clayey soil in arid climate in the vicinity of the sea.

In 2011, the area was surveyed using the G858 total field cesium magnetometer in gradient mode the upper sensor being at 1.05 m height and the lower at 0.4 m. The inter-profile distance was 1m and the final restitution mesh 0.5x0.5 m^2. Most of the archaeological remains revealed by the magnetic map seem to belong to the late occupation of the site, probably to the medieval period (figure 1). In the NE part of the map, the gradient map clearly shows what can be interpreted as the continuation of the Dilmun fortification (Figure 2). Along the southern side of the fortification and parallel to it, we can see a rectangular building of 20m by 35m. A path of 5m width is also visible between this building and the fortification. It is difficult to describe more precisely the internal organization of the building but its location and orientation may suggest that it belongs to the Dilmun period.

In 2014, a part of this area was covered by EMI low induction number prospection, using the CMD (GfInstrument Ltd, Brno) in both HCP and VCP configurations. The frequency is 30 kHz. In the field it can be used in a continuous recording mode by a walking operator. In Qal'at al-Bahrain, this mode was used with a 0.1s recording step, the clearance of the coil centres above the ground being h=0.12 m.

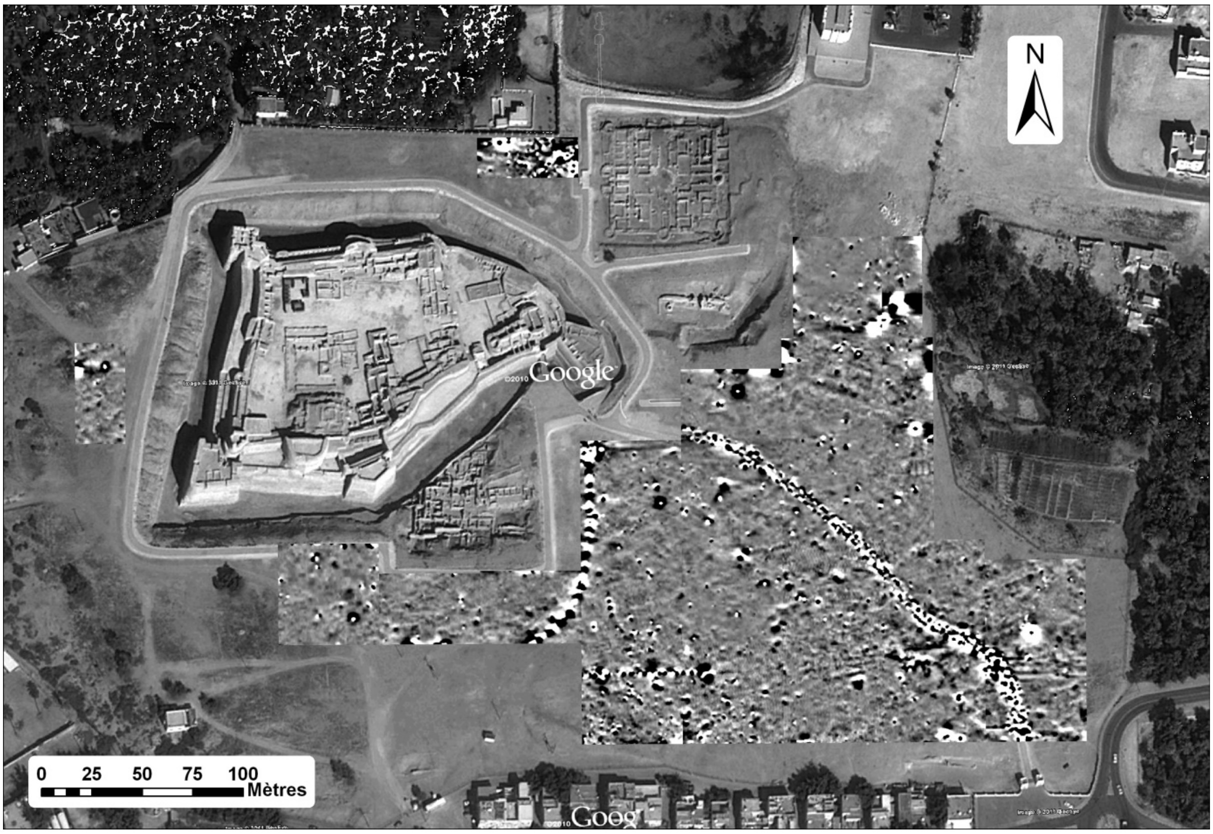

Fig. 1 Magnetic survey of the site of Qal'at al-Bahrain.

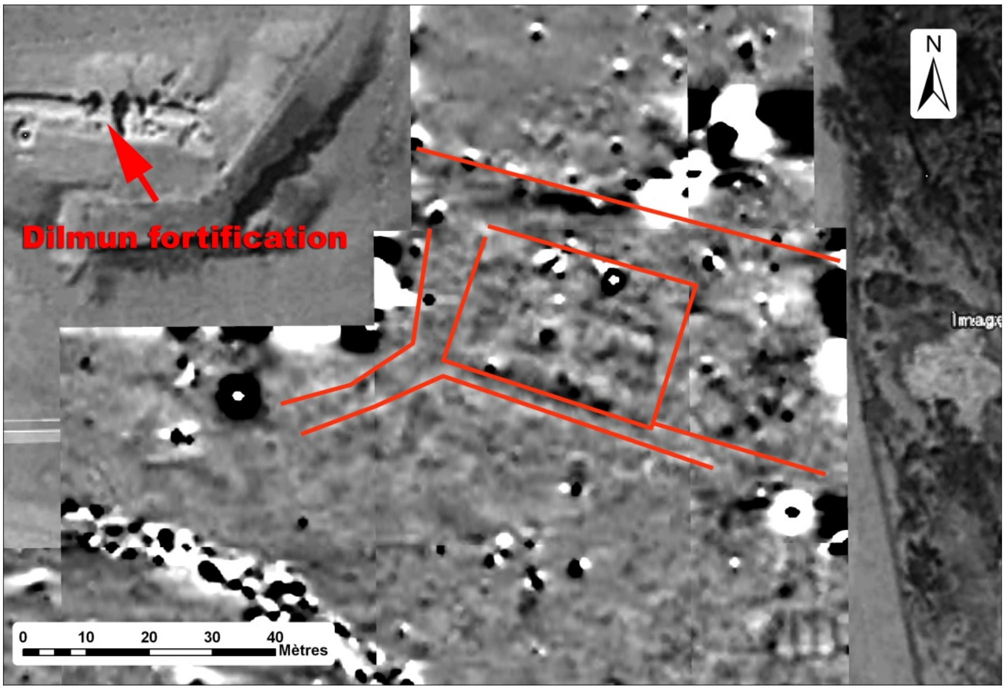

Fig. 2 Detail of the area with the continuation of the Dilmun fortification and the building along it.

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The four apparent conductivity maps obtained for HCP and VCP configurations and both 0.71m and 1.18m inter-coil distances are perfectly coherent: the slight increase of the resistivity between VCP and HCP and between 0.71 m and 1.18 m can simply be explained by a conductivity decrease with depth. The resistivity variations are clearly different from those of the magnetic properties exhibited by the magnetic map.

In high conductivity soil context a part of the In-Phase response is generated by the conductivity, to correct for that effect one must calculate at each point of the survey the In-Phase response corresponding to the conductivity formerly calculated using the quadrature response. After subtraction of this part, the remaining part is usually considered as generated by the soil magnetic susceptibility.

For the magnetic susceptibility, the first observation, totally unexpected and contrary to all the experience acquired with this instrument and other EMI devices, is the total disagreement between the variations in HCP and those in VCP configuration: to HCP maxima correspond VCP minima and reciprocally. Moreover, the correlation with the resistivity map is high, higher than that with the magnetic survey map.

After a series of controls we propose the assumption that the In-Phase responses obtained with the CMD at Bahrain were determined by the dielectric permittivity response rather than by the magnetic susceptibility.

Bibliography

BibbyT.G. 1972.*Looking for Dilmun*. Pelican Series, Penguin Books, Harmondsworth.

Crawford H. 1998. Dilmun and its Gulf neighbours. Cambridge: Cambridge University Press.

Lombard P. (éd.) 1999.*Bahreïn. La civilisation des Deux Mers, de Dilmoun à Tylos*. Catalogue de l'exposition organisée à l'Institut du Monde Arabe (Paris), du 18 mai au 29 août 1999, Institut du Monde Arabe & Éditions SNZ, Paris et Gand.

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A WALK THROUGH THE LILLIPUT BARROWS

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Two tumuli (ST 733704) sit at 180m elevation on a north eastern spur of the Lansdown plateau, dominating the Hamswell valley, at the head of the Swainswick valley running south to the River Avon at Batheaston. They were excavated in 1909 with trenches running East-West and North-South through the centre of each mound and were considered to be twin round barrows. The west mound contained burnt material, animal bones and fragments of black pottery. The east mound contained the remains of a cremation with small pieces of human bones. The location of the barrows on the false crest as seen from the valley bottom would be normal for round barrows. The barrows were revisited in 1960 and were again thought to be two round barrows, but with debris dumped at the western end of the east barrow.

Visual inspection of the western barrow shows a vertically truncated circular mound with the centre dug out, confirming the impression of a round barrow, however the east barrow is 3m high, on a rectangular base 16x10m with the long axis oriented ESE, and with a steep face to the E, suggestive of a long barrow. These appearances suggest a round barrow to the west and a long barrow to the east. The location is not what one would expect for a long barrow, yet this would be most likely some 2000 years earlier than the round barrow.

We have been considering re-excavation of these barrows to understand the discrepancies between appearance and report, but we decided first to subject the barrows to intensive geophysical survey to see how much we could determine from non-intrusive methods. We also wished to present the findings visually in ways which would be clear to the general public, either at the site which is 100m from the Cotswold National Trail, in a printed report or on a website. We started with standard resistance and magnetometry techniques, then proceeded to resistivity pseudosection profiling of a 50x50m square covering both barrows at 1m electrode spacings, to provide depth information to 3.3m. Measurements of elevation were made at each electrode position over the 50mx50m grid to provide topographical contours.

The standard planar resistivity and magnetometry plots confirm the prominent circular ditch and centre of the round barrow to the west: in the east barrow they show areas of high resistivity, suggestive of stone, but with no clear shape. The standard resistance and magnetometry maps were then overlaid on the topographical surface. These showed respectively a line of high resistance along the N face of the east barrow and an interruption of the ditch around the west barrow at the apparent point of intersection with the east barrow.

Interpretation of the sequence of vertical sections produced by resistivity profiling requires considerable expertise and practice; it is hard to relate them to surface topography or to features displayed by magnetometry. One approach is 'Walking through' such cross-sections, with the current position marked on a longitudinal section and on a surface contour map or photograph. This requires a dynamic and preferably interactive display.

The integration of resistivity data across sections allows the creation of a 3-D; E-W, N-S, elevation, positional matrix, with a resistivity value in each cell. Binary classification into areas of high or low resistivity not only simplifies the images but also allows the creation of internal isosurfaces and apparent volumes within a 3-D display, on which surface contours can be overlaid. This model can then be viewed from different perspectives to aid interpretation. Such perspectives can be physical viewpoints at the site or can be provided by a photographic image of the barrows taken from that viewpoint. A dynamic system would allow a 'walk around and over' the barrows.

Ideally, the displays should clearly demonstrate the nature and topography of each barrow, damage from earlier excavation, areas apparently undisturbed, and the barrows' place in the wider landscape. We will discuss to what extent each of these aims is achieved.

Fig. 1 The barrows as they appear today, seen from the north-east.

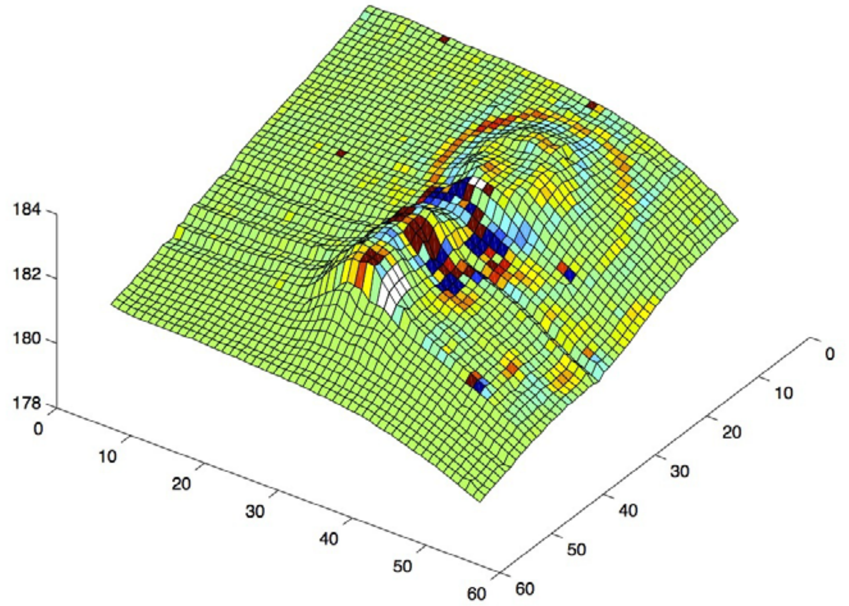

Fig. 2 Magnetometry draped over the physical topography of the barrows, viewed from the north-east, gives a good way of locating features seen in plan, but does not show interior detail. Note that there is a ditch round the western barrow, but not round the eastern barrow.

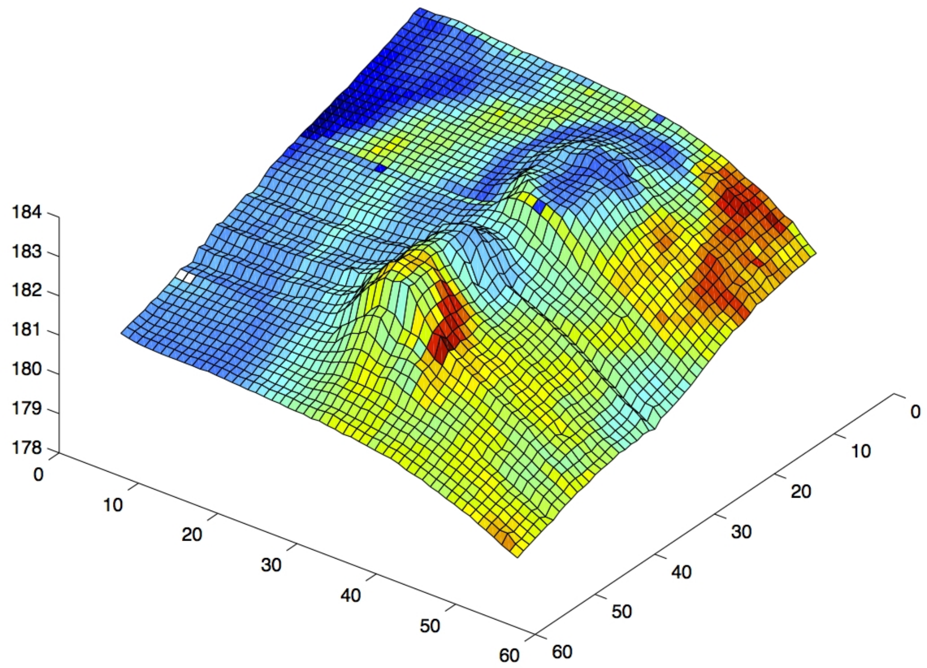

Fig. 3 Resistance, also viewed from the north-east, provides complementary detail, but is still only based on surface measurement.

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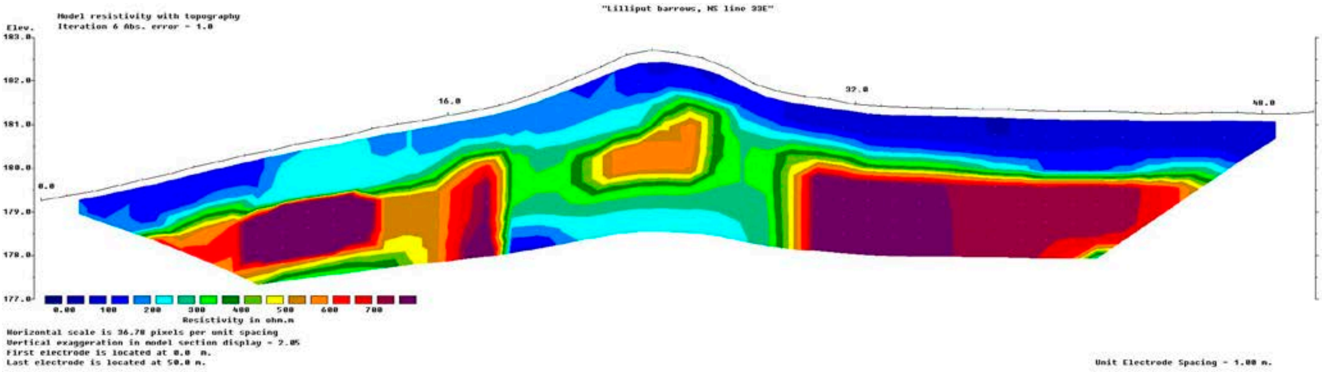

Fig. 4 A single north-south resistivity profile through the east barrow (along line 33E, right hand axis in figures 2 and 3, seen from the west,) gives good detail on the physical make-up of the barrow, but you need to look through another 50 to see the overall picture.

ARCHAEOLOGICAL GEOPHYSICS AND PRECISION FARMING

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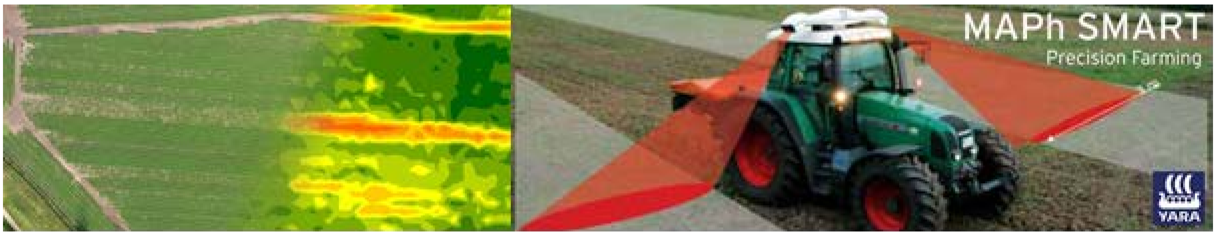
Precision farming consists of a number of technologies that enable the recording and management of soil, and crop, variation to produce food in a more efficient and sustainable way. As part of this, companies are using geophysical sensors to map soil variation over 100,000s of hectares in the UK and assessing those variations through more targeted soil surveying and soil sampling.

Archaeological geophysics has become an essential tool for studying and understanding archaeological sites and landscapes through detailed surveys. By using technologically advanced non-invasive sensors, the development of more multi-technique platforms and better software, archaeological geophysics has important skills, knowledge and expertise in researching soil variations.

Both subjects regard soil data as essential for their studies, yet they have both remained in relative isolation to each other. With the rise of precision farming, and the importance of archaeological geophysics, what potential is there for integration, data exchange and future research linking the two subjects?

Through four selected topics; site management, combined geophysical platforms, robotics and automated surveys, and big data and accessibility, the contrasts and comparisons were made and the likely potential from each topic was extracted. There exists significant potential to provide short term benefits to archaeological geophysics in the exchange of existing geophysical data if problems over data protection can be mitigated. There could also be wider benefits for this data to aid archaeo-geophysical surveying and interpretation, as well as heritage management. In the longer term, further research into magnetic techniques for precision farming and the development of automated survey systems in archaeological geophysics will provide more efficient use of time, labour and data. This research is being continued more practically since it is a key resource linking knowledge of the soil for global food production with knowledge gained through archaeological investigations.



COMMERCIAL EXHIBITORS

BARTINGTON INSTRUMENTS

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Bartington Instruments is a world leader in the design and manufacture of high precision, low noise fluxgate magnetometers, gradiometers and magnetic susceptibility instrumentation. Archaeologists and geophysicists worldwide use our instruments for surveys and high accuracy measurement of geomagnetic fields, or detecting underground structures.

The Grad601gradiometer system has become an industry standard in the UK for commercial archaeological investigations. The handheld system – consisting of a data logger, a battery cassette and either one or two Grad-01-1000L sensors mounted on a rigid carrying bar– is now complemented by the addition of a Non-Magnetic Cart, which enables Grad601 equipment to be mounted on a multi-sensor platform. Combined with the logging software and GPS, this lets existing Grad601users either upgrade to a multi-acquisition platform or use the standard handheld version, depending on field constraints.

The new Grad-13 digital gradiometer provides a new alternative to archaeo-geophysics by giving the user access to either total field data or vector data, for enhanced interpretation of the results.

Up to 12 Grad-13 or Grad601sensors can be mounted on the lightweight Non-Magnetic Cart, enabling a far wider and quicker coverage of the area being surveyed. The 4 metre, 20kg cart is constructed from a set of carbon fibre tubes with a single tool used to operate all locks and catches. It can be pushed or towed by a single operator, or be configured for towing behind a small vehicle with an additional 4 metre, 9kg attachment.

Our versatile MS2/MS3 magnetic susceptibility instrumentation has a suite of interchangeable sensors and probes for measuring the magnetic susceptibility of many types of material including soils, rocks, core samples, powders and liquids. Samples can be studied in the field or laboratory. Magnetic susceptibility measurements quickly provide information about the level of magnetic enhancement of the soil, enabling areas of likely archaeological content to be discerned.

www.allied-associates.co.uk

- sales@allied-associates.co.uk
- rentals@allied-associates.co.uk

+44 (0) 1582 606 999

GF Instruments Mini Explorer

An Archaeology essential for increased data capture due to its design. Using 1 transmitter and 3 receive coils the Mini allows simultaneous measurements @ 0.5,1, & 1.8m providing time slices of the survey area. The instrument offers:

- Bluetooth
  Fixed cable connection
  (The latter useful in towed configurations)
- GPS
- large internal memory
- fast response
- Data compatible with inversion and mapping software.

New from GSSI, UtilityScan DF

Designed for utility location and excellent for archaeology.
The 800 and 300-Mhz antenna combination, offers high resolution near-surface data (top meter) whilst the 300 offers deep scanning.
This system can be configured for;

- 2, 3 & 4 wheeled Cart configurations
- Towed manually
- Mounted on a vehicle for rough terrain conditions.

The latest product from GF Instruments

Multi Kappa a Mag Sus meter for multi-layer surveying.
Coil diameters of 125,250 & 500mm results in depths of;

- 5cm
- 10cm
- 20cm.

Lightweight and portable the Multi Kappa can be used in point or mapping mode and with client owned GPS.

The latest release from GSSI

The all new and powerful SIR-4000 controller.
This new device allows connection of current analogue antennas, and soon to be released Digital antennas.
Features include;

- real time GPS logger
- 3-D graphics
- faster computing capacity
- IP65, Enhanced 10.4" LED display with internal high brightness, Active matrix 1024 x 768 resolution and 32-bit colour

DW CONSULTING

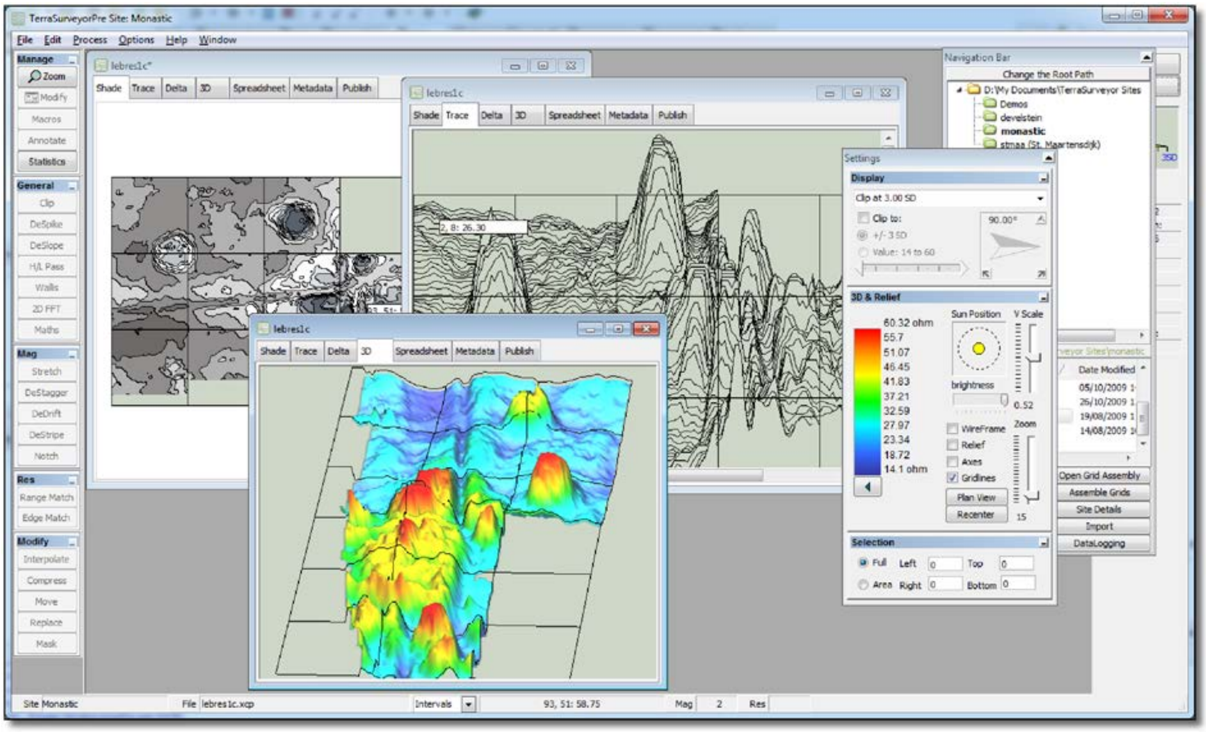
Boekweitakker 28, 3773 BX Barneveld, The Netherlands

www.dwconsulting.nl dwilbourn@dwconsulting.nl

DW Consulting produces software for acquiring, assembling, processing, visualizing and publishing Geophysical data. The programs have been specifically designed to meet the needs of archaeologists and continue to be developed in close co-operation with many instrument manufacturers and users.
The two main programs are:

TerraSurveyor
This targets 2 dimensional data such as that created by Magnetometers & Resistivity meters.

TerraSurveyor3D
This was developed to display volumetric data from Magnetic Susceptibility down-hole probes. However it can also handle other 3D datasets such as pre-processed GPR data.



TerraSurveyor Software

GEOMATRIX EARTH SCIENCE LTD

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Find us on Facebook www.geomatrix.co.uk @GeomatrixES

Geomatrix Earth Science is a dedicated instrument supply company specialising in Geophysical Instrumentation for the investigation of near surface ground properties. We offer one of the largest short term Geophysical Instrumentation rental pools in Europe and pride ourselves on our commitment to unbeatable service for our customers.

Rental pool Items for Archaeological Prospection:

Caesium Vapour and Fluxgate Gradiometer systems; including 6 Geometrics G-858 Cs vapour and 3 Bartington 601-2 Fluxgate gradiometers.

Ground Penetrating Radar systems; Geomatrix has started to supply Utsi Electronics GPR systems; currently offering single and 8 channel GPR controllers with a variety of antenna (from 250MHz- 4 GHz). We can currently support 400MHz and 1GHz antenna arrays and will be incorporating lower frequency arrays shortly.

Resistance and Resistivity instruments; Geoscan Research RM85 Advanced; the system offers an internal multiplexer and integrated GPS logging function. The RM85 is accompanied by the PA20 (supplied with a 0.5m, 1m and 1.5m beam) or with shallow sounding accessories. Multiple ERT systems are also available with RES2DINV inversion software.

Towed Instrument system; unique to Geomatrix is the Geophysical Equipment Exploration Platform (GEEP). GEEP offers the ability to record multiple datasets from complimentary instrumentation on a single towed platform. GEEP permits large areas to be surveyed in great detail with multiple sensors whilst maintaining high data quality.

EM Conductivity instruments; featuring 2 Geonics EM38MK2 & a GF Instruments CMD Explorer both instruments are suitable for electrical conductivity mapping and the identification of buried metallic objects

New to the Rental pool; Geomatrix have recently incorporated a TerraPlus KT10 Magnetic Susceptibility and Conductivity meter for soil analysis.

Contact sales@geomatrix.co.uk for further information.

GEOSCAN RESEARCH Celebrating 30 Years 1984 - 2014

Heather Brae, Chrisharben Park, Clayton, Bradford, BD14 6AE, UK

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Geoscan Research designs and manufactures geophysical instrumentation for professional and amateur archaeological use. Our products are also used in environmental, forensics, geological, civil engineering and peace-time military applications.

The product range comprises earth resistance meters, fluxgate gradiometers, mobile sensor platforms and associated Geoplot computer software. Our products are low cost, user-friendly, light-weight and have proven reliability.

New - MSP25 Mobile Sensor Platform

The MSP25 Mobile Sensor Platform comprises a wheeled resistance square array, upon which a fluxgate gradiometer and GPS can also be mounted, providing fast, simultaneous, detailed resistance and magnetic surveys.

The platform comprises four spiked wheels set 0.75m apart on a rugged aluminium and stainless steel frame. A Geoscan Research ADVANCED RM85 Resistance Meter and Expansion Port Interface Box 1 are mounted centrally. Provision is made for attaching a towing system.

The platform pivots around its centre allowing the wheels to maintain contact with undulating ground. A pair of quick-release/latch handles allows steering along traverse lines and rapid traverse shift at grid edges when zigzag surveying. Logging can be controlled either by a sample trigger system or by an optical encoder system integral to one of the wheels.

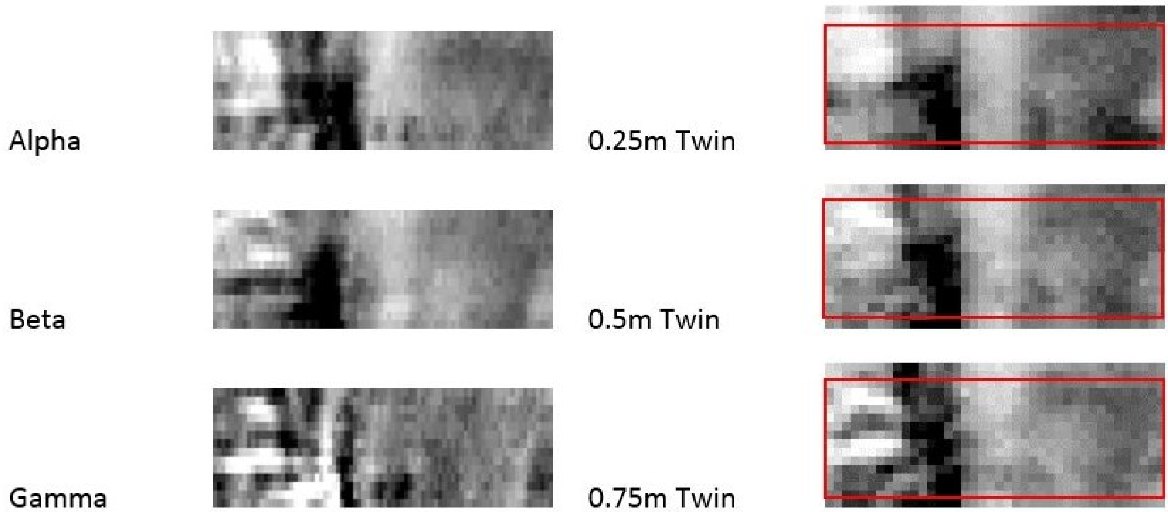
The RM85 can collect single or multiplexed Square array data: alpha, beta and gamma resistance measurements along with GPS position for each reading. Surveys are normally conducted in a regular gridded fashion; Non-Gridded surveys can be collected using GPS referenced data.

The system enables rapid resistance surveys to be made. For example alpha, beta, gamma and GPS can be logged at a sample interval of 0.25m at a rate of 0.6s/m, alpha, beta and GPS at 0.3s/m. Intensive surveys at a sample interval of 0.125m can provide very detailed information. Square array measurements avoid the trailing remote probe cable of a Twin array. Since a gradiometer mounted on the platform is at distance from the operator, the requirement for non-magnetic personnel is relaxed and allows use by less skilled operators.

High Resolution MSP25 Surveys

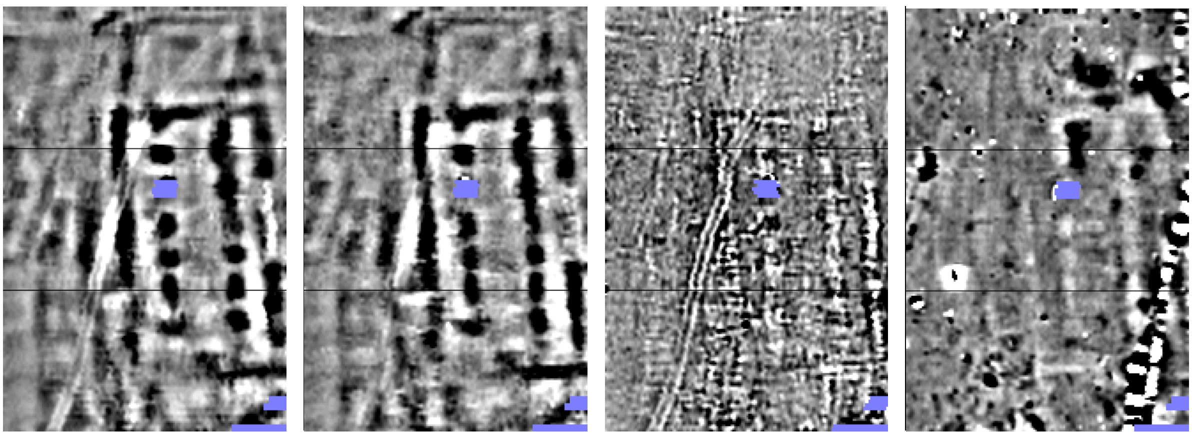
High resolution surveys are made possible with the MSP25/RM85 combination. The survey below of a small area (3.5m by 10m) has a well-defined wall running across the area. An MSP25 was used to collect alpha, beta and gamma measurements at a 0.125m sample interval and 0.25m traverse interval. A PA20 was used to collect 0.25m, 0.5m and 0.75m Twin at a sample and traverse interval of 0.25m.

The results are complex but at the intense sampling used, detailed structure is apparent. MSP25 data is much faster to collect than the Twin array and could provide useful extra information in more confined areas, such as in garden archaeology or forensic work; the absence of Twin remote probe cabling is an advantage in confined areas. In addition, surveys done in separate areas can be more easily matched together than with the Twin since Twin measurements are dependent on remote probe spacing.



Rapid Large Area MSP25 Surveys

The results below are of a combined resistance and gradiometer survey at Fountains Abbey (picture opposite). An MSP25 was used to collect alpha, beta and gamma measurements at a 0.25m sample interval and 0.5m traverse interval over an area of 40 x 60m; the MSP25 was moved at about 0.7s /m for rapid area coverage.



Alpha (HPF) Beta (HPF) Gamma FM256

You can see clear indications of building foundations as high resistance features (dark). Additionally the line of a later small tramway used to transport stone is also visible (light) crossing the foundations. The gradiometer results also indicate the building foundations as a negative response, together with services.

SENSYS SENSORIK & SYSTEMTECHNOLOGIE GmbH

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Fig. 1 3-axis Fluxgate sensor fGM3D/100

SENSYS is based close to Berlin, Germany. The company designs and manufactures high precision survey and measurement equipment for magnetic and electromagnetic applications such as single axis, three axis and differential fluxgate magnetometers, magnetic susceptibility instruments, TDEM coil system and associated data processing equipment. Furthermore SENSYS develops its own data analysis software based on customer needs.

Fig. 2 Magneto MX V3 16-channel system with modular cart

Fig. 3 Magneto MXPDA 5-channel cart system during a survey session at the Wadden Sea with customized wheels

The product range comprises hand held iron detectors, multi channel systems to be carried or pushed, as well as large area survey systems towed by car, vessel or underwater ROVs. All systems can be equipped with state-of-the-art RTK DGPS for a direct referencing of measurement data. Beside non-invasive surveys equipment, SENSYS also produce borehole measurement systems for vertical, angled or horizontal measurements. Furthermore, the range of single probes and sensors is steadily growing, enabling the integration of SENSYS products into third party systems. This makes all SENSYS equipment suitable for challenging applications in the field of UXO detection, military, naval surveys, archaeological prospection and scientific field and lab studies.

Fig. 4 Magneto MX 16-channel system during a survey session at Stonehenge

With more than 20 years of experience, SENSYS is not only delivering products to its customers but also taking the highest care of training, service, repair and support.

FORTHCOMING NSGG EVENTS IN 2015

Geophysics field exhibition & demonstration, NSGG Test site, University of Leicester, 14/05/2015

Engineering Geophysics for Critical Infrastructure, venue to be confirmed, 16/07/2015. A joint meeting with The Engineering Group

Please check the NSGG website meetings page for further details as these develop: http://www.nsgg.org.uk/meetings/

OTHER CONFERENCES OF INTEREST IN 2015

The 11th International Conference on Archaeological Prospection will be hosted by the Institute of Archaeology and Ethnology of the Polish Academy of Sciences, Polish Center of Mediterranean Archaeology of the University of Warsaw and Scientific Association of Polish Archaeologists, in Warsaw, Poland, between the 15th and 19th September 2015. http://www.iaepan.vot.pl/ap2015/

ACKNOWLEDGEMENTS

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Finally thanks to all our presenters and commercial exhibitors for their contributions which made the meeting possible as well as to everyone who has attended and participated in an extremely successful event.