Recent Work in Archaeological Geophysics

The Geological Society
Burlington House, Piccadilly, London W1J 0BG
Tuesday 4th December 2012

Programme

Lecture Programme:

0915-1000	**Registration and Coffee**
1000-1005	Introduction
1005-1020	*Multi Depth Electromagnetic Survey – changing the way we prospect for archaeology?* J Bonsall, C Gaffney, T Sparrow and I Armit.
1025-1040	*Void characterisation through multi frequency composite Radargrams.* M Guy.
1045-1100	*A comparison of the FlashRes64 Imaging System and Tigre ERT system.* R Fry, C Gaffney and F Pope-Carter.
1105-1120	*They may all be dead but they still ain't equal ...* A Schmidt and G Tsetskhladze.
1125-1155	**Tea/Coffee break**
1155-1210	*Detailed Prospecting within the Stonehenge Landscape.* E Baldwin, C Gaffney, V Gaffney, W Neubauer and K Loecker.
1215-1230	*Landscape geophysical surveys at Brú na Bóinne World Heritage Site: survey techniques, data quality, and initial archaeological interpretation.* I Hill, K Barton, C Brady, L Williams and M Krajňák.
1235-1250	*Magnetic and electromagnetic measurement systems for large area surveys.* W Suess.
1255-1300	Morning closing remarks
1300-1430	**Lunch (available locally)** NSGG AGM in the lecture theatre at 13:30 (open to all Geological Society members)
1430-1445	*Is it time for a National Mapping Programme for geophysical survey data?* J Lyall.

1450-1505	*What a difference a year makes: The impact of environmental dynamics on multiple sensor responses over archaeological features, an example from Cherry Copse, Cirencester.* R Fry, D Boddice, D Stott, A R Beck, C Gaffney, N Metje and A Schmidt.
1510-1525	*Did we find anything? Feedback and Statistical analysis of Ground Truthed Magnetometer Data.* J Bonsall, C Gaffney and I Armit.
1530-1600	**Tea/Coffee break**
1600-1615	*3-D GPR investigation of a residential area in the Roman town Ammaia (Portugal).* L Verdonck, D Taelman and F Vermeulen.
1620-1635	*Mirrors and Villas – how geophysics is revealing the gaping holes in our knowledge of late Iron Age and Roman settlement in Dorset, UK.* P Cheetham and H Simpson.
1640-1655	*GPR in-depth - A chronological interpretation of high resolution GPR data from Visegrad, Sibrik, Hungary.* K Tolna.
1700-1715	*Below 1 nT: interest of weak magnetic anomalies for the study of ancient gardens.* C Benech.
1720-1730	Conclusion
1735-1900	International Society for Archaeological Prospection (ISAP) AGM in the lecture theatre.

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

Magnetic characterization of ceramic kilns: Examples from the north and the south sides of the Mediterranean sea. A Jrad, Y Quesnel, P Rochette and C Jallouli.

Archaeological by-products of Unexploded Ordnance. A Butcher and M Brown.

Early Medieval Castle Wahrenholz – Lower Saxony, Germany. C Schweitzer and C Frey.

Geophysics on Solsbury Hill, Bath. J Oswin and R Buettner.

Magnetometer and Ground Penetrating Radar Surveys in the Neolithic flint mine of Arnhofen, Lower Bavaria, Southern Germany. J Koch, J W E Fassbinder, R Linck, K Eisele and M M Rind.

Application of Remote Sensing Techniques at Brú na Bóinne World Heritage Site, County, Meath, Ireland. I Hill, K Barton, C Brady, L Williams and M Krajňák.

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Roman villae rusticae in the Bavarian part of Noricum. L Kühne, R Linck, J W E Fassbinder, J Koch, F Becker and F Klauser.

The Appliance of Science and The Community. P Masters.

Geology Strikes Back. P Morris.

Satellite-based geophysical prospection of the Roman fortress of Qreiye-Ayyāš in Syria. R Linck, J W E Fassbinder, S Buckreuss and S Seren.

Should archaeologists be concerned about naturally varying magnetic fields? S Macmillan, S J Reay.

Geophysical investigation in Dakhleh Oasis (Egypt): Discovery of an unknown settlement at Ayn Birbiyeh. T Herbich.

Magnetic and electromagnetic measurement systems for large area surveys. W Suess, Sensys Gmbh.

A geophysical survey of the castle site, Saffron Walden, Essex, UK. T Dennis and R Potter.

Unravelling palaeohydrology: revealing prehistoric landscapes with a multi-receiver electromagnetic induction survey. P De Smedt, P Crombé and M Van Meirvenne.

Commercial Exhibitors:

Allied Associates Geophysical Ltd

Bartington Instruments Ltd

DW Consulting

Geomatrix Ltd

Geoscan Research Ltd

Utsi Electronics Ltd

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LECTURE ABSTRACTS

MULTI DEPTH ELECTROMAGNETIC SURVEY-CHANGING THE WAY WE PROSPECT FOR ARCHAEOLOGY?

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Low frequency electromagnetic (EM) techniques using Slingram instruments have been used for archaeological prospecting since the 1960s. Traditionally in Europe, EM surveys have not enjoyed widespread use (Gaffney 2008); this has been due to a number of factors, such as limited data collection ability, inherent issues of instrument drift, a lack of depth analysis and partly due to an over-reliance upon magnetometer, earth resistance, and ground penetrating radar technology. Despite this, EM surveys have previously offered a number of benefits over traditional magnetic and electrical methods, principally the simultaneous acquisition and co-location of quadrature and in-phase data to assess soil properties similar to those identified in earth resistance and magnetometer surveys. The measurement of quadrature and in-phase components allows the calculation of conductivity and magnetic susceptibility, respectively. Under certain practical conditions EM surveys provide a very reasonable approximation of these properties and are therefore capable of identifying a broad range of archaeological features including cut features, masonry and areas of burning. However, previous studies have indicated the values are only estimates as the conductive and magnetic components are not entirely separated (Tite and Mullins 1973 ;Tabbagh 1986a ; Linford 1998).

Both commercial and academic prospecting strategies have recently been driven by a need to resolve all (or most) archaeological features, rather than those that exhibit exclusively magnetic properties, by the acquisition of high resolution data in an increasingly efficient manner (Gaffney et al. 2012) and by the investigation of archaeological features at depth using 3D or pseudo-3D methods. These drivers have previously been met by high-speed multi-method investigations employing magnetometer, earth resistance and/or GPR surveys (Dabas 2009; Trinks et al. 2010; Campana 2011), however the development of a new generation of multi-depth instruments suggest that EM prospecting may have a role to play. In this presentation we assess the abilities of a new electromagnetic system EM, the CMD Mini-Explorer, for the prospecting of archaeological features.

The Mini-Explorer is an EM probe which is primarily aimed at the environmental / geological prospecting market for the detection of pipes and geology. It has long been evident from the use of other more limited EM devices that the CMD might be suitable for shallow soil studies and applicable for archaeological prospecting. Of particular interest for the archaeological surveyor is the fact that the Mini-Explorer simultaneously obtains both quadrature ('conductivity') and in-phase ('magnetic susceptibility') data from three depth levels. As the maximum depth range is probably about 1.5m, a comprehensive analysis of the subsoil within that range is possible. As with all EM devices the measurements require no contact with the ground thereby negating the problem of high contact resistance that often besets earth resistance data during dry spells. The use of the CMD Mini-Explorer at a number of sites has demonstrated that it has the potential to detect a range of archaeological features and produces high quality data that are comparable in quality to those obtained from standard earth resistance and magnetometer techniques. In theory the ability to measure two phenomena at three depths suggests that this type of instrument could reduce the number of poor outcomes that are the result of single measurement surveys. The high success rate reported here in the identification of buried archaeology using a multi depth device that responds to the two most commonly mapped geophysical phenomena has implications for evaluation style surveys.

Configuration	Coil Separation	Depth of Investigation	Coil Orientation	EM Measurement	Archaeological Geophysical Data
1-HCP-Q	0.32m	0.5m	Horizontal Coplanar	Quadrature	Apparent Conductivity
1-HCP-I	0.32m	0.5m	Horizontal Coplanar	In-Phase	Apparent Magnetic Susceptibility
2-HCP-Q	0.71m	1.0m	Horizontal Coplanar	Quadrature	Apparent Conductivity
2-HCP-I	0.71m	1.0m	Horizontal Coplanar	In-Phase	Apparent Magnetic Susceptibility
3-HCP-Q	1.18m	1.8m	Horizontal Coplanar	Quadrature	Apparent Conductivity
3-HCP-I	1.18m	1.8m	Horizontal Coplanar	In-Phase	Apparent Magnetic Susceptibility
1-VCP-Q	0.32m	0.25m	Vertical Coplanar	Quadrature	Apparent Conductivity
1-VCP-I	0.32m	0.25m	Vertical Coplanar	In-Phase	Apparent Magnetic Susceptibility
2-VCP-Q	0.71m	0.5m	Vertical Coplanar	Quadrature	Apparent Conductivity
2-VCP-I	0.71m	0.5m	Vertical Coplanar	In-Phase	Apparent Magnetic Susceptibility
3-VCP-Q	1.18m	0.9m	Vertical Coplanar	Quadrature	Apparent Conductivity
3-VCP-I	1.18m	0.9m	Vertical Coplanar	In-Phase	Apparent Magnetic Susceptibility

Table 1. Coil Configuration, orientation and effective depth of investigation for electromagnetic measurements collected with the Mini-Explorer. The depth of investigation has been determined by the manufacturer (GF Instruments) and should be only regarded as indicative.

As with other modern EM devices, the Mini-Explorer measures apparent conductivity (quadrature) in mS/m and the in-phase ratio in ppt, which is largely determined by the magnetic susceptibility contribution of the soil. The simultaneous acquisition and co-location of quadrature and in-phase data means that the same volume of earth is investigated for any given sample point, something which magnetometer and earth resistance surveys are unable to do, no matter how accurately the data are collected. This gives the Mini-Explorer a significant advantage over conventional magnetometer and earth resistance surveys in terms of analysing the geometry and geophysical magnitude of responses from sub-surface archaeological features.

In the presentation we will demonstrate:

- The ability of the Mini-Explorer to detect a wide range of archaeological features. Excavations and 2D geophysical data have confirmed that the conductivity and in-phase responses have identified ditches (including significant enclosed settlements and mounds), pits (including post-pit circles), inhumations, walls and banks. The instrument performed well within the variables assessed such as geology, soils, vegetation cover and climate. The instrument has for example successfully identified archaeology upon magnetically strong geologies; beneath layers of peat; on grazed, neglected and upland pasture and over very dry soils during particularly hot weather.

- The depth range of the CMD Mini-Explorer, as suggested by the manufacturers, has been shown to be reasonably accurate when compared to excavation data, although the effective range is influenced by the physical properties of the underlying soil, which will vary at each site.

- It has been shown that the CMD Mini-Explorer has the ability to determine the presence of a variety of discrete archaeological features across a range of site types and locations. The depth range is suited to shallow soils and, given the variables involved in the estimation of depth, is particularly useful for the investigation of complex stratigraphy such as those found on archaeological sites.

We conclude that the instrument is suitable for prospecting surveys of areas of unknown archaeological potential – if archaeological features are present we have found that at least one of the datasets would indicate a measurable and understandable signal. This point is very important if one considers the use of a multi depth EM system in commercial or evaluation surveys. The use of a multi depth EM sensor appears to reduce the chances of incorrect technique choice, especially in areas of difficult geology or variable soil depth.

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VOID CHARACTERISATION THROUGH MULTI FREQUENCY COMPOSITE RADARGRAMS.

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Introduction

As part of a study to identify the extent of potential tunnels beneath Highworth town centre, Wiltshire, the Optimal Spectral Weighting (OSW) algorithm formulated by Booth *et al* (2009) was utilised to construct a multiple frequency composite radargram in an effort to increase the frequency bandwidth and ultimately enhance subordinate reflectors produced by the voids.

Voids are relatively common targets since they can form through natural physical and chemical processes or be fashioned as part of anthropologic activities. These can however be particularly difficult targets to interpret as the response characteristics are determined by the target dimensions relative to the wavelength and the electrical permittivity contrast.

Figure 1: **Schematic diagram of the dimensions of the tunnels/ cavities emanating from number 40a High Street.** The tunnel depicted to the right of the diagram (Northern structure) is brick lined and it is possible to see into the air pocket. Whilst the narrower entrance (south structure) looks to be cut into the limestone bedrock but this is highly speculative due to the entrance being sealed. (Diagram not to scale)

Generally voids generate multiples of high amplitude reflections (Al-Shayea *et al. 1994*). Casas *et al* (1996) states "…The main characteristic of cavities is the presence of a strong convex reflector at the top, with low frequency signals below it…" (reiterated by Kofman *et al* 2006; 285). The low frequency reflections are results of resonant scattering within the air pocket and are dependent on the void diameter being greater than the EM pulse wavelength (Kofman 1994). If the wavelength of the EM pulse is not relative to the size of the void then resonant scattering does not occur reducing interpretation confidence.

Figure 42: Georeferenced 225MHz Amplitude slice [1.05-1.2m].

Survey Methodology

Highworth is a small town located in the North East corner of the Borough of Swindon, NGR SU 4199 1926, and is situated on a limestone knoll, 133m above sea level (Barron 1976; Wiltshire County Council 2005).

GPR profiles were collected in the centre of the town focusing on a small area of the Market Square so as to characterise reflectors. The Market Square currently serves as a car park, surrounded by two storey buildings. Profiles were orientated South–North parallel to the façade of N^{o} 40a High street. A Sensors and Software Pulse Echo 1000 GPR system was deployed with 450MHz, 225MHz and 110MHz bow tie shielded antenna. A 0.25m traverse interval and a 0.05m sampling interval were selected for all antennas. Data processing was conducted using the Sandmeier Reflex W and Deco RadExPro software.

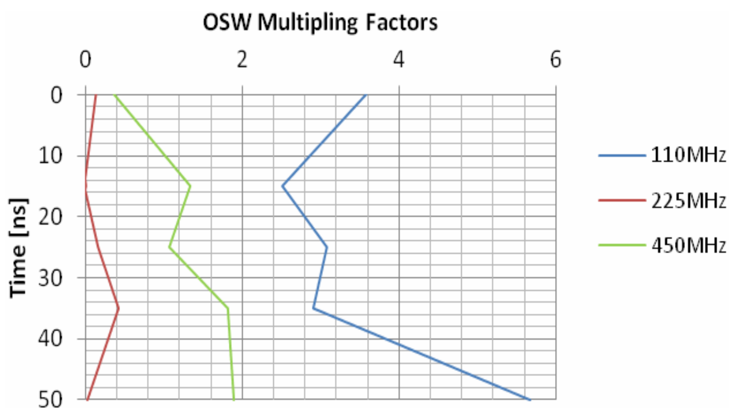

Figure 3: Multiplying factors used by OSW algorithm to construct the second frequency composite profile. The 225MHz multipliers are considerably smaller than that of the 110MHz and 450MHZ central frequency component, effectively reducing the influence of reflectors from the 225MHz radar gram in the composite.

Results and Conclusions

Initially time/depth slices were developed as a means of identifying the extent of the voids beneath the market square. Unfortunately high amplitude backscatter, along the western extent of the survey area, masked the reflected signals from the voids. Subsequently a multi frequency radargram was produced in an effort to enhance 2D interpretations.

In contrast to the 450MHz central frequency radargram the composite radargram shows better wavelet definition in the area where the smaller structure should be located. The signal labelled [b] is thought to be in the right location and depth to represent the interface of the ceiling and void/rubble infill of the small structure. The reflection characteristics of the anomaly [b] however have not been significantly enhanced. Interestingly the reflected signals with a 5ns-12ns have been suppressed as a result of greater 110MHz weighting factor over this time window, this defect is enhanced by the minimal contribution of the 225MHz due to the small weighting factors.

Within my presentation I will discuss, in detail, the results of the OSW composite radargram and outline the potential of the OSW algorithm for future projects.

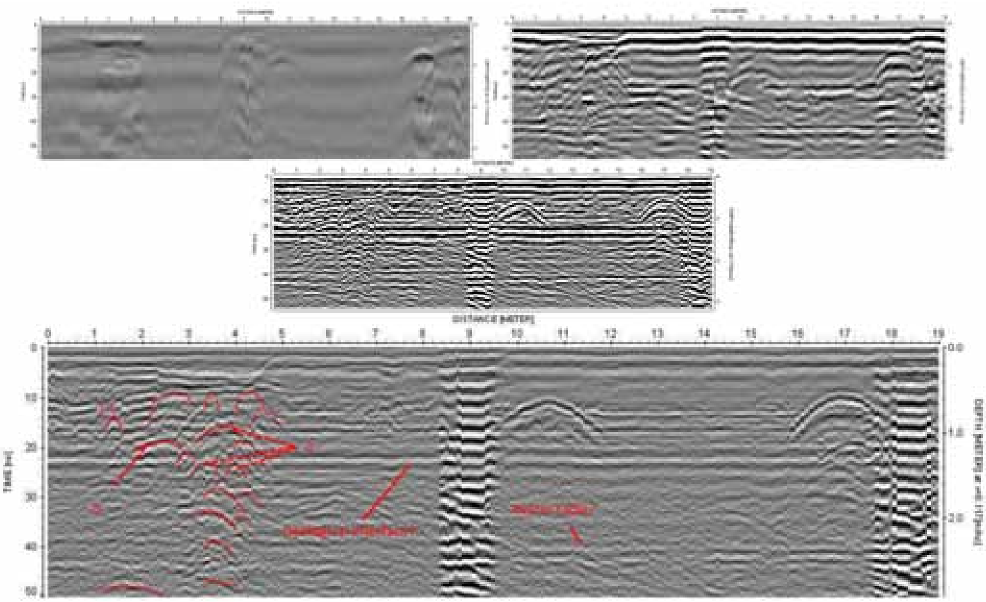

Figure 4: **Component radargrams and composite profile.** The top left radargram is the processed 110MHz component, the top right the 225MHz and the central 450MHz. The bottom radargram is the second frequency composite profile which balanced the whole amplitude spectra. [a] denotes a group of signals thought to be consistent with the depth and location of the larger bricked lined cavity; whilst [b] is conducive of the location and depth of the smaller cavity.

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References

Al-Shayea N, Gilmore P, Woods R (1994) Detection of buried objects by the GPR method. GPR '94 roceedings of the 5th International Conference on GPR, Kitchener, Canada, pp. 1-18. (Cited in Kofman *et al* 2006)

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A COMPARISON OF THE FLASHRES64 IMAGING SYSTEM AND TIGRE ERT SYSTEM.

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Introduction

A novel approach in contrast to the traditional electrical resistivity imaging data acquisition procedure is that of a multi-channel, free-configuration system, not constrained in its data collection by any one conventional array. The FlashRes64 system undertakes a resistivity imaging survey by recording all possible combinations of potential measurements from a set pair of current electrodes which change position at each measurement station. For a line of 64 electrodes, 62 potential measurements are made every second for a selected current (source and sink) combination. This allows for extremely quick data acquisition and a vast increase in the spatial resolution of the survey. The system allows for two survey modes, a ‘Quick Survey’ which can collect 15,151 data points within 9 minutes, and a ‘Normal Survey’ mode which can collects 64,424 data points within 40 minutes of survey. Each survey can be processed as a full ‘tomographic’ dataset or can be extracted into conventional array geometries and combined together. A comparison of the FlashRes64 with a conventional Electrical Imaging System (the Allied Associates Tigre System) will be explored in this paper.

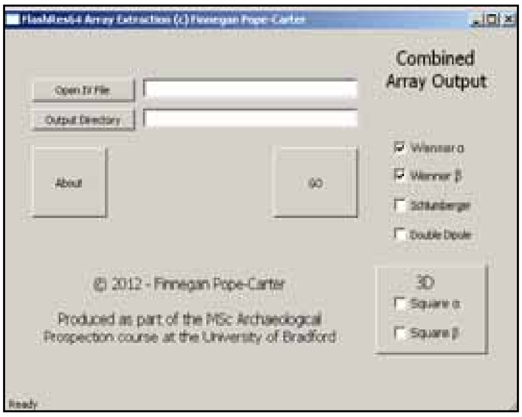

Figure 1.Screenshot of the array extraction program

FlashRes64 Method

The FlashRes64 system is designed to collect data simultaneously in many array types, and collect data at a much faster speed than traditional ERI survey instruments. The system collects as many potential measurements as possible for each combination of current (source and sink) electrodes. The position of the current electrodes automatically switches during data collection allowing for 62 potential measurements to be recorded at each current pair position every second. Further details of this method can be seen in (Fry *et al.* 2011).

Using this data collection technique, as many potential measurements are made as possible, providing a rich and detailed high-resolution resistivity point cloud beneath the ground surface. From this, an almost tomographic dataset can be analyzed and inverted through both the system's in-house inversion program, or through commercially available software such as Res2DInv.

An extraction software program developed at the University of Bradford (Pope-Carter 2012) is also able to extract conventional array datasets consisting of (pseudo-)Wenner, Wennerβ, Wenner-Shlumberger and Double-Dipole 2D datasets, which can be combined together as one mixed array. For full 3D surveys further Square α and β arrays are extracted alongside 2D arrays along all axis. This software outputs data straight into the format used by Res2D/3DInv and BERT inversion software (Fig. 1).

Examples of previous surveys which the FlashRes64 accurately imaged both a 2D section over a ditch, as well as semi fully-3D dataset over a segmented ditch enclosure at Stonehenge can be seen in previous work (Fry *et al.* 2011). Here, a comparison of both full 3D and semi fully-3D data collected from the FlashRes64 and semi fully-3D data collected from the Allied Associates Tigre ERT system will be made over a former stable block at Temple Newsam (Leeds, UK).

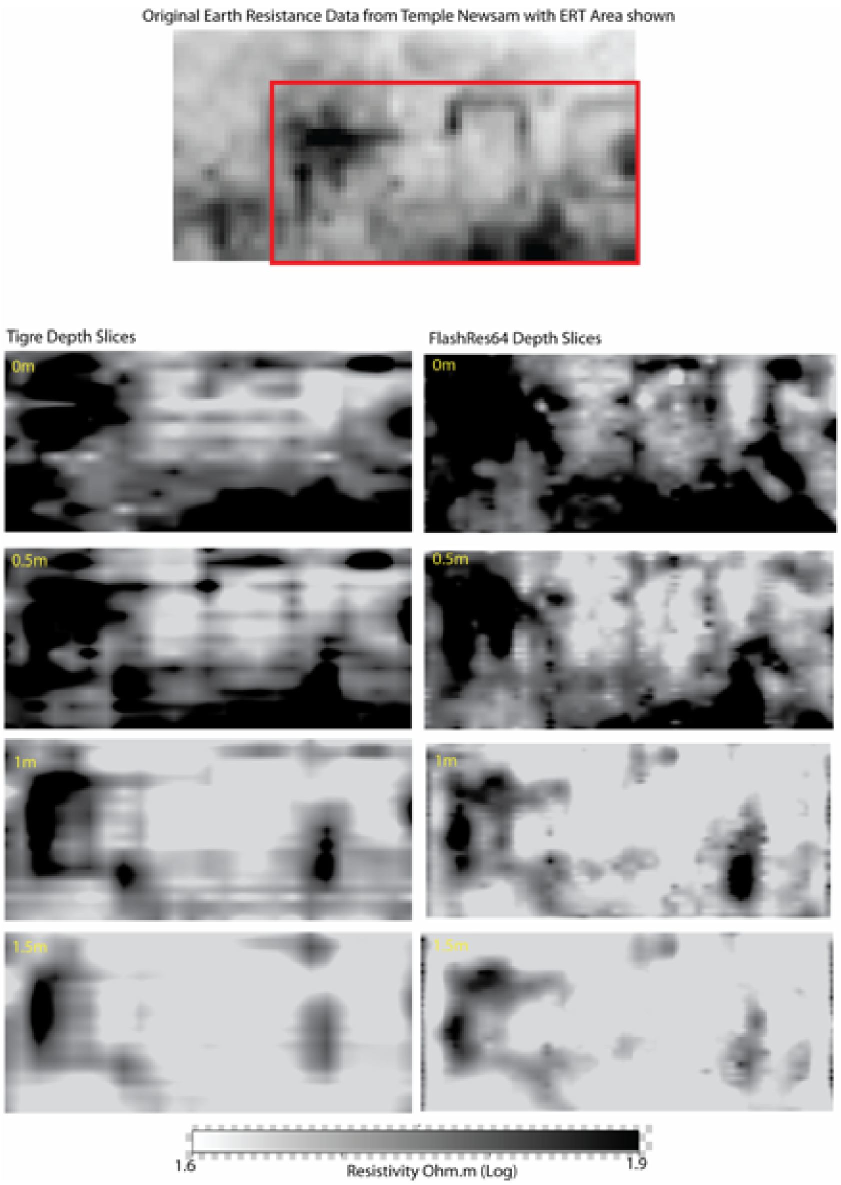

Figure 2. Comparative depth slices from semi fully-3D surveys using the Allied Associates Tigre ERI system and the FlashRes64. (Top) the semi-fully 3D survey area imposed on the earth resistance dataset; (Below, left) the Tigre ERI depth slices; (Below, right) the FlashRes64 ERI system depth slices

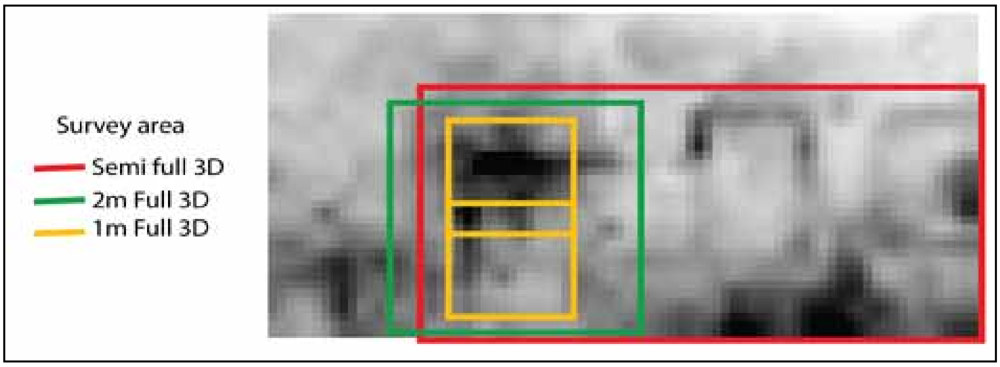

Figure 3. Comparative plot of all the electrical imaging surveys undertaken imposed on the original earth resistance grayscale

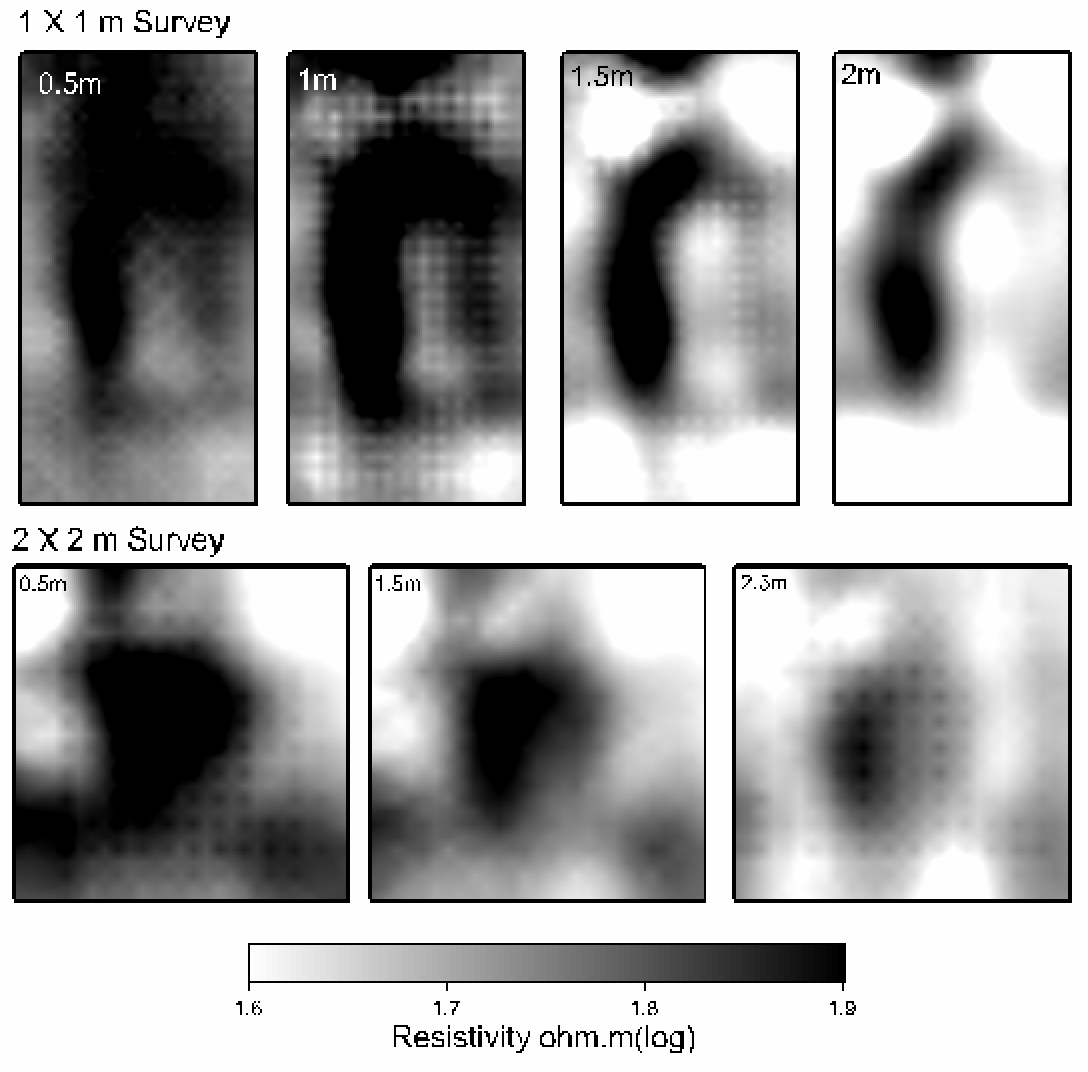

Figure 4. Data collected from a full-3D survey over the rectangular building at both 1m gridded probe separation, and at 2m gridded probe separation.

Comparison of ERI systems over structures – Temple Newsam, Leeds

A test was conducted over the area of a suspected stable block at Temple Newsam (Leeds UK). FlashRes64 and Allied Associates Tigre ERI surveys were undertaken simultaneously over an area previously surveyed with a Geoscan twin probe array (Fig. 2). The semi-fully 3D surveys were conducted with a probe separation of 0.5m and a traverse interval of 1m. In total, 16 Tigre and FlashRes64 traverses were collected.

As can be seen in Fig. 2 the two methods of survey have both detected the main features under investigation. The data from the Tigre seems slightly clearer and more defined; however the features identified are comparable. The biggest advantage of the FlashRes64 is the ability to undertake such a survey in very little time. As can be seen in Table 1, the whole survey took just 5 hours with the FlashRes64 and over 2 days with a conventional ERI instrument.

A smaller area was chosen for further investigation with a full-3D field setup. This involved placing electrodes in a grid position over the rectangular building seen at greater depths in Fig. 2. Three surveys were conducted, two with a grid (7m x 7m) set up at 1m probe separation and the third grid at 2m (grid size of 14m x 14m) probe separation. The 1m separation surveys were combined prior to inversion to create a rectangular survey area (Fig. 3).

From the data collected from the Full 3D surveys (Fig. 4), it is clear in this instance that the 1m separation survey is more capable of defining the discrete feature under investigation than the 2m separation survey; however the high resistivity feature is visible in both. This is due to the increased spatial resolution of the smaller probe spacing at shallow depths. The full-3D surveys do not exhibit the striping artifacts that are present in both semi fully-3D surveys and the feature under investigation is considerably clearer and more defined in the 1m full-3D survey than in the semi full-3D surveys.

Currently 3D data collection requires data to be collected using the full survey mode, meaning that the 3D dataset can be collected in 40 minutes. It is hoped that further development of the extraction software including the ability to extract sensitivity and noise optimized datasets will result in a even faster data acquisition time.

Conclusion

The FlashRes64 system provides rapid data for examining changes in the electrical resistance of the earth with depth, and is the first to demonstrate the potential of a free-electrode-configuration system for archaeological prospecting. One of the biggest advantages of the system over current methods is the speed at which the system can collect data, enabling a full 2D section to be recorded in 9 minutes at its quickest configuration. The data from the comparative survey shows that the FlashRes64 is also able to accurately image archaeological deposits to standard as good as conventional systems with this added advantage of survey time. Development of full-3D survey with the system is possible and has shown to have added advantages in terms of feature definition.

The table below shows the results for the comparison tests taken over Temple Newsam.

Survey	Instrument	Total data points collected	Array selected	Time (per survey traverse : for entire survey)	Available survey solutions
Semi-fully 3D survey	Tigre ERT	418	Wenner	47 minutes : 2.5 days	2D survey Quasi-2D survey Semi-3D survey
Semi-fully 3D survey	FlashRes64	15,151 (short survey mode)	Free configuration 'tomographic' array Wenner*, Wennerβ*, Double-Dipole*, Wenner Schluberger*,	9 minutes : 5 hours	2D survey Quasi-3D survey Semi-3D survey
Fully 3D survey	FlashRes64	64,424 (long survey mode)	Free configuration 'tomographic array' Square α*+, Square β*+, Square γ*	40 minutes	Full 3D survey

*pseudo arrays with extraction program +3D surveys only

Table 1. Comparison summary of the two systems

References

Fry, R, Gaffney, C, Sparrow, T & Batt, C (2011) FlashRes64 Electrical Resistivity Imaging for Archaeological Applications. 9th International Conference on Archaeological Prospection. Izmir, Turkey:

Pope-Carter, F (2012) Electrical Resistivity Tomography: A comparison of inversion techniques MSc Thesis. Division of Archaeological, Geographical and Environmental Sciences. Bradford: The University of Bradford

THEY MAY ALL BE DEAD BUT THEY STILL AIN'T EQUAL…

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Geophysics has surpassed the stage of merely locating archaeological features. The information from detailed GPR surveys can sometimes be sufficient to draw important archaeological conclusions beyond the spatial layout of sites. The classical city of Pessinus in Anatolia was a temple state held in high regards by the Romans for its link with the mother-goddess Cybele. The city was therefore embellished by Roman Emperors with a temple for the Imperial Cult, a theatre, and a processional street ending in a monumental arch. In previous investigations of this site most attention was focussed on the monumental buildings, located in a dry river valley cut into the Neogene/Pliocene high-plateau pediment. However, a 'shadow settlement' exists on these plateaus overlooking the city's valleys, formed by several extended necropoleis that were built from at least the Roman to the middle Byzantine period. These cemeteries became notorious for widespread looting that involved the destruction of some finely carved underground marble grave monuments. As a result archaeological investigations mainly focussed on the recording of already 'excavated' graves and their sad state to day (Fig. 1). Any further directed excavations would have drawn even more attention to these burial monuments which are spread out far on the wide plateaus so that their protection is virtually impossible. Even the reporting of surface surveys and geophysical investigations (including this abstract) from these areas has to be limited to avoid any clues for further illicit activities.

Figure 1: A looted burial monument.

To enable at least some archaeological research a high-resolution GPR survey was started in 2011 on one of the necropoleis, near to some extensively looted monuments. The selected area measured 60 m × 40 m and appeared entirely featureless on the surface, apart from a pipeline trench. A surface investigation revealed scatters of fine Roman pottery (Samian ware) as well as thick and coarse ceramics, probably from roof tiles. As the plateau is heavily eroded by very severe spring rains and the survey area lies on a slight slope the actual location of these surface finds was not deemed to be directly correlated to subsurface structures. The annual erosion processes will have reshaped the plateau considerably since classical times, which is demonstrated by the large stones and limestone blocks that are deposited on the steep slopes that lead from it into the dry valleys. The location of burials along the plateau's current edges, the visibility of the city of Pessinus and the overall spatial layout of the necropolis are important archaeological issues that need to be resolved to better understand the relationship between the city and its cemeteries. It would be of particular interest to link these spatial considerations with the status of the buried people.

The GPR survey was undertaken with one Mala 500 MHz antenna on a sledge, recording traverses with a separation of 0.25 m and a trace separation of 0.04 m. The data were processed with bandpass filtering so that clear timeslices could be generated. In the area chosen for this pilot test the data show three distinct types of burials.

- Type A: an elaborate grave monument built of stone blocks (probably marble) with a structural layout that changes considerably with depth, in the shape of a miniature house (Fig. 2).
- Type B: a sarcophagus-like rectangular block that extends over a limited depth range, where it shows as a distinct isolated feature (Fig. 3).
- Type C: a cut into the limestone geology, which manifests itself as a persistent low-reflection GPR anomaly that does not vary, while the extent of the geological features around it shift with depth. There is no direct evidence for a burial in the cut (Fig. 4).

This new classification, purely derived from GPR data, has already created considerable archaeological interest and will be compared to historic archaeological excavation records from earlier campaigns to test its wider applicability. So far there is no evidence for a consistent correlation between the location of the burials and their type. However, they appear to be mainly aligned with the contour lines of the current surface topography. If that were a consistent trait it would suggest that ease of construction and maintenance were more important than the orientation relative to Pessinus, or alignment with cardinal directions. It will be essential to cover a larger area of this necropolis in subsequent field seasons to test this and several other emerging archaeological hypotheses, based on the geophysical results. The investigation also raises the difficult question as to how best to report archaeological and geophysical findings from sites highly vulnerable to looting. Should accurate location records even be withheld from official reports if these might be made available under Open Data guidelines or just as 'innocent' online conference proceedings (e.g. Kazı Sonuçları Toplantıları)? These questions are probably far more difficult than the interpretation of high-resolution data and require much wider discussion.

		
Figure 2: Type A - burial house	Figure 3: Type B - sarcophagus	Figure 4: Type C - cut

DETAILED PROSPECTING WITHIN THE STONEHENGE LANDSCAPE

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Initial analysis from the 2010 – 12 field seasons of the Stonehenge Hidden Landscape Project (SHLP) suggest that our knowledge of this key archaeological landscape is being revolutionized by the integration of remote sensing and geophysical prospection with context aware visualization. It is an aim of the SHLP to provide a context which combines the existing landscape with prospection and other archaeological data in a seamless fashion. The data rich environment that has been produced clearly relates to the primary objective of the project which is to produce an uninterrupted dataset of above and below ground remains for archaeological analysis and reinterpretation within the context of the wider Stonehenge landscape.

By creating this interpretative context the SHLP partners will develop the research to enhance the available remote-sensed database and integrate the data in a novel manner that informs archaeological research and heritage management for regional and national curators. The project complements and informs the current English Heritage "Stonehenge WHS Landscape" project allowing the results of other major projects such as the Stonehenge Riverside Project to be understood within the wider landscape context.

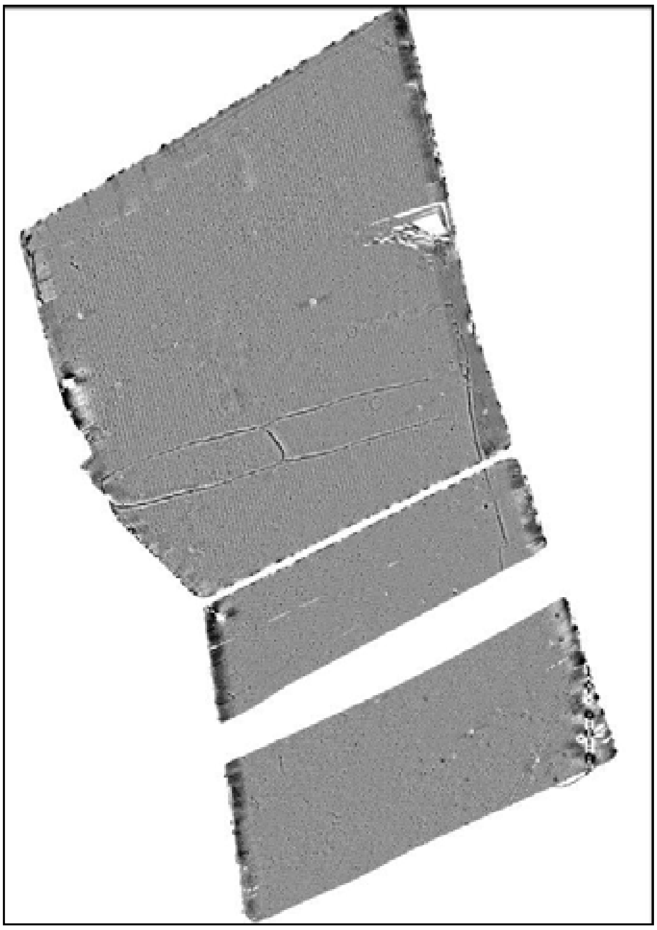

Figure 1.
Part of the most recent magnetometer responses from the area of the Lesser Cursus.

The presentation will briefly describe some of the recent technical developments and the key interpretative aspects that relate to recent data collecting. Some detailed discussion will be spent on the area around the so-called Lesser Cursus as this neatly encapsulates the verification and enhancement of the existing knowledge base via large scale data-rich strategies. Geologically the survey area lies above Late Cretaceous Chalk (Calcium Carbonate) dating from approximately 85 million years ago. The top layer has been degraded by periglacial weathering during last glaciation which produced underlying fracture patterns which have remained practically undisturbed since about 14,000-12,000 years ago and are typical of frozen ground near the fringes of ice sheets. The land has been used for agricultural purposes in historical times but is adjacent to a military training area of the early 20th Century. The area of the Lesser Cursus has recently reverted to pasture from post-war ploughing and the recent survey is the first chance to study the monument since that change.

Invasive and non-invasive investigations during the 1980s (Richards 1990) and early 1990s (David and Payne 1997; RCHME 1979, p.19–20) demonstrated that the Lesser Cursus is of two phase construction: the phase 1 monument comprised a narrower western enclosure – half the present size with an internal bank and possible north eastern corner entrance; subsequently, the perimeter ditch was enlarged and extended in phase 2, doubling the monument to its present open-ended size of approximately 400m length and 60m width. An external bank was added to the now centrally-located cross ditch (and former eastern extent). Geophysics also identified an oval ring ditch, already noted in aerial photography, and a number of possible circular features within the eastern half of the monument as well as several possible pit-like features (David and Payne, 1997. pp.87–89, Fig 8).

High-resolution magnetometer survey (sampled at 0.125m x 0.25m spacing) was chosen to confirm the extent and definition of the monument as recorded previously by air photography and geophysics (see above) and identify targets, possibly new, for the application of complementary geophysical techniques, such as ground penetrating radar (GPR), electrical resistivity profiling and electromagnetic imaging.

Important findings include:

- Previous archaeological interventions made in the 1980s (Richards 1990) are also apparent in the new survey.
- Cursus ‘openings’ in the northern and southern ditch identified in the 0.25m x 1m resolution magnetometer survey carried out in 1990s ((David and Payne, 1997. pp.87–89) are confirmed in the higher resolution dataset.
- A narrowing and gap evident internally at the northern junction of the central cross ditch (as noted and discussed by Richards (1990; pp81) is apparent in the ditch response. This may indicate a break in the phase 2 ditch revealing the narrower, back-filled phase 1 ditch – possibly a third entrance in the perimeter?
- The ring ditch in the eastern half of the Lesser Cursus is revealed to comprise at least 9 segments forming a 15m diameter ring which when previously recorded was thought whole (see David and Payne, 1997. pp.87–89 and Fig 8). One south west segment cuts, or is cut by, the weaker response of much a smaller circular feature, the latter forming a small cluster of possibly two to three (weak) penannular features. Two further penannular features are located externally to the north ditch.

- Numerous pit-like responses are noted throughout the survey area. Caution is noted though in interpreting these anomalies, as a similarly large pit-like anomaly, identified within the western end of the Lesser Cursus in the 1983 geophysical survey, was excavated close to the northern ditch but found to be a natural periglacial hollow of irregular plan (Bartlett in Richards 1990 and Richards 1990, p. 78-80). Other pit-like responses from across the Stonehenge area have been similarly excavated to reveal pits of natural origin (Bartlett, A. in Richards 1990; Gater, J. in Richards 1990).

The archaeological discussion of the new data from the Lesser Cursus clearly highlights the validity of previous surveys as well as providing improved definition to a range of features: in particular the segmentation of the ring ditch contained within the monument's east end. As such this first look at the new data demonstrates the additional interpretive perspective to be gained from re-surveying significant areas within Stonehenge landscape.

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Richards, J. 1990. The Stonehenge Environs Project - Historic Buildings and Monuments Commission for England Archaeological Report No 16. London: English Heritage

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LANDSCAPE GEOPHYSICAL SURVEYS AT BRÚ NA BÓINNE WORLD HERITAGE SITE: SURVEY TECHNIQUES, DATA QUALITY, AND INITIAL ARCHAEOLOGICAL INTERPRETATION

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This paper presents initial results from the first use of the Geophysical Exploration Equipment Platform (GEEP) in Ireland in carrying out a multi-sensor survey in the vicinity of an earthen mound known as Site E situated within the Brú na Bóinne World Heritage Site.

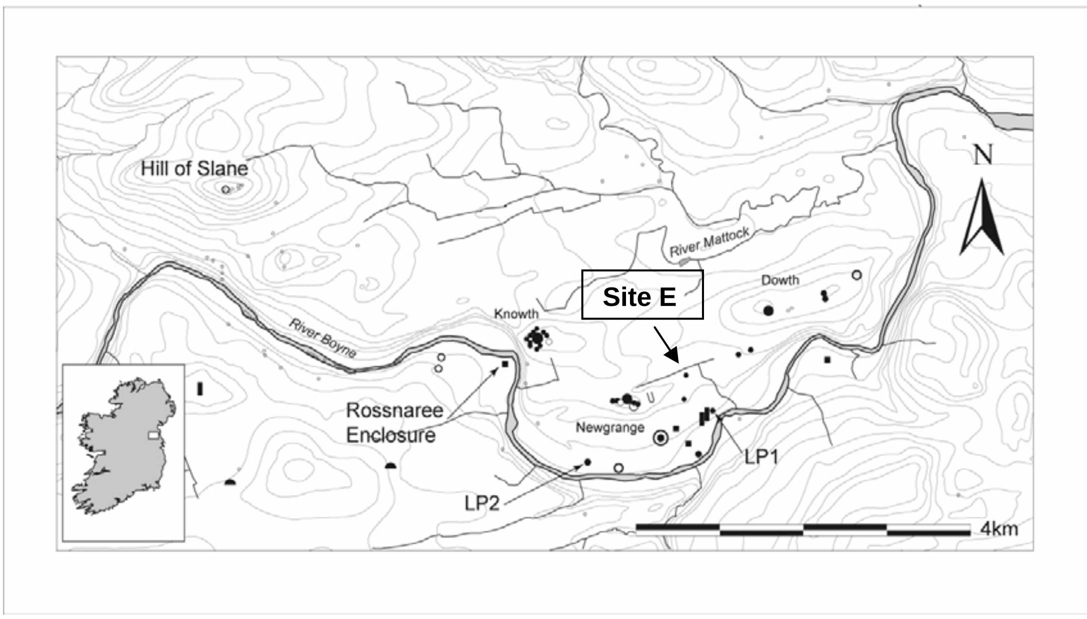

Fig 1: Location map of the Brú na Bóinne World Heritage Site and Site E
(map: Conor Brady)

The Bend of the Boyne, or Brú na Bóinne (Fig 1), has been an important ritual, social and economic centre for thousands of years (Fig 1). Its universal value was recognised in 1993 when it was designated a UNESCO World Heritage Site (WHS), only one of three on the island of Ireland. The international significance of Brú na Bóinne has been gradually revealed through a process of discovery and research which began over 300 years ago.

The GEEP was configured with four Geometrics caesium vapour sensors spaced 1m apart and a central DUALEM multi-frequency electromagnetic array (Fig 2). The basic dataset collected comprises total magnetic field data and simultaneous conductivity soundings at six depths.

Fig 2
GEEP configured with four Geometrics caesium vapour sensors spaced 1m apart and a central DUALEM multi-frequency electromagnetic array. The GPS antenna is located in the centre of the platform and the tow cable can be seen extending to the lower right of the photo. (photo : Kevin Barton).

The GEEP was towed by a small tractor unit with the tow cable also functioning as a data transfer cable which was connected to a signal processing unit on the tractor (Fig 3). After signal processing, for logging and quality control purposes as the survey was in progress, data were transferred via a Wi-Fi link to a centrally located laptop computer. Survey coverage (Fig 4) was monitored both on an onboard computer and on the laptop computer.

Fig 3

GEEP tractor unit with combined tow and data cable linked to the rear-mounted signal processing unit. The Wi-Fi antenna is located behind the tractor operator. (photo: Kevin Barton)

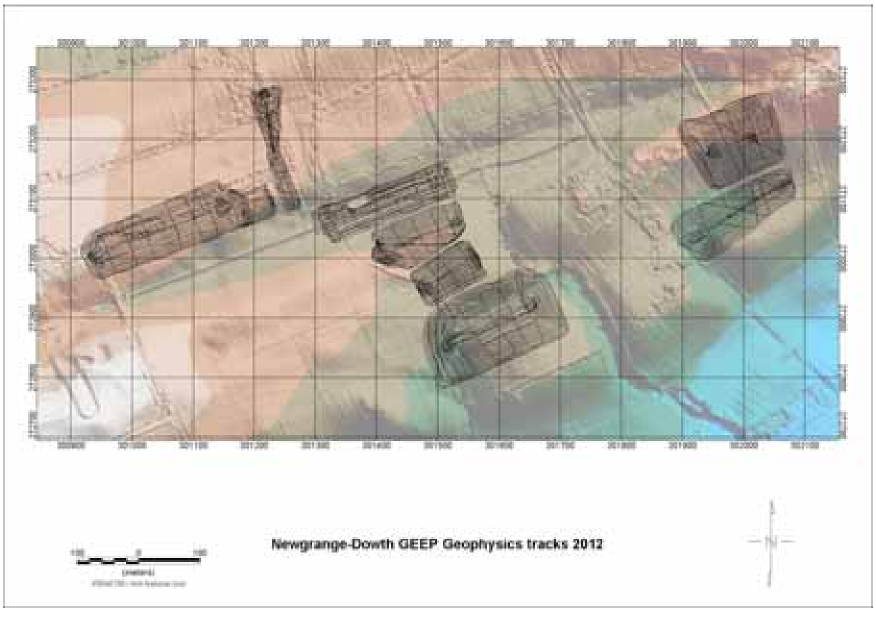

Fig 4:
GEEP survey coverage superimposed on LiDAR data. Site E Is located at 301400E, 273000N.Lidar data courtesy Meath County Council and the Discovery Programme. (image : Ian Hill)

The GEEP results and a comparative study of GEEP collected data with traditional hand-carried magnetic gradiometry, earth resistance and magnetic susceptibility survey will be presented.

MAGNETIC AND ELECTROMAGNETIC MEASUREMENT SYSTEMS FOR LARGE AREA SURVEYS*.*

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As-Is Situation

The demand for a faster non-invasive evaluation of large areas before excavation is constantly growing. Thus *SENSYS* tailored its geomagnetic push cart and vehicle towed survey systems to archaeological requirements, supporting judgment of excavation planning.

For the NSGG Day Meeting on Archaeological Geophysics 2012, SENSYS will give an overview of those systems, backing up the performance with archaeological projects realized with such systems.

The role of SENSYS

Starting in 1990, *SENSYS* became a well known company in the field of high precision survey and measurement equipment for geomagnetic and geo-electric applications. 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 ROV. Beside non-invasive survey equipment, *SENSYS* also produces borehole measurement systems, data analysis software and enables GPS referencing of measurement data. Furthermore, the range of single probes and sensors is steadily growing, enabling the integration of *SENSYS* products into complex systems. This is making *SENSYS* equipment suitable for challenging applications in archaeological and scientific areas.

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

Those strengths and the ambition to protect and explore cultural heritage made *SENSYS* a valuable partner for organizations like the DAI (Deutsches Archäologisches Institut), the RGK (Römisch-Germanische Kommission) and even for independent archaeologists. As an example *SENSYS* equipment and geophysical expertise was used to explore more than 300 ha around Stonehenge, UK. *SENSYS* also supported surveys in the East and South of Europe and has recently participated in a site survey in Northern Spain.

Besides, *SENSYS* customers used the magnetometer systems in Africa and Asia. Having scanned an area of more than 3,500 ha of desert near the coast in Saudi Arabia, this customer allowed *SENSYS* to use the full data set of the survey in order to give an interpretation of social and cultural structure of the past.

Archaeological survey systems from SENSYS

As customer needs are very diverse, *SENSYS* is mainly providing four different systems for their archaeological customers. The systems can be divided into passive and active survey systems.

Passive survey systems

Passive systems record the differences in the Earth's magnetic field. These systems detect magnetic objects with very high precision. It is even possible to detect different layers of soil. As a result, graves, barrows, ring ditches, former settlements etc. can be detected with these systems.

Carried system MAGNETO® DLM

For small areas and uneven ground with bumps, bushes and trees *SENSYS* is providing a light weight probe carrier that can be carried with a belt and can be equipped with three or five magnetometers and a data logger. The magnetometers have a higher sensitivity compared to other *SENSYS* sensors for industrial applications in order to detect smallest signatures in the ground. Recording a whole field, the surveyors can generate a greyscale or colour coded map and detect large structures from ancient infrastructures.

Push cart system MAGNETO® MXPDA

If the terrain allows for a push cart system and an extended width of the sensor array, *SENSYS* is proving a two meter version on a push cart with a full DGPS support, making the setup of outlines, rectangular survey fields etc. obsolete. Customers value the high precision of ± two centimetres for the geo-referencing of the measurement data. Furthermore, a larger area can be covered in less time with this kind of system.

MAGNETO® MXPDA

Vehicle towed system MAGNETO® MX

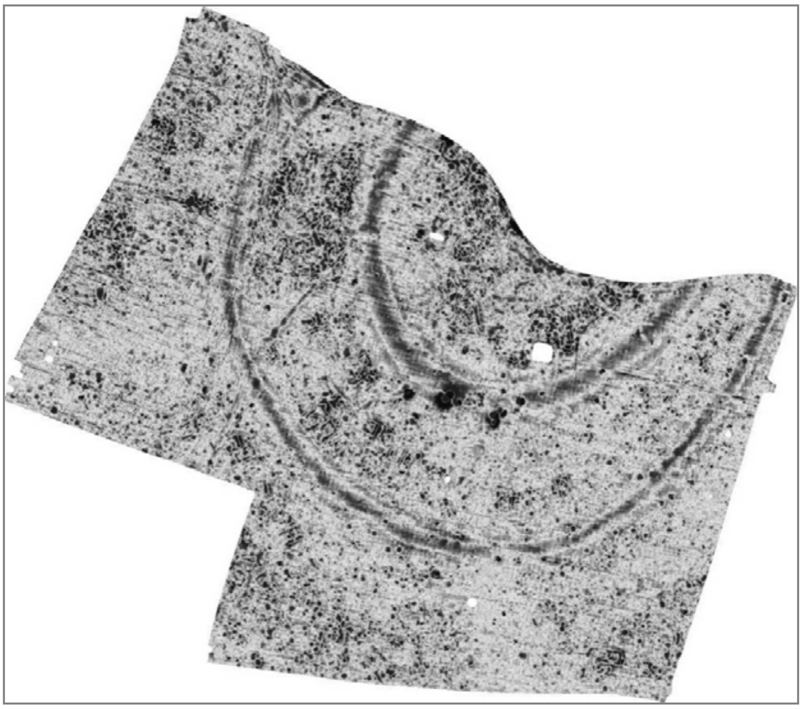
For areas around Stonehenge, UK and Avebury, UK as well as in Vrable, Slovakia, the DAI used the biggest and most precise system you can get on the market in terms of non-invasive large area magnetic ground surveys. The MAGNETO® MX system is towed by car and allows fast scanning of very large areas. Part of the system is a four meter trailer that is equipped with up to 16 magnetometer probes. The probes are placed in a distance of 25 centimetres to each other. This setup allows for an outstanding data base for precise interpretation with the *SENSYS* MAGNETO® software.

MAGNETO® MX

Active survey systems

Active systems introduce a current into the ground to force not only magnetic but also conductive objects to react by generating a secondary field of eddy currents.

With active systems, *SENSYS* addresses more difficult characteristics of the ground consisting of highly mineralized soils or having a high pollution of clay bricks, metal scrap etc.



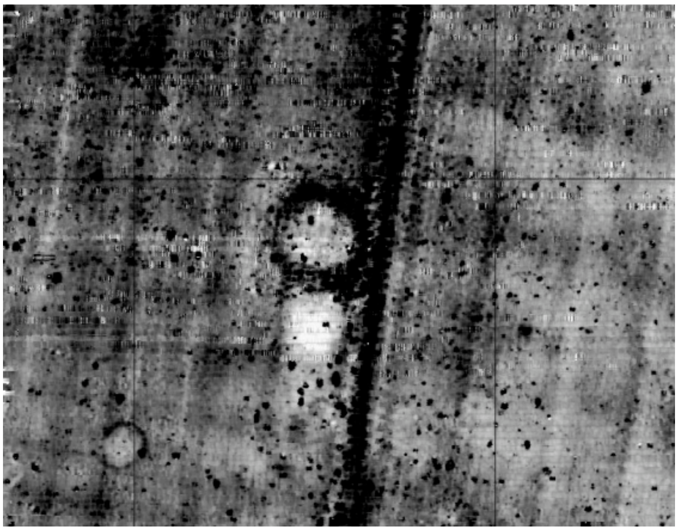
Bronze Age Settlement in Vrable, Slovakia located with MAGNETO® MX

Vehicle towed system AMOS

The active vehicle towed system AMOS was used by *SENSYS* and the DAI for archaeological surveys Stonehenge. The system was used to compare the measurement to the passive system and to close measurement gaps where passive systems couldn't be used. The AMOS system is unique in its resolution of measurement data as it features a big transmitter coil sending out currents into the ground. Two car batteries are used to power up the system. More important, sixteen receiver coils over two levels record the secondary field from conductive objects over certain intervals. By using one big transmitter, but a high number of receiver coils, measurement data is very precise and the interpolation between the coils is very stable. The AMOS system allows to look through disturbing near surface structure and to concentrate on conductive structure.

AMOS

To sum up it can be said that passive as well as active survey systems are valuable tools for the archaeological prospection of areas prior to excavation. The decision on the system to be used depends on various aspects, as each system has its special advantages.



Various barrows near Stonehenge, UK located with AMOS

IS IT TIME FOR A NATIONAL MAPPING PROGRAMME FOR GEOPHYSICAL SURVEY DATA?

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Firstly, it should be stated that the main component of this presentation relates to the UK, and England in particular. However, I believe that many other countries will soon be facing the same dilemma, and so I hope that the topic will prove constructive to delegates from across the globe. At this stage I wish only to state the case for establishing a national mapping programme for geophysical survey data; the mechanisms of how this might be achieved are beyond the scope of a 20 minute presentation, although I welcome any comments on this in the discussion phase.

The proliferation of high speed multi-channel data collection over recent years has led to an ever increasing data mountain, with hundreds of hectares now routinely being collected annually. The potential for collecting thousands of hectares per year is already here, and it is only a matter of time before this is achieved. The question is how do we deal with this impending minefield? What do we do with all this data?

Many of the topics I wish to discuss were raised at the CAA 2012 ISAP Geophysics roundtable, and admirably summed up by Kayt Armstrong and Chris Gaffney in the ISAP newsletter 32. However, we need to grasp the nettle and act quickly, and this will require an unprecedented level of agreement between both research and commercial interests, as well as a political sea change.

I will begin with a (very!) brief history of how other branches of remote sensing have dealt with this issue. I will then move on to a short discussion of how we define the different returns from our various techniques. The final part of my argument will be how (or if) all of the different organizations working within different regional areas could agree on a standard procedure for geophysical survey outputs. Achieving this is vital, as without a standard approach, we cannot even begin to establish a framework for a national mapping programme.

WHAT A DIFFERENCE A YEAR MAKES: THE IMPACT OF ENVIRONMENTAL DYNAMICS ON MULTIPLE SENSOR RESPONSES OVER ARCHAEOLOGICAL FEATURES, AN EXAMPLE FROM CHERRY COPSE, CIRENCESTER.

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Introduction

The DART Project (www.DARTproject.info) has been running for over two years. The fifteen month data collection program is now nearing completion, with monthly geophysical, monthly spectroradiometry, and hourly in-situ Time Domain Reflectometer (TDR) and temperature recordings captured on both clay and free draining sites at Harnhill (Cirencester, UK) and Diddington (Cambridgeshire, UK). The main goal of the DART Project is to further understand the dynamics of archaeological feature detection (in this case a ditch) using these techniques, especially over the more traditionally difficult soils such as clays. It is envisioned that the project will aid the future detection of archaeological features by providing a better insight into optimal detection times and techniques.

Contrast in archaeological prospection is ultimately a product of soil properties, topographic variations, environmental conditions and land management techniques. By embedding monitoring probes, the DART project is examining four specific locations in great detail so that we can identify how changes in environmental readings impact on sensor readings. Such aspects greatly affect the success of archaeological prospection (both geophysical and aerial). Over our study period, the British weather has been less than ordinary. The summer of 2011 was one of the hottest summers on record, and it was followed by an equally record-breaking warm and dry winter, causing drought conditions in January and February. This unprecedented hot and dry spell was then followed by the wettest April to June period ever recorded, making our survey year one of the most unpredictable and extreme years on record. This has meant that the DART project has been in the fortunate position of being able to measure the influence of these extreme weather conditions, and has a dataset indicative of both drought and saturation conditions on both fine grained and freely draining soils.

The basis of this presentation considers how the environmental conditions affected the ground-based (geophysical and TDR) data from one of our free-draining sites. The datasets represent two snapshots in time from a site near Cirencester named Cherry Copse. Data collected between June 2011 and June 2012 indicate how the sensor response has varied throughout the year. The ditch at Cherry Copse is cut directly into freely draining coral limestone bedrock, and contains a loamy-silt ditch fill (Fig. 1).

Fig. 1 The excavation of the ditch at Cherry Copse with vegetation-mark in the background (image available from Flickr: **http://www.flickr.com/photos/49053676@N02/5633654389/sizes/l/** under a Creative Commons licence provided by Robert Fry)

Geophysical Survey

The geophysical location was guided first by a fluxgate gradiometer survey to locate the ditch, from which a 10m x 10m earth resistance survey grid was established (Fig. 2). Measurements were taken at a monthly interval using a multiplexed-twin probe instrument configuration using a Geoscan RM15 data logger, with multiplexer attached to a PA20 frame (more details on the geophysical methodology can be found at http://dartproject.info/WPBlog/?p=861).

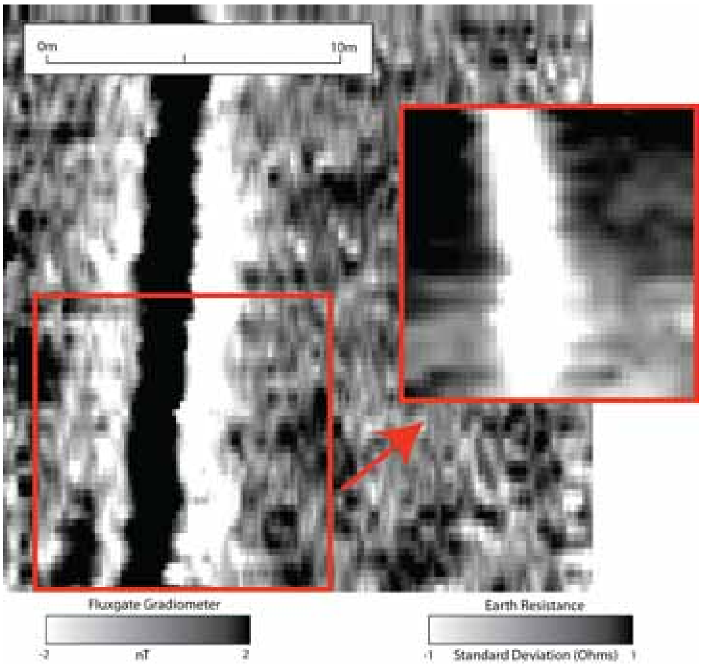

Fig. 2 Fluxgate gradiometer survey over the ditch at Cherry Copse with associated earth resistance survey area outlined in red

The earth resistance data collected with a twin-probe separation of 0.5m have an estimated depth of investigation of between 0.25-0.5m, and prior to analysis, was minimally processed (de-spiked to remove erroneous measurements caused by poor ground contact). A scheme was developed to examine the lateral feature response between different surveys at different times (in this example June 2011 and June 2012). Data transects running approximately perpendicular to the feature (an E-W orientation) were taken across each grid to delineate lateral variation. Twenty transects are available in a 10x10m grid. To determine heterogeneity in feature response these transects were added together and averaged. The results, along with the associated box and whisker diagram for each averaged data point can be seen in Fig.3.

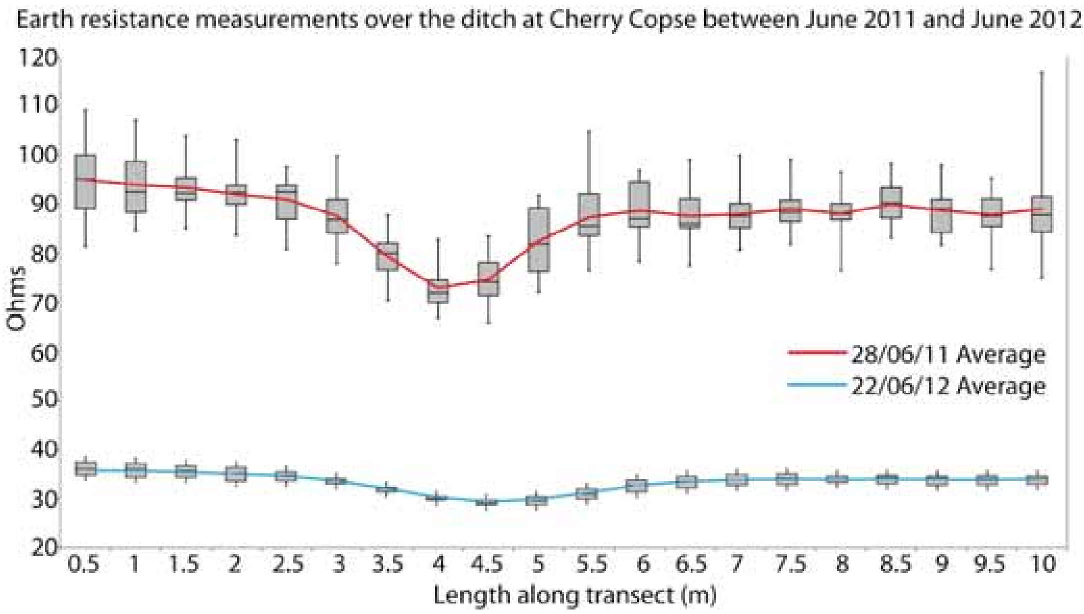

Fig. 3 Graph showing the differing earth resistance response caused by the ditch at Cherry Copse over the same area at different times of the year

The difference in response from the two surveys is rather dramatic, the hot summer of 2011 showing a clearly marked ditch response, although a much higher (noisier) spread of data. Some of this variation can be explained by variations in the feature width and orientation. The background response decreased by around 55-60 ohms (Ω) between the two dates, suggesting that the soil composition (a mix of solid particles, moisture content and gas) altered significantly over the course of the year. The magnitude of the anomaly caused by the ditch also reduced significantly. Although still visible in the dataset, the difference between the ditch and background readings were only around 5Ω in the latter survey, compared to a contrast of around 18Ω in June 2011. Given the extreme weather between April and June, it is likely that the 2012 readings show the soil in a state of near saturation, where both the ditch fill as well as the bedrock surrounding it have become similar in their moisture content as to leave little trace of the anomaly at all (Carr 1982, Cott 1997, Hesse 1966, Scollar et al. 1990). These sources indicate that the moisture content is by far the biggest factor, and will be discussed here. Temperature profiles were also recorded and will be discussed in later publications.

Moisture Content

In situ time domain reflectometer (TDR) sensors are installed both within the ditch fill and around the 'natural' soil surrounding the ditch at Cherry Copse. TDR is a widely used electromagnetic method of monitoring both geophysical parameters of the soil (relative dielectric permittivity (RDP) and conductivity) as well as water content, through a variety of mixing models. A discussion of the operation of TDR can be found on the project blog (http://dartproject.info/WPBlog/?p=1512).

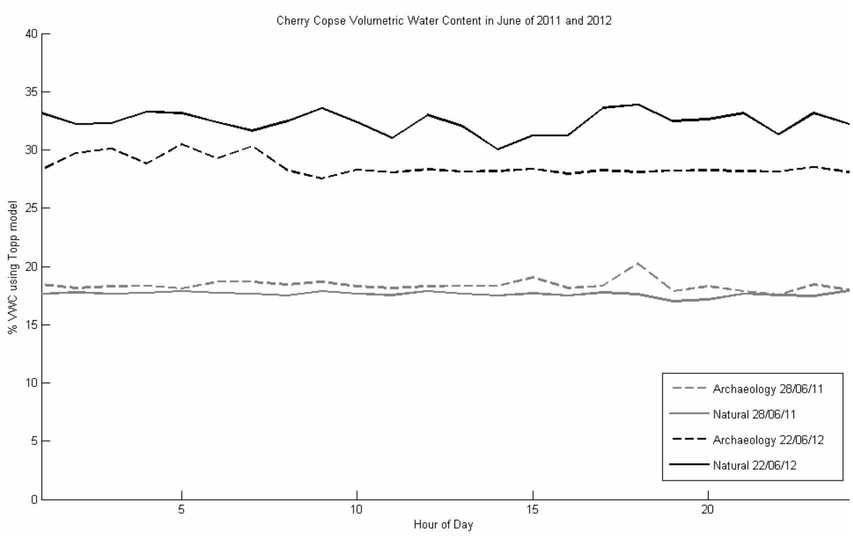

Fig.4 Calculated volumetric moisture content throughout each survey day from two TDR probes placed at depths between 20-30 cm within the ditch-fill and the 'natural' at Cherry Copse

Data are shown from two probes at the monitoring station; the data are contemporaneous to the monthly geophysical surveys, and the RDP has been converted to volumetric water content (VWC, θ) (Fig. 4) using the model suggested by Topp et al. (1980):

$$\theta = 4.3\ X10^{-6} * \varepsilon^{3} - 5.5\ X10^{-4} * \varepsilon^{2} + 2.92\ X10^{-2} * \varepsilon - 5.3\ X10^{-2}$$

(Where θ = VWC and ε = apparent permittivity.)

A depth of 20-30 cm was chosen for analysis, which relates to the shallow nature of the soil outside the archaeological feature (c. 25-30 cm). It is felt that this provided a compromise between a depth representative of the earth resistance measurement volume and contiguous data between the ditch and 'natural' soil. Additional probes from the same depths and contexts showed values consistent with the data presented here (within 1% VWC). As expected, the data for 2012 show a much higher volumetric moisture content, supporting the idea of lower earth resistance. However, the overall contrast in VWC between the ditch and the surrounding soil is greater in 2012 where the ground saturation is highest.

Discussion of the ground-based techniques

At these two dates, there is a correlation between increased moisture content of the soil and the decline in the earth resistance anomaly for the ditch feature at Cherry Copse. However, in June 2012 there appears to be a larger contrast in the moisture content data between the natural and the ditch fill than in 2011. This appears to contradict the earth resistance data, which show greater contrast in 2011 during the dry period (further discussion below). Another unusual feature of the TDR dataset is that in June 2012 the 'natural' topsoil appears to have a larger moisture content than conditions within the ditch, inverting from the original order in 2011.

During times of saturation, the topsoil is more water-retentive than the material making up the ditch-fill. This would usually result in an inversion of the ditch response from a lower resistance anomaly to a higher resistance anomaly; however although the contrast has considerably reduced, the feature remains lower resistance with respect to the background. This can potentially be explained by the volume of soil sampled by resistance measurement. The TDR probes measure a much smaller volume of soil in a known location, and are therefore more specific, whereas the earth resistance method employed relies on a larger volumetric measurement with greater uncertainty in the induced measurement location. This means that each measurement of earth resistance is potentially a combination of many different archaeological contexts, which, away from the ditch, will include not only the topsoil, but also a considerable influence from the shallow bedrock across the site. This can explain why the ditch anomaly, although significantly reduced, remains a lower resistance anomaly overall.

Another factor to consider is that the earth resistance technique is dependent not only on moisture content and temperature, but also the availability of soluble ions to carry charge. Conductivity increases with VWC at low overall water contents but the rate of increase can slow as water content increases before stopping in many soils at c.20-30% VWC (Smith-Rose 1933). An increase in water content, beyond the point where available ions exist, will therefore not necessarily increase the conductivity any further, and it is possible that this saturation level has been reached in June 2012. Further investigations into these values will be based on both laboratory measurements and the multi-temporal sensor readings.

Conclusion

Contrast in heritage remote sensing is ultimately a product of soil properties and environmental conditions. Understanding these phenomena is critical for future airborne and ground based heritage detection strategies: particularly those that use novel sensors. It is clear that moisture content, although a big factor in this changing response may affect different techniques in different ways - and is not the only factor in the detection of archaeological remains.

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DID WE FIND ANYTHING? FEEDBACK AND STATISTICAL ANALYSIS OF GROUND TRUTHED MAGNETOMETER DATA.

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Geophysical assessments are frequently used in commercial developer-led projects as part of a wider programme of archaeological investigation. A common problem shared by many archaeological geophysicists is a lack of adequate and accurate feedback from subsequent phases of an archaeological investigation. Interpretations are based upon the known physical properties of soils and archaeological features, assumptions and experiences from previous investigations. All too frequently, grey literature reports from intrusive investigations remain unpublished or inaccessible, often resulting in anecdotal feedback via the very simple form of 'it worked' or otherwise. When presented with evidence, both positive and negative, geophysicists can make better, more accurate archaeological interpretations in the future through the experiential learning process, but only if suitable ground truthed data is available. In this presentation we examine the statistical analysis of examples from ground truthed magnetometer surveys over linear road corridors in Ireland.

Just over 1,100 hectares of detailed magnetometer survey were used to assess multiple linear corridors across Ireland between 2001-2010. 67% of the survey events were ground-truthed during this period via test trenches and detailed (open / resolution) excavations. A large amount of geophysical interpretation drawings and detailed excavation plans have been made available as digital CAD or GIS data, which were rigorously analysed in a GIS via statistical methods, to generate meaningful statements about the success or otherwise of magnetometer data. Due to the inherent bias of test trenches for the assessment of large and linear features, comparisons have been made only between detailed magnetometer surveys (typically carried out at 1m x 0.25m) and open area excavations, ensuring that small features, such as pits, hearths, post-holes *etc.* were also assessed. Irish legislation requires a 100% soil recovery rate for development-led investigations / threatened sites; therefore the entirety of the archaeological features were excavated (with no sampling), greatly improving the confidence in the statistical analysis. The road schemes try to avoid all known archaeological features, so that the statistical analysis represents a reasonably good sample of the landscape, as opposed to those surveys that occur upon known archaeological features.

Geology has been found to be a significant driver in the success or otherwise of magnetometer surveys. The technique is particularly successful at identifying burnt features and enclosed occupation sites upon favourable geology. However, many ditched enclosure features have been missed due to poor magnetic contrasts on limestone, or obscured by strongly magnetic igneous & metamorphic geology. Some of the geological problems faced by geophysicists working on limestone are demonstrated by the complete absence of a large ditched medieval ringfort enclosure in high resolution magnetometer data (0.5m x 0.1m), despite the same data clearly identifying the subtle remains of a Neolithic structure just 20m away.

Geology	True Positive	False Positive	True Negative	False Negative
Shales & Calp Limestone	30%	70%	83%	0.3%
Limestone	7%	93%	92%	1%
Igneous Intrusions	5%	95%	91%	2%

Table 1. Some geological types encountered across entire road schemes, rather than specific archaeological sites.

Statistical analyses of entire route corridors suggest that shales and calp have been particularly good for magnetometer surveys, whilst limestone is quite poor. Limestone overlain by peat is very poor as a result of having a reduced or impeded magnetic response due to waterlogging. Magnetometer data collected on near surface igneous rock is severely affected by strong geological anomalies, whilst igneous covered by a suitable thickness of drift deposits can allow for very good magnetometer data, capable of identifying very clear and coherent archaeological features.

Small earth-cut features such as post-pits, post-holes and inhumations, could not be identified using a standard methodology (1m x 0.25m), even upon the most favourable geologies.

Very low instances of True Positive responses (claims that 'there are archaeological features here' verified by excavation) demonstrate not only problems with Boulder clay / tills, which are present for 58% of the sites examined, but also a tendency to over-interpret geophysical data from narrow linear corridors that limit the 'wider appreciation' of anomalies within their local geological / landscape context. Irish fields are only 3-5 hectares in size on average, when traversed by linear corridors only very small areas of these are examined, therefore a constantly changeable background impacted by cultivation furrows, current vegetation etc, is apparent, often making it difficult to judge and interpret the importance of individual anomalies.

Whilst archaeologists may place emphasis on the importance of True/False Positive responses, a significant outcome for the research has been the consistently high percentage of True Negative occurrences (claims that 'there are no archaeological features here' verified by excavation data). True Negative responses are important because they give a confidence level to the curator / end-user for a particular survey / geology / location type; demonstrating a level to which the results can be relied upon for an entire road scheme. This is commercially very important as the timetable for a major infrastructure project can be adversely affected by the discovery of previously unknown archaeological features.

The academic analysis of ground-truthed geophysical data will have a great impact beyond Ireland, as it defines the capabilities and limitations of magnetometer surveys in terms of geology, landscape and site type that can be applied elsewhere. The assessment of non-magnetic archaeological features or sites on unfavourable geologies, require alternative - and in some cases, more labour intensive – techniques to suitably appreciate the underlying archaeology. In light of this information, Irish curators are beginning to respond to this by considering how and where magnetometer surveys should be used in the future and where other, more appropriate techniques, might be beneficial.

3-D GPR INVESTIGATION OF A RESIDENTIAL AREA IN THE ROMAN TOWN AMMAIA (PORTUGAL).

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Ammaia is situated about 10 km west of the border between Portugal and Spain, south of the village of São Salvador da Aramenha (district of Portalegre). Except for a few farms, the site has remained virtually undisturbed by modern construction. Since 1994, excavations undertaken by the Fundacão Cidade de Ammaia and the universities of Évora and Coimbra, have focused mainly on areas marked by extant structures, such as the *forum* and the southern gate. Since April 2009, the Radio-Past project (www.radiopast.eu) combines different geophysical and other prospection techniques to map the entire area of the Roman town and its surroundings.

Since most of the site is covered with sandy silt colluvium, conditions were expected to be favourable for ground-penetrating radar (GPR). The first GPR survey was carried out in May 2008 over part of the *forum* and the adjacent baths (Verdonck *et al.*, 2008). In the next years, a fluxgate gradiometer survey investigated the biggest part of the intramural area, and in smaller areas earth resistance surveys were conducted (Corsi *et al.*, in press; Verhegge *et al.*, 2010). In 2010 and 2011, a mainly residential area was investigated west and southwest of the *forum* with GPR. The GPR surveys were conducted with a network comprising several single 500 MHz antennas. In 2010, an area of ~7600 m² was prospected with three antennas and a transect spacing of 0.25 m. Part of this area was investigated using a transect spacing of 0.05 m (Figure 1). For the July 2011 campaign southwest of the *forum*, an array of six antennas was employed; there the transect spacing was 0.05 m.

Processing included dewow, time zero alignment, gain and band-pass filtering (100 MHz-1 GHz). Spikes, caused by overhead power lines, were replaced by the mean of the two adjacent traces. Ringing from near-surface metal objects was removed by a band-reject filter (Verdonck *et al.,* 2012). Two- and three-dimensional phase-shift migration was used for imaging the data with 0.25 m and 0.05 cross-line spacing, respectively. The migration velocity was estimated by applying a 2-D *f-k* migration algorithm to single GPR profiles, using a range of constant velocities. For the 3-D data sets, migration-focusing tests were based both on profiles and time-slices. For the correction of the topography, several methods were applied: plane fitting (Streich and van der Kruk, 2006), topographic migration (Lehmann and Green, 2000) and 3-D topographic correction after migration (Leckebusch, 2007).

In contrast with the *forum,* with well-preserved, thick wall structures and organized according to a plan, similar to other towns in the Roman world, the interpretation of the residential areas was more complicated, for reasons which have been observed in other prospections of urban domestic areas (e.g., Benech, 2007). For example, there is a strong variation in the width and the state of preservation of the walls, and it can be difficult to distinguish walls, thresholds and drains. As a consequence, the delimitation of the different houses in an *insula* is often problematic, especially because of different building phases and alterations.

A peristyle house with a hypothetical extent of ~800 m² is located in *insula* XV. A large room, centrally located in the western wing of the house, probably is the *triclinium* (the most important reception and dining room; Figure 1, 1). The threshold of a wide door, opening to the peristyle is visible in the GPR data as an elongated, strong reflection with sharp edges (Figure 1, 2). In *insula* X, an alteration joined several units, which in an earlier phase seem to have been Independent. One of the original dwellings is characterized by a nearly symmetric house plan. In a later phase, a peristyle was constructed over this house (Figure 1, 3). Below a large room interpreted as the *triclinium* of the house after the alteration, there are vestiges of another house from the earlier phase. As for the smaller houses, several examples of a simple pattern, characterized by a courtyard ringed by a single layer of rooms, were detected within the 2010 and 2011 GPR survey areas. In other cases, it was more difficult to discern a regular house plan.

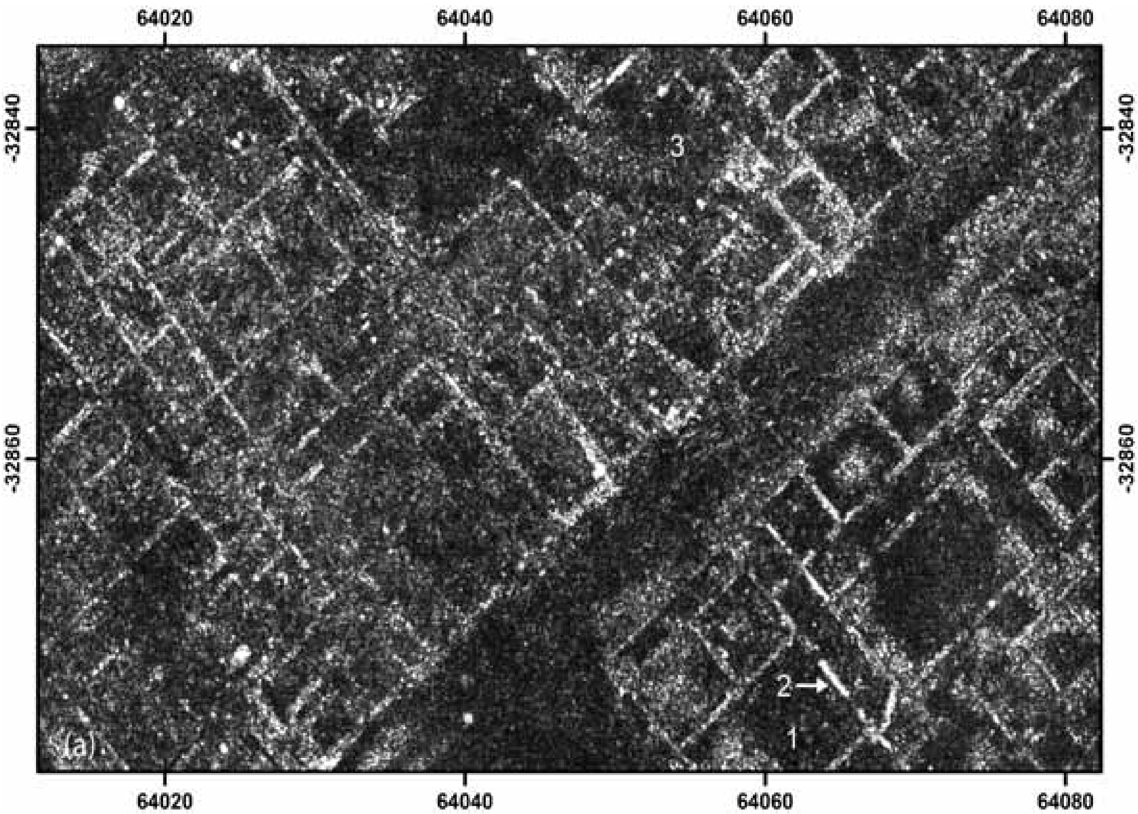

Figure 1: Part of the ~7600 m² area prospected with three antennas and a transect spacing of 0.25m which was investigated using a transect spacing of 0.05 m.

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MIRRORS AND VILLAS – HOW GEOPHYSICS IS REVEALING THE GAPING HOLES IN OUR KNOWLEDGE OF LATE IRON AGE AND ROMAN SETTLEMENT IN DORSET, UK.

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The area of modern Dorset corresponds roughly to the core of a Late Iron Age cultural group named the Durotriges. They are considered to be an enigmatic and loosely confederated group that retained their cultural identity of distinctive burial practices and uninscribed coinage well into the Roman period, disappearing as a distinct cultural grouping around AD120 (Papworth 2008). The process of Romanisation of the countryside appears to have progress in this area at a much reduced rate when compared with further east, and it was only in the very late 3rd century AD, some 250 years after the conquest, that high status buildings that can be classed as Romanised farmsteads and the more luxurious villas appear in the Dorset landscape.

Even then, the numbers appeared to be low in comparison with other areas to the north and east, with only 13 villa sites known from the hinterland of Roman Dorchester (Dunovaria) (Putnam 2007: 95-96). This flowering of high Romanisation was extremely short-lived as most of these sites went into decline by the 350s AD. Recent work that is heavily focused on geophysical survey approaches is now giving access to much greater understanding of the period and in particular the density and continuity of occupation throughout the entire period and beyond into both pre and post-Roman periods.

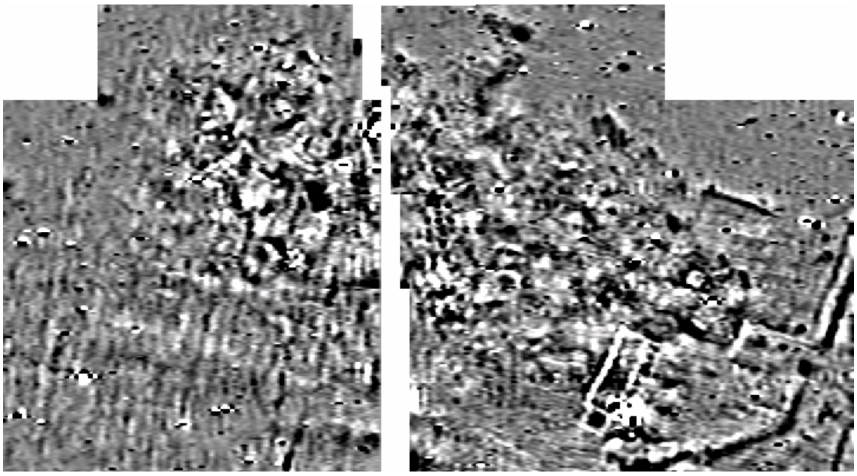

Figure 1. Fluxgate gradiometry results from a multi-period intensively occupied settlement undiscovered by other methods adjacent to the site of a 'mirror' burial. Note towards the bottom right of the plot the clear negative response of the walls of a Roman building, one wing of a range detailed further by earth resistivity. Interpolated 0.125x1.0m reading intervals. Grid size20x20m. Survey area 160x100m. Black positive & white negative. Clipped at -5 to +5 nT

One site that demonstrates this continuity is adjacent to where a spectacular Late Iron Age 'mirror' burial was recently discovered. Little was known as to the context of these 'mirror' burials, but recent geophysical work has shown that these are to be found adjacent to large long-settled sites which have developed from Iron Age beginnings through to highly Romanised villa settlements (Figure 1). Identifying and investigating such sites is key to understanding the process of cultural change and the recent work undertaken here has shown that we actually know little of the number and complexity of such sites. Working closely with amateur archaeological and metal detecting groups, large numbers of new sites are being identified and investigated very effectively through the use of geophysical survey. What is being revealed is what must be some of the most intensively occupied landscapes in Britain with, in some areas, field after field after field covered in significant archaeological sites of the Iron Age and Roman periods.

So whilst aerial photography and surface collection have in the past suggested such densities of occupation it is only through geophysics that we can get anything like a full picture of what these intensively occupied landscapes were like. The site shown in Figure 2 had failed to show on any aerial photography and was only discovered by the report of a few Roman artefacts found by metal detectorists. Recent surface inspection of the site after ploughing failed to reveal any concentrations of pottery or other surface materials that would suggest a site of any significance. In fact the field not only contains a major multi-period site that extends north and south of the area of the existing survey, but the whole of the area surveyed is covered in traces of field systems.

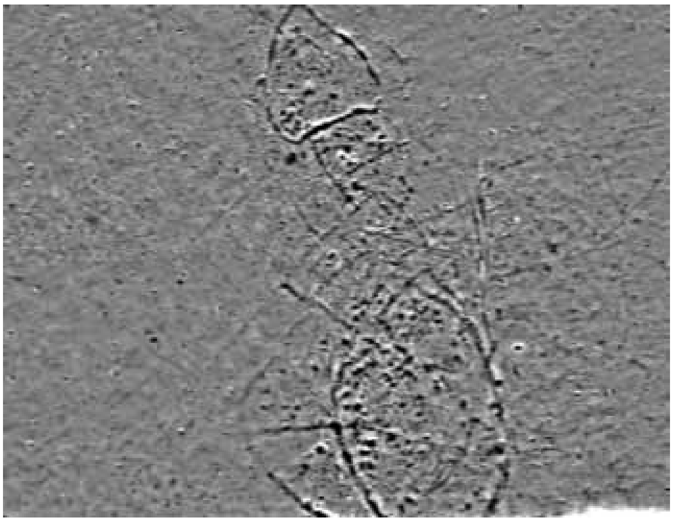

Figure 2.
Fluxgate gradiometry results showing pits and ditches of a multi-period site unknown prior to geophysical survey. Excavation confirmed a late Iron Age/Roman-British date range for the site. Interpolated 0.125x1.0m reading intervals. Survey area 260x200m. Black positive & white negative. Clipped at -5 to +5 nT

The conclusion is that in this area, and probably more universally, without large scale geophysical survey, then the archaeological analysis of past landscapes is extremely problematic as other techniques cannot provide such uniform recovery (Cheetham 2008). Currently all the survey in this project has been undertaken manually, but is hoped that in future years the newly available high resolution mechanised gradiometry systems will become more widely applied as large scale geophysical surveys are imperative in providing the uniform recovery required for the robust analysis, and so understanding of, archaeological landscapes.

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GPR IN-DEPTH - A CHRONOLOGICAL INTERPRETATION OF HIGH RESOLUTION GPR DATA FROM VISEGRAD, SIBRIK, HUNGARY.

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This paper presents three dimensional interpretations of archaeological features detected by high resolution GPR and their comparison to excavation data. Although the precision of data acquisition in geophysical prospection is highly developed, there is a continuous need for the improvement of the archaeological and chronological interpretation of the data. An optional solution is to combine archaeological stratigraphy with GPR data at different spatial resolutions which results in the stratigraphic interpretation of the data and enhances its potential use in chronological interpretation.

The methodological approach is to test the potential of geophysical data in the assessment of the temporality by identifying the main stratification of the features, and to combine depth information with horizontal data and the measured depths with the stratigraphy recorded at the excavations. The aim of the comparison is to determine the relative chronological ordering of the features from GPR data using the stratigraphical position which can be then presented in three dimensional space.

Technically data analysis is performed with the help of GIS. As a first attempt, features identified layer by layer in the GPR data, are digitized and stored in a geodatabase. Base heights and descriptive information are also given to each feature in order to recreate their spatial arrangement.

The methodology is tested at a case study site from Visegrád, Hungary. Here a Late Roman fortification was partly unearthed and its eleventh-century reuse was also recorded. Besides the fortification, which was presumably by the time of the Hungarian state formation transformed to a royal administration centre, other remains of the same period were also unearthed on the hill: a two-phased church with is cemetery a settlement with a parish church and its cemetery and ruins of a monastery illustrates the importance of the site. In order to present the archaeological interpretation of the site, the stratigraphic sequences and the artefacts were previously analyzed. As a result of the archaeological analysis of the features the architectural and functional interpretation of the site is now available. The excavation documentation, stored at the archives of Hungarian National Museum King Matthias Museum, was recorded manually in the 1970's and then transformed and imported into a GIS database. Accurate topographical measurements were also taken during the excavations; therefore, a complex site plan presenting all the relevant materials creates the basis for further research. Based on the field measurements and cadastral and topographical maps, an elevation model of the site is also available which creates the framework for the 3D re-modeling of the excavation data.

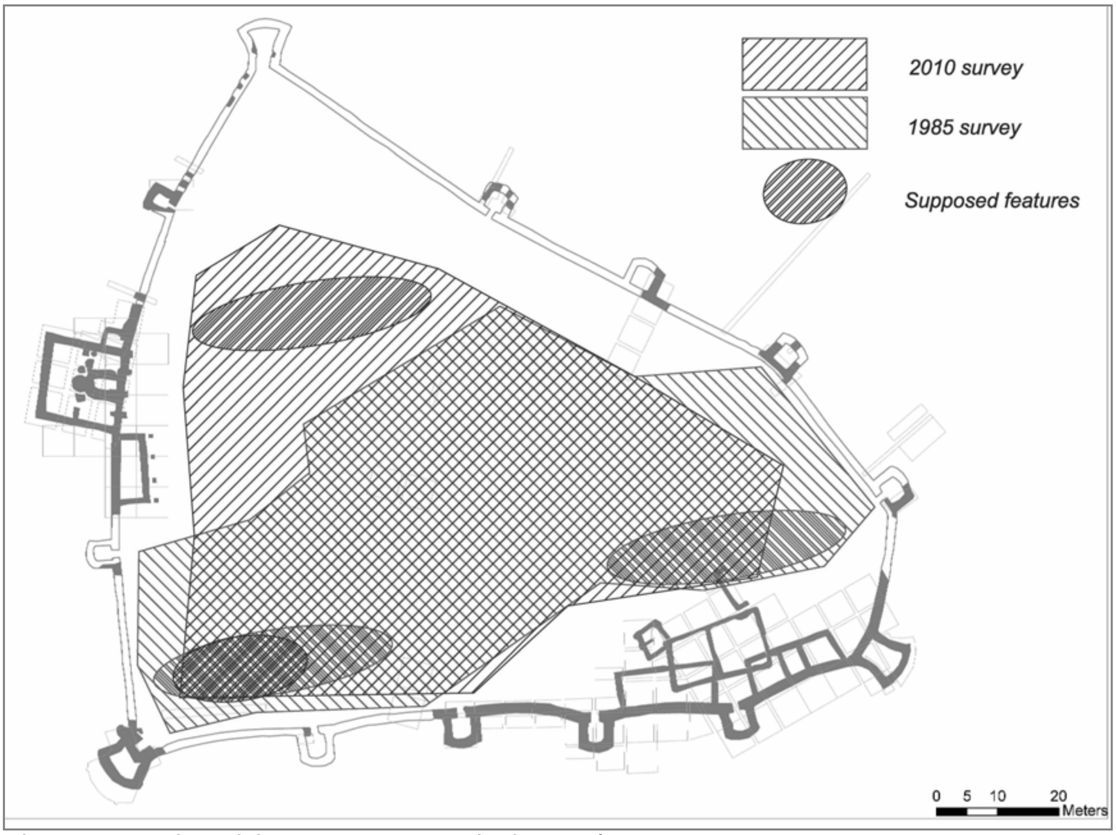

Figure 1 Location of the measurements in the castle area

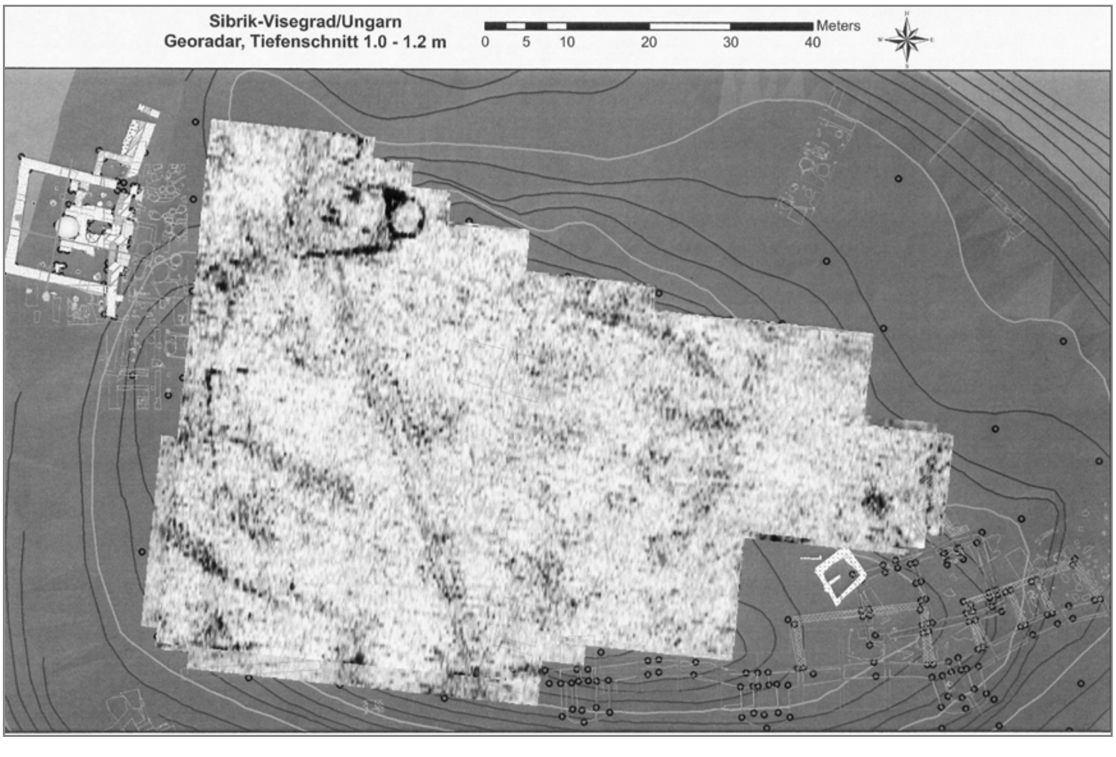

Figure 2 Results of the measurements from 2010

Geomagnetic measurement was first conducted at the site in 1985. The aim of this survey was to identify stone buildings inside the castle area. In 1985 the western part of the inner area was intentionally not researched. In

2010 however a new survey was carried out in the framework of a co-operation between Falko Daim (Römisch-Germanisches Zentralmuseum, Mainz) and István Feld (University of Eötvös Loránd, Budapest). The measurements were carried out by the Archeo Prospections® team directed by Sirri Seren (Zentralanstalt für Meteorologie und Geodynamik, Vienna). At this time the inner part of the castle area was measured again with magnetometry as well as with georadar. As a result of the measurements the GPR showed a previously unknown, church-like building near the square shaped tower in the western part of the castle area, while the geomagnetic measurements also indicated the buildings in the south eastern corner. The appearance of the church-like building suggests a new interpretation also for the other ecclesiastical units of the area. As no archaeological excavation has yet been done on the newly found building, its chronological determination can only be based on its parallels in form and function. As the inner stratigraphy of the excavated features is available from other parts of the site, it seems possible to decide which chronological layer is associated with the building, based on the depth information of the GPR data.

The research is a part of my PhD research at the Initiative College for Archaeological Prospection at the University of Vienna.

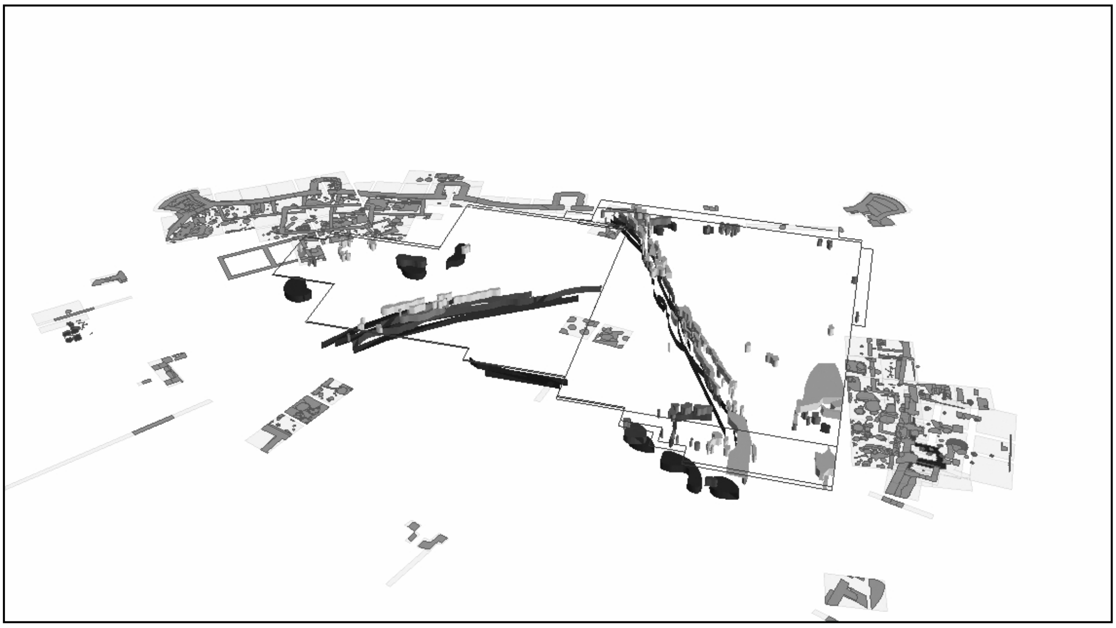

Figure 3 Interpretation in 3D

BELOW 1 NT: INTEREST OF WEAK MAGNETIC ANOMALIES FOR THE STUDY OF ANCIENT GARDENS.

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The site of Pasargades is located in the province of Fars (south of Iran) on an alluvial plain at an altitude of 1900 m. This city was founded by Cyrus II the Great, in the middle of the 6th century B.C. and became the first capital of the new Achaemenid Empire. Pasargades declined after the foundation of Persepolis but it remained a dynastic place where all the Achaemenid kings were crowned. The visible remains extend on a surface of 300 ha approximately. Only the main monuments have been excavated and studied. Then we know practically nothing about the spatial organization and administrative, economic and social functioning of this capital.

The royal park of Pasargades is one of the most significant remains of the site. They are considered as the prototype of the "Persian Garden" which has been widely used in Iran and India, particularly during the Islamic period, and until the modern period. Only the central part of this park has been excavated, offering a limited vision of their organization. The magnetic surveys carried out between 1999 and 2008 by the French and Iranian mission (directed by R. Boucharlat, CNRS) revealed a more ambitious project and an impressive control of the water supply to create what the Greeks named a *paradeisos*.

Figure 1: Aerial view of Pasargades with location of main monuments.

The whole survey has been carried out with a caesium gradiometer G 858 (Geometrics). Beside the results which allowed the retrieval of the main characteristics of the organization of the gardens, the magnetic map shows also very weak anomalies. These anomalies are partly covered by the magnetic signal of modern ploughing and partly mixed with the electric noise of the gradiometer. The location and the orientation of these anomalies undoubtedly prove their belonging to the ancient gardens.

Considering their shape and amplitude, the origin of these anomalies doesn't look to be from built remains but rather from "environmental arrangements" for the organization of the gardens. The linear anomalies probably indicate ditches, or small channels, for the irrigation of the vegetation of the garden: the few channels still visible couldn't indeed provide water for the whole surface of the park. Some of them, a little bit larger, seem to correspond to the paths which allow perambulation through the different parts of the park. We observe also some alignments of more punctual anomalies: they could be the result of trees plantations. The presence of trees is noted by ancient authors: for instance Strabo mentions the existence of groves, or clumps, around the tomb of Cyrus the Great. The magnetic map shows also larger positive or negative anomalies on larger portions of field: their shape and organization seem to show they correspond to different divisions of the gardens with different kind of vegetation which influenced the magnetic properties.

The identification of the nature of all these anomalies is most of the time doubtful. Pasargades is the only case of garden we have from this period; therefore it is not possible to make archaeological comparisons with other archaeological sites. In later periods, the model of the "Persian Paradise" spread throughout the Near East and even the Mediterranean world but the environmental conditions are most of the time different and any comparison about the kind of vegetation was used in these gardens must be made carefully.

Figure 2:

Ike view of the water channels in the central garden. ©B.-N. Chagny, Mission Pasargades 2003.

The interest of the magnetic survey has been already proved and this interest is not denied even in the case of 2500 years old gardens. The ability of the method to detect such subtle evidence is highly valuable for the study of ancient gardens and is certainly a great method of research which could highly complement traditional botanical and geomorphological studies.

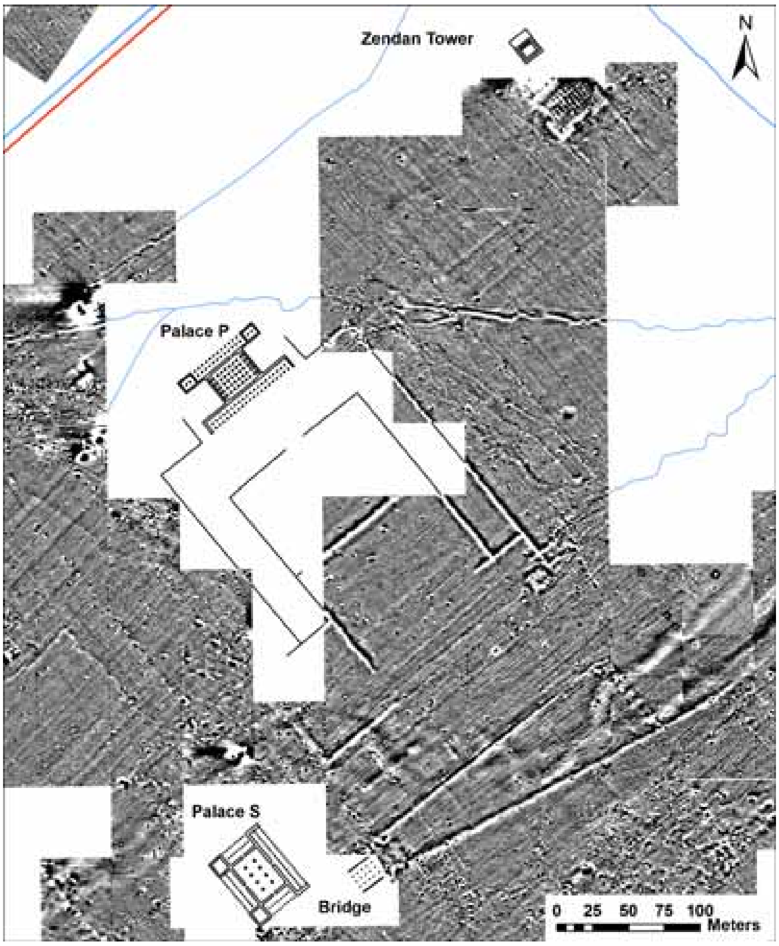

Figure 3: Detail of the magnetic map on the central part of the gardens (Scale -1/+1 nT/m, min white/max black).

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POSTER ABSTRACTS

MAGNETIC CHARACTERIZATION OF CERAMIC KILNS: EXAMPLES FROM THE NORTH AND THE SOUTH SIDES OF THE MEDITERRANEAN SEA.

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The magnetic signature of kilns is influenced by their geometry which differs with each civilization. We thus model several kinds of such kiln using magnetic field and magnetic property measurements in order to differentiate them.

Introduction

The kiln is a typical archaeological feature which can be found in all civilizations after the discovery of controlled fire. Here we resume typical magnetic signatures of the ceramic production kilns from two civilizations: the Gallo-Roman civilization from the northern side of the Mediterranean sea and the Punic civilization from the southern side of the Mediterranean sea. To constrain our model we correlate the magnetic measurements with other geophysical methods and laboratory measurements.

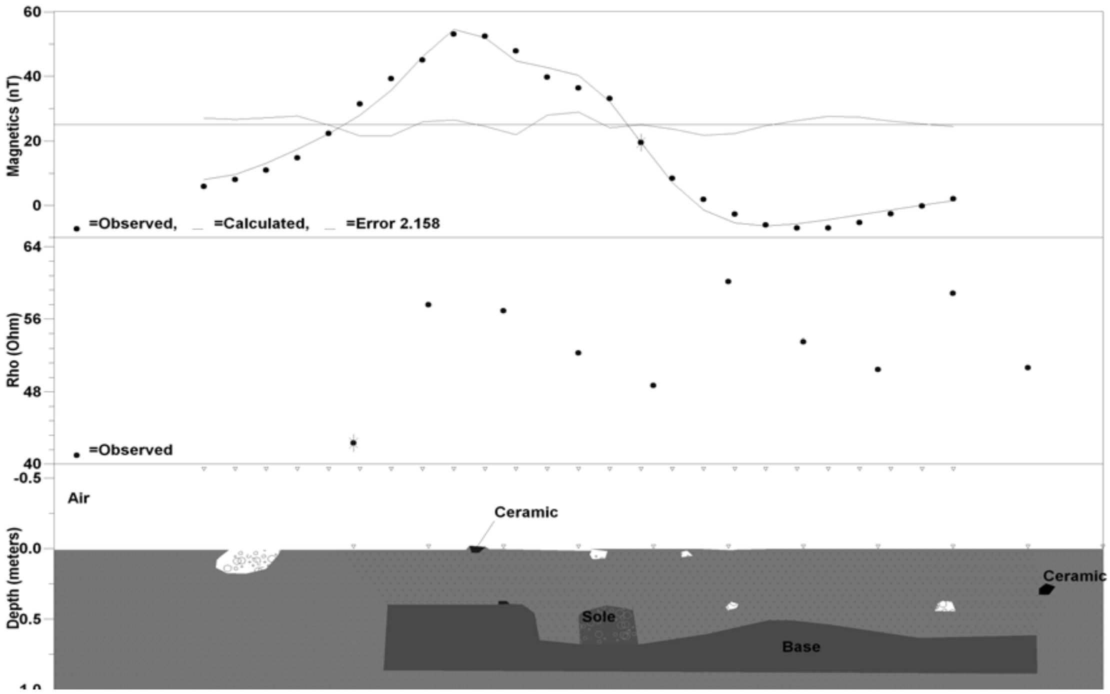

Figure 1: Model of the Gallo-Roman Kiln of Cordouls

A Gallo-Roman kiln in the South of France

We have conducted a magnetic field prospection (caesium vapour magnetometer) on the archaeological site of Cordouls (Puylaurens, Tarn). An isolated magnetic field anomaly of about 50 nT in amplitude with SW-NE orientation was found (Figure 1). The excavation revealed a Gallo-Roman kiln with the same orientation. We first used a simple modelling approach (with Geosoft Oasis montaj) to predict the magnetic field signal using constraints from electrical resistivity measurements performed at the same place (before excavation), as well as from magnetic property measurements of ceramic samples found above this kiln.

A Punic kiln from Carthage in Tunisia

We also modelled the magnetic signature of a known Punic kiln located in Carthage (Tunisia).

Punic kiln plan　　　　Punic kiln photo

Figure 2 : Punic Kiln of Carthage

The resulting model can be used to predict the typical signature of such large kilns, and can then help find other similar buried kilns by magnetic field prospection in the Punic port of Carthage (Figure 3). Indeed, the most important Punic ceramic production site is still unknown.

Figure 3 : Prospected area (grey) in the Punic Port of Carthage

Acknowledgments
We gratefully acknowledge the archaeologists responsible for the two sites; in France, Mr Philippe Boissinnot, and in Tunisia: Mr Samir Aounallah and Mr Moez Achour.

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ARCHAEOLOGICAL BY-PRODUCTS OF UNEXPLODED ORDNANCE

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Introduction

The MoD estate is currently in a significant period of change, with numerous sites being assessed for redevelopment or disposal. Activities historically occurring on these sites may result in a diverse range of issues and responsibilities, such as unexploded ordnance, kilns, crashed aircraft, buried ditches, disposal sites, old fuel tanks and former structures. Early identification of these liabilities increases knowledge of the site, helping effective risk mitigation and preventing delays, and it is here that Land Quality, Explosive Ordnance and Historical Environment specialists within the MoD have been collaborating.

Figure 1: Towed magnetometer array at RAF Lyneham, surveying as part of the transition program.

Within the Explosive Ordnance community, there have been significant developments in towed magnetometer arrays (Figure 1) with the aim of identifying the precise location of subsurface bombs. The resulting magnetic datasets are also in common use within archaeological and land quality assessments; therefore through the acquisition of a single dataset, three different subject areas can be addressed. Occasionally, even if the intended aim of the survey was not archaeological, the results can yield finds of archaeological interest, and examples of intend and unintended archaeological geophysical surveys are presented here.

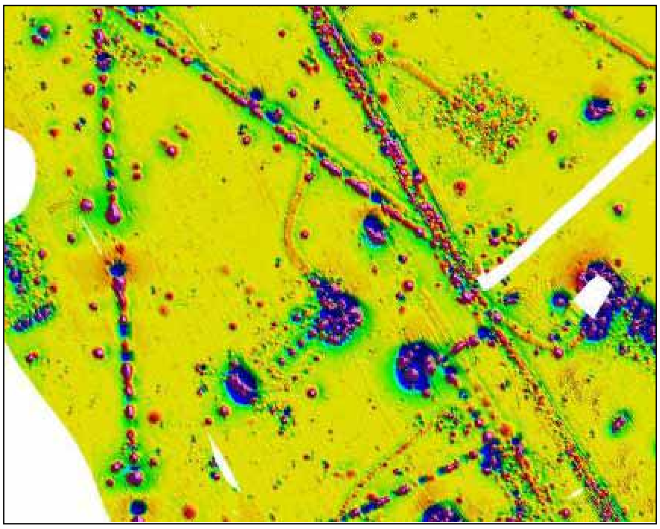

Figure 2: Magnetic results showing former structures and areas of concern on a former MoD site.

Celts on the Cricket Pitch at RNAS Yeovilton

At RNAS Yeovilton the proposed development on the north side of the site required survey due to legacy land quality and unexploded ordnance issues. Archaeological advisors within the MoD were also interested in this area of the site due to the discovery of Roman buildings during recent construction works.

The surveys showed a number of unexpected features including a former athletics track and former structures, but the real surprise came on the cricket pitch where a settlement from the Iron Age (800 BC – AD 43) was identified. Similar Prehistoric settlements have been identified nearby on aerial photographs taken of private agricultural land adjacent to the cricket pitch; but how far these remains extended onto MOD land was previously unclear.

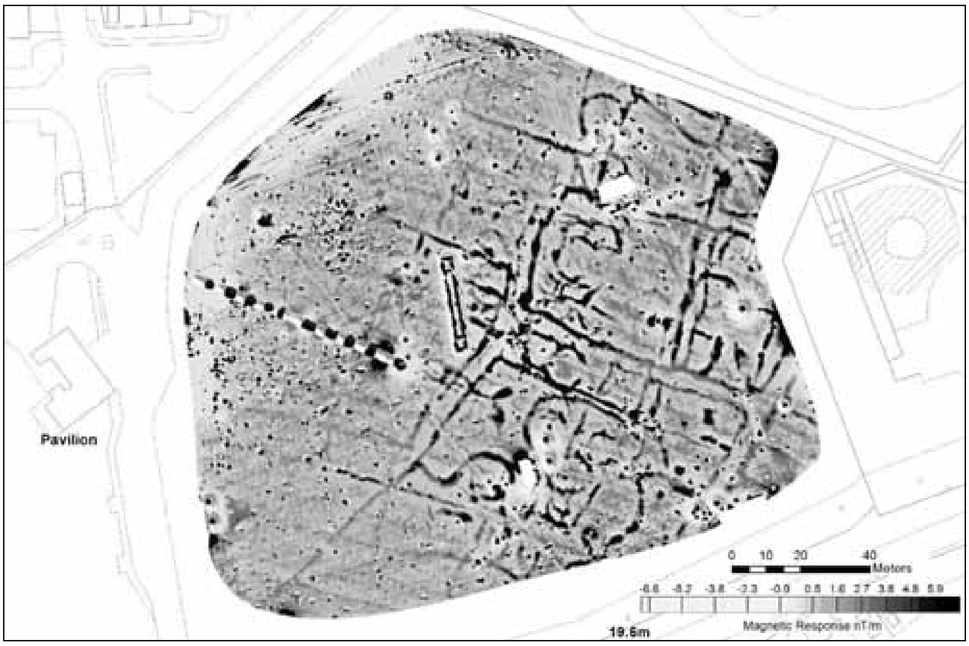

Figure 3: Archaeological results from the cricket pitch at RNAS Yeovilton, showing an Iron Age settlement with the cricket crease in the centre.

The results of the survey included anomalies showing a network of tracks, enclosures, small fields and circular features that are the remains of timber houses typical of this period. Some of the remains also seem to overlie one another, suggesting that the settlement had developed over time. One settlement shift seems to have been from droveways and paddocks to larger, square fields suggesting a change over time from shepherding to more mixed agriculture. The apparent longevity of the site also suggests that this site probably developed into the nearby Roman site, whose inhabitants were the descendants of the earlier famers on the cricket pitch site. This area was ruled out for development for a variety of reasons, meaning that cricket continues and the archaeology remains undisturbed.

Near Surface Assessment of RAF Lyneham

RAF Lyneham is currently undergoing transition from an RAF station to a Defence Technical Training establishment. As part of this process an assessment of the land quality, explosive ordnance risk and archaeological potential was required and a total of 300 hectares (Figure 4) was surveyed. Survey equipment included a 4m wide magnetometer array, using Foerster gradiometer probes at a 0.5m spacing under RTK GPS control.

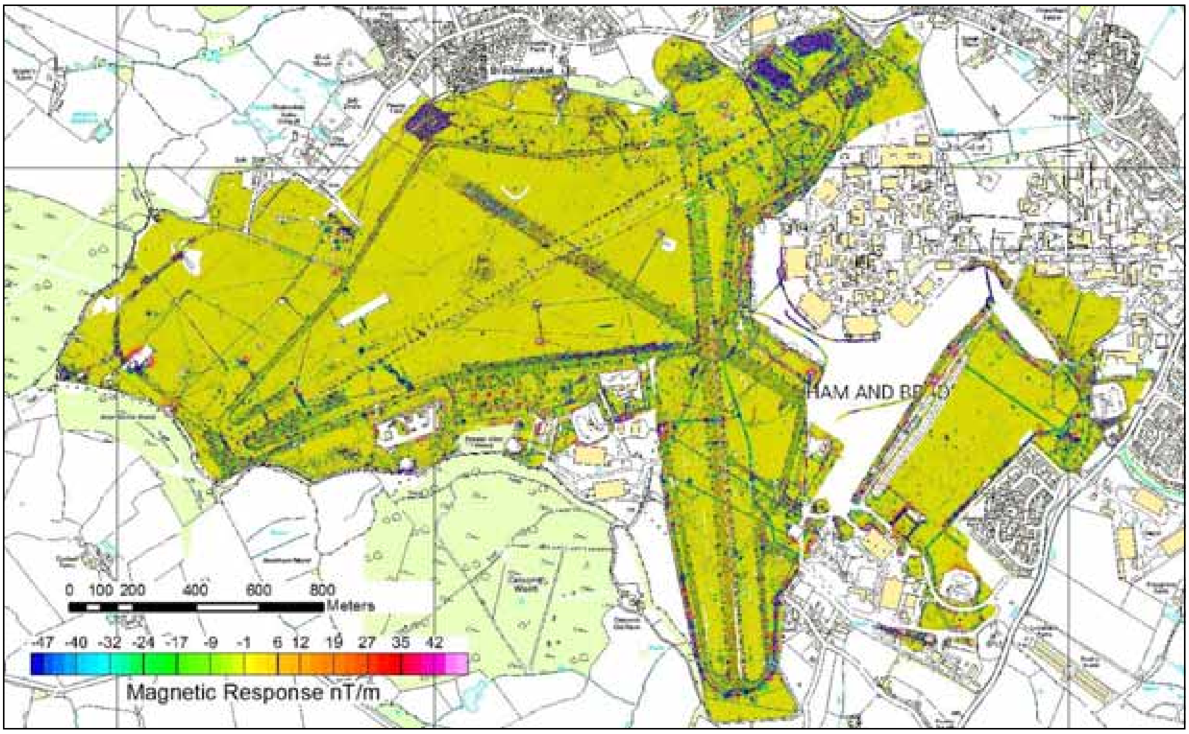

Figure 4: Magnetometer results from RAF Lyneham, acquired using a towed magnetometer array using 0.5m spaced forester gradiometer probes under RTK GPS control.

The survey results were dominated by structures associated with the RAF base, with ‘quieter’ areas within the survey data giving insights into the landscape prior to military ownership. Within the north-west of the site a number of unknown features were identified suggesting post holes or a pit grouping. As they appear in a rectangular arrangement they are thought to represent structural remains. However, the majority of the features of archaeological interest appear to be agricultural land boundaries. While these remains enhance understanding of the landscape in this part of Wiltshire, they are not regarded as particularly significant. No remains were identified relating to the village and medieval priory at Bradenstoke, on the site's northern perimeter.

Figure 5: Features of archaeological interest overlaid by aircraft parking pans. Thought to represent possible structural remains.

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EARLY MEDIEVAL CASTLE WAHRENHOLZ – LOWER SAXONY, GERMANY

A distinct geophysical image of a construction of wood and earth[1]

C. Schweitzer[2] and C. Frey[3]

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Situation / History

The castle at Wahrenholz, located in Lower Saxony, Germany, is an excellent example of an early medieval earthwork. Luckily there are not only archaeological findings but also written sources that give insight into its construction. Being commissioned by a cleric, Bishop Bernward of Hildesheim, Wahrenholz castle is also an example of inland colonialisation and territorial lordship administrated by the church.

Bernward became Bishop of the diocese Hildesheim in 993. With the mitre in Hildesheim Bernward took over the most important clerical function in early medieval Saxony. The safety of his territory became his first priority. Since 983 the Slavic tribes settling beside and east of the river Elbe had been at war with the Saxons. They fought against the missionary efforts and attempts to make them part of the kingdom. Also Vikings sailed the Elbe and conducted raids in the areas around. Therefore, a fearful atmosphere ruled decisions in eastern Saxony in that time.

The biography of Bernward, written by his old teacher Thangmar, gives an insight into the actions Bernward took. According to him, wide parts of Saxony were under attack by pirates and barbarians. Like a shepherd guarding his herd, says Thangmar, Bernward opposed the enemies of christianity. He built a first castle at the confluence of the rivers Aller and Oker (Mundburg) and soon after that a castle in the very north of his diocese, at Wahrenholz. Here the enemies had a base according the vita, and by building of the castle Bernward brought peace and safety to the area.

Early Interest in Prospection

The prominent location of Wahrenholz castle, just opposite the old watermill, along with the written sources attracted early interest in the heritage site with the first examinations starting in 1873. In 1916 a local teacher discovered wooden posts and pottery sherds. The German prehistorian and archaeologist Carl Schuchhardt excavated several trenches across the hill in 1919. But only short notes and a small location sketch are preserved. Schuchhardt describes the castle Burg Wahrenholz as an artificial, flat mound, built in a swampy area protected by two branches of the multi-channel river Ise (Schuchhardt, 1931). The oval-shaped living area on top of the mound comprised an area of 22m by 32m, the width of the enclosing wall varied from 8 to 12m. The encompassing, 8m wide berm was fortified with a strong wooden cover which was – in his eyes – most uncommon for German castles of this time. The outermost protection was probably a branch of the river Ise in combination with a water ditch which closed the gaps.

Geophysical Prospection

Aerial photographs of the site by C. Frey discovered one semioval dark mark in the meadow which later could be identified to be the berm of the castle. The existence of an aerial archaeological feature encouraged Hans-Wilhelm Heine (†), NLD, Hanover, to propose geophysical prospection in order to uncover the extent, design and internal features of the castle. A first attempt in April 2011 applying Cesium Magnetometry (SmartmagSM-4/4G, Scintrex, Canada) of 1,2ha completely failed. None of the expected features could be imaged. The magnetization contrast of the construction of wood and earth was obviously too small. More success was achieved by a resistivity suryey of 0,4 ha which was carried out in May 2012 using the RM 15-instrument from Geoscan Research, England, in twin mode with the multiplexer MPX15 for double twin electrode measurements (Fig. 3). The southern part of the oval-shaped earthwork is clearly imaged on the unfiltered apparent resistivity map with the central living quarter, wall, berm and water ditch. The northern part of the earthwork is covered by the state road L286. The superimposed design sketch from Schuchhardt, 1919, delineates very well the borderlines between the fortification elements of the earthwork (Fig.4).

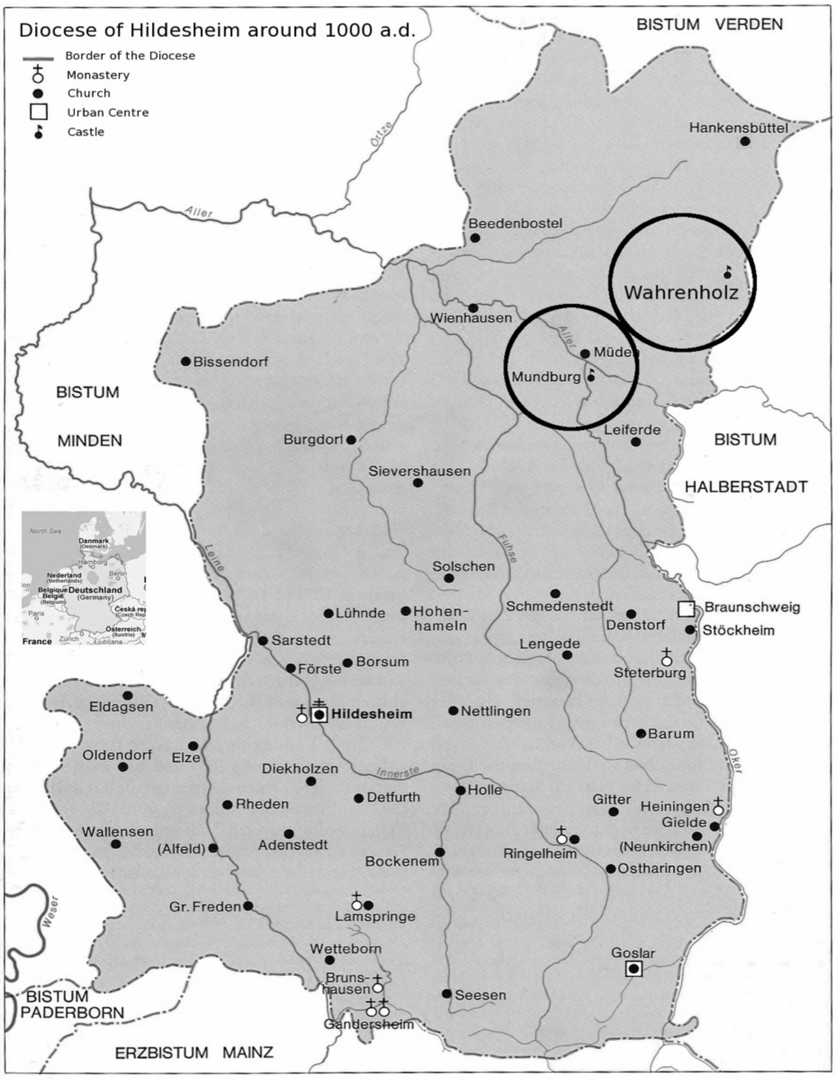

Fig.1. Map of the historical diocese of Hildesheim with castles of Wahrenholz and Mundburg.

Fig.2. The site of Bishop Bernward's castle Wahrenholz with the remaining flat mound and the old watermill Wahrenholz.

Only the central living part is completely accessible for geophysical prospection which shows up as an oval area of ca. 25m by 32m with slightly enlarged impedance. Rectangular and quadratic structures might be interpreted as buildings or living facilities. But Schuchhardt's excavation trenches from 1919 with unknown location could be equally imaged causing some uncertainty in interpretation. The 10m to 14m broad wall is separated from the 8m to 10m wide berm by a 2m oval-shaped low-impedance stripe which is not visible on aerial photos. Perhaps the imaged archaeological feature represents a deep-seated substructure required during the construction of the artificial mound. There are still uncertainties about the construction and dimension of the outermost fortification, the water ditch, which is not clearly imaged. A digital height model with a superimposed resistivity map is planned in order to verify the equal height conditions at the foot of the hill which is a prerequisite for the existence of a protecting water ditch.

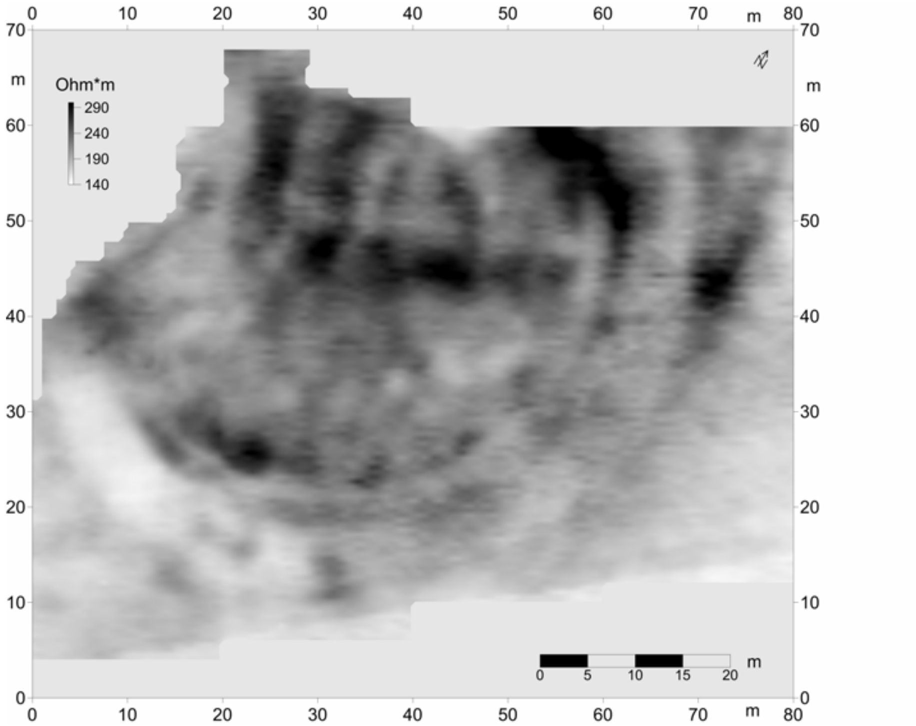

Fig. 3.Castle Wahrenholz. Apparent unfiltered resistivity map. Area 0.4 ha, RM-15, Geoscan Research, England, MPX15, parallel twin, point distance 0.5m by 0.5m.

Conclusion

Wahrenholz castle, an artificial, flat mound built by Bishop Bernward of Hildesheim, is a well-preserved early medieval stronghold of earth and wood which could be imaged in detail by non-invasive resistivity prospection. The interpretation of the geophysical image is confirmed by a sketch design of an old excavation by Carl Schuchhardt in 1919. The principle of prospection to try different geophysical methods and not to rely only on one single method finally led to the successful imaging of the castle. This non-invasive procedure monitors the state of preservations of the site and allows the planning of future activities. Small excavation trenches could verify the castle design resulting from interpretation. The new insight in the construction of this earth work allows a better understanding and an integration of Schuchhardt's knowledge laid out in short notes in 1919. It is also intended to perform geophysical prospection on Bishop Bernwards first castle Mundburg built at the confluence of the rivers Aller and Oker (Fig.1). Before starting this kind of investigations the exact location of the castle has to be identified which is still under discussion.

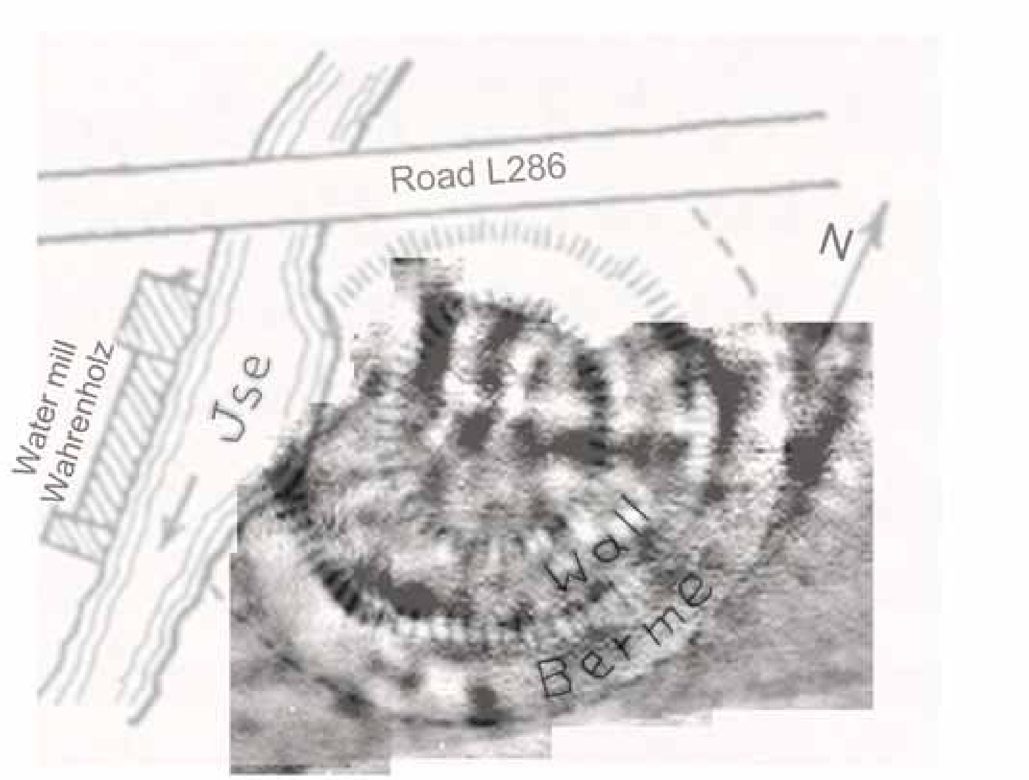

Fig.4.Castle Wahrenholz. Sketch design by Carl Schuchhardt, 1919, superimposed on apparent filtered resistivity map. Area 0.4 ha.; RM-15, Geoscan Research, England, MPX15, parallel twin, point distance 0.5m by 0.5m.

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GEOPHYSICS ON SOLSBURY HILL, BATH.

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Solsbury Hill may be best known in song, but it is a hillfort which dominates the Avon Valley just to the east of Bath. It forms a triangular crown on a detached mound of chalky limestone from the Great Oolite series, touching 200 m OD at its summit. Although this looks impressive from below (see Figure 1), it is actually overlooked by the surrounding hills of Charmy Down, Bathampton Down and Lansdown, so it is relatively sheltered. It commands fine views westward down the Avon over Bath, south up the Avon towards Salisbury Plain and eastward along the By Brook.

The hilltop was presented to the National Trust in the early twentieth century and is mainly retained for leisure and for its natural history, and also let for summer grazing. It was cultivated mainly for Barley well into the nineteenth century, and low retaining walls of cultivation lynchets are still visible.

From below, the hilltop appears to be a flat plateau above the steep rise to the ramparts, but it is actually a low dome of some five metres height. This means that there is very little intervisibility from one side to another. How this affected its original use cannot be known, but it certainly created problems in laying out survey grids.

A magnetometer survey using a Bartington 601-2 was carried out in April 2012. In all, this comprised about 250 grids of 20 m square. A twin – probe earth resistance survey has been started, but this is a much slower process. It has not been completed, but has been concentrated around the edge of the monument.

Figure 1

A random point magnetic susceptibility survey has also been done using a Bartington MS2, with reading locations recorded on hand-held GPS. This was limited to the accuracy of five metres, but gave a good representation of large scale features on the hilltop.

Magnetic anomalies were strong on the hill top and a spectacular magnetometry plot resulted. See Figure 2. Indeed, the greatest problem was finding a spot quiet enough for calibration. The sets of lines which run across the hill top are from the mediaeval and post–mediaeval ploughing. These overlie features of greater interest. Over 20 circular anomalies can be detected. These cluster more on the eastern side of the hill, which is more sheltered. There is a large, slightly ellipsoidal feature near the south end, which may possibly have been a round barrow.

A central round feature aligns with ditches approaching from the southeast, suggesting there was an entrance here. There is a modern entrance to the hill top here, but it has a very steep approach. The main entrance is generally taken to be in the northwest, where a more gradual ascent can be made through a break in the ramparts. This latter entrance is marked by splayed linear features inside.

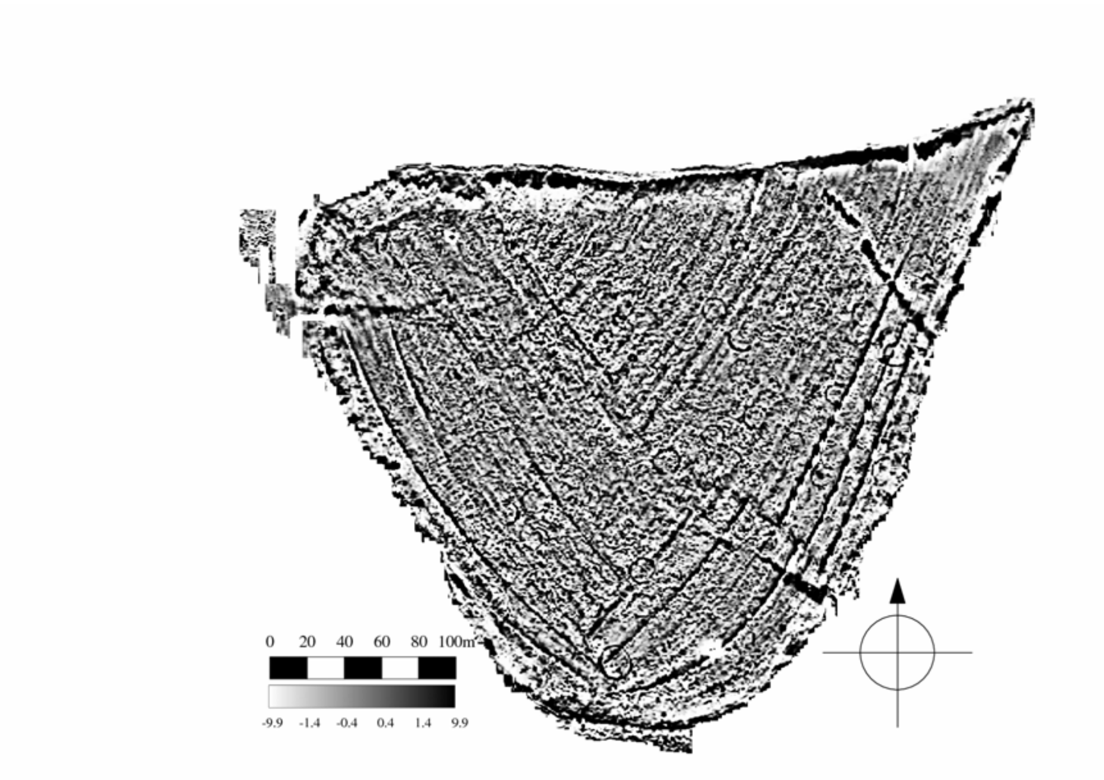

Figure 2

An interrupted ditch appears to cordon off the northeast corner, and within that northeast enclave, there are few signs of round houses, but numerous clusters of anomalies, possibly post holes. Perhaps this was a granary area.

The thick black line around the edge is taken to be an internal ditch, which sits just inside the ramparts. The ditch is not visible on the surface, apart from a short length just around the southern extremity. There, it appears approximately 1 m deep. Excavations in the 1950's showed signs of habitation in the northern portion of the ditch. The ramparts rarely rise more than 1.5 m from floor level inside the hill fort, but fall precipitously some 10 m on the outside all round the edge of the hill top. In some places around the circumference, rampart and inner ditch have been nibbled away by later quarrying, but there is still the steep drop.

Magnetic susceptibility measurements give high readings, and the area of the internal ditch appears particularly high. The soil appears very thin, perhaps not much more than 0.1 m, shallow enough that the magnetic susceptibility may be a very good reflection of all the magnetometry, but seen at lower resolution.

Twin–probe resistance appears to show features quite clearly, but in negative. That is, positive anomalies in the magnetometry appear as low resistance. In particular, the internal ditch around the rampart is low resistance and apparently featureless. This suggests an accumulation of over 0.5 m of soil washed down from the hill top, so that any structural features are too deep to detect.

Solsbury Hill would appear to be unusual amongst Wessex hillforts in the large number of round houses it contains. Perhaps an equivalent may be found at Chalbury Hill near Weymouth, which is also detached from surrounding higher ground, and which has visible hut circles. The cordoned–off northeast precinct is certainly an unusual feature. The site is worthy of more intense scrutiny.

Acknowledgements.

The survey was carried out using volunteers and equipment of the Bath and Camerton Archaeological Society. We would like to thank National Trust and the freeholders of Batheaston for allowing access to this site, and English Heritage for granting a licence to survey.

MAGNETOMETER AND GROUND PENETRATING RADAR SURVEYS IN THE NEOLITHIC FLINT MINE OF ARNHOFEN, LOWER BAVARIA, SOUTHERN GERMANY.

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Introduction

The Neolithic chert mine of Arnhofen situated in an estuarine environment on the hilly landscape of the upper Danube region is a monument of international significance. Numerous tools made from the premium fine-grained, banded grey tabular flint are recorded from many prehistoric sites since the Early Neolithic when regular flint mining appears to begin by Linear Band communities in Lower Bavaria. While the Middle Neolithic period witnessed the greatest intensity of mining, raw material from Arnhofen was distributed over a broad distance of more than 500 km into different cultural spheres of Central Neolithic Europe: towards the Danube river and the Rhine-Main area to the Middle Elbe-Saale region in the north to Bohemia in the east further down the Danube river to distant Neolithic settlements in Lower Austria. At the foothill of the Franconian Alb more than a thousand mining shafts testify the remarkable prominence of the typical *Arnhofener Plattenhornstein* (Fig. 1).

Fig. 1. Arnhofen. Pit shafts of the Neolithic chert mine uncovered during former excavation seasons.

Archaeological Excavations

Discovered within recent gravel mining activity during the 1970's the Neolithic flint district of Arnhofen was primarily subjected to rescue excavations under the tutelage of the Bavarian State Department for Monuments and Sites. In 1998 M. M. Rind firstly initiated a priority program coordinated by the Kelheim County Office for substantial excavation campaigns in order to get new information regarding prehistoric mining technology. As a result more than 600 mining shafts with a diameter of 0.7 – 2.2 m and a maximum depth of 8.5 m were well documented by the end of 2008. Covered by thick sand as a remnant of the Freshwatermolasse and gravel strata deposited by the river Abens during the Quaternary, the Arnhofen flint deposits were secondarily transferred into unique geological circumstances readily accessible for the benefit of humankind.

Archaeological Prospection

As recent archaeological investigations focused on detailed studies of limited sections in the late 90's, the whole extension of the Arnhofen mining district has been estimated to cover an area of a maximum 28 ha in total. In terms of a new re-evaluation a minimal surface of at least 40 ha was suggested to include more than 130.000 mining shafts while the original boundaries have not yet completely been identified by previous investigations. Therefore a new project funded by the German Research Foundation was started in order to fully investigate the original extent of this unique prehistoric site by combining both geophysical and archaeological survey methods.

Magnetometer Survey

During 2011 geophysical measurements were conducted by the use of a Caesium Magnetometer at a maximum distance of 1.5 km from the former excavation site. The southern boundary of the site was already detected within the archaeological excavation area, the results of the magnetometer prospecting however revised the westernmost extension of the chert district. In this area, the magnetometer data indicates clear evidence for mining activity spreading to the very south of the modern village (Fig. 2). Due to the gravels that were secondary overburden at the very top of the pithead and recent layers of humus topsoil, the investigation of subjacent Neolithic features are exclusively detectable by geophysical prospection methods. Beside numerous mining shafts there are few settlement patterns that can a priori be associated to Neolithic fireplaces or seasonal dwellings.

While the northern boundary is as yet unknown, the overall extent of the Arnhofen mining area can also be completely revised. A huge area of more than 2.0 km of the site was already proved by aerial archaeology prospecting, however, this method revealed only chert pits by their positive crop marks. But with the addition of our magnetometer measurements we found pits showing positive as well as negative magnetic anomalies (Fig. 3). This finding is verified by former archaeological excavation results which showed heterogeneous back fillings of single mining shafts.

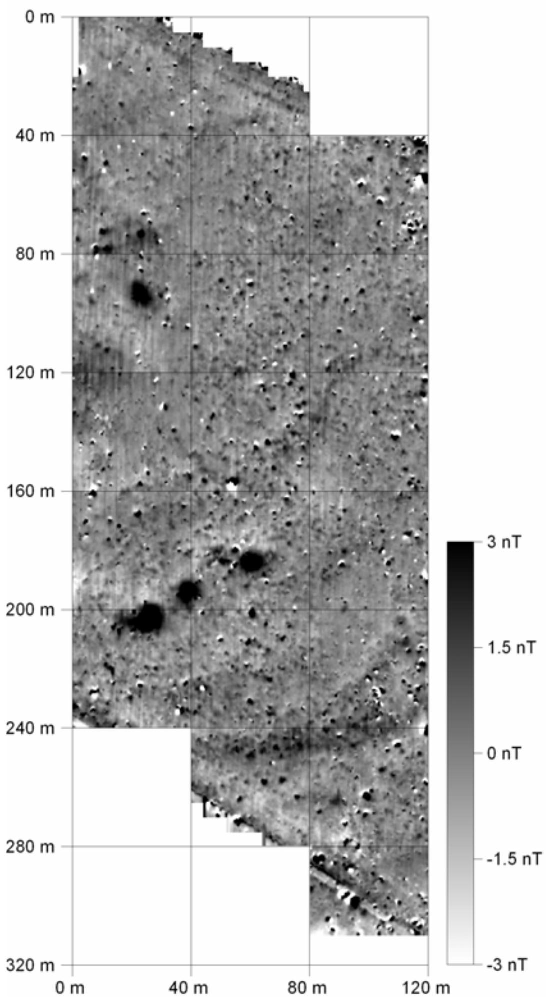

Fig. 2. Magnetogram of a newly discovered mining zone in the westernmost area of the Arnhofen chert district. Caesium Magnetometer Smartmag SM4G-Special in a duo-sensor configuration, dynamics ± 3nT in 256 greyscales, sensitivity ±10 pT, sample interval 0.5 x 0.25 m, interpolated to 0.25 x 0.25 m, 40 m grid.

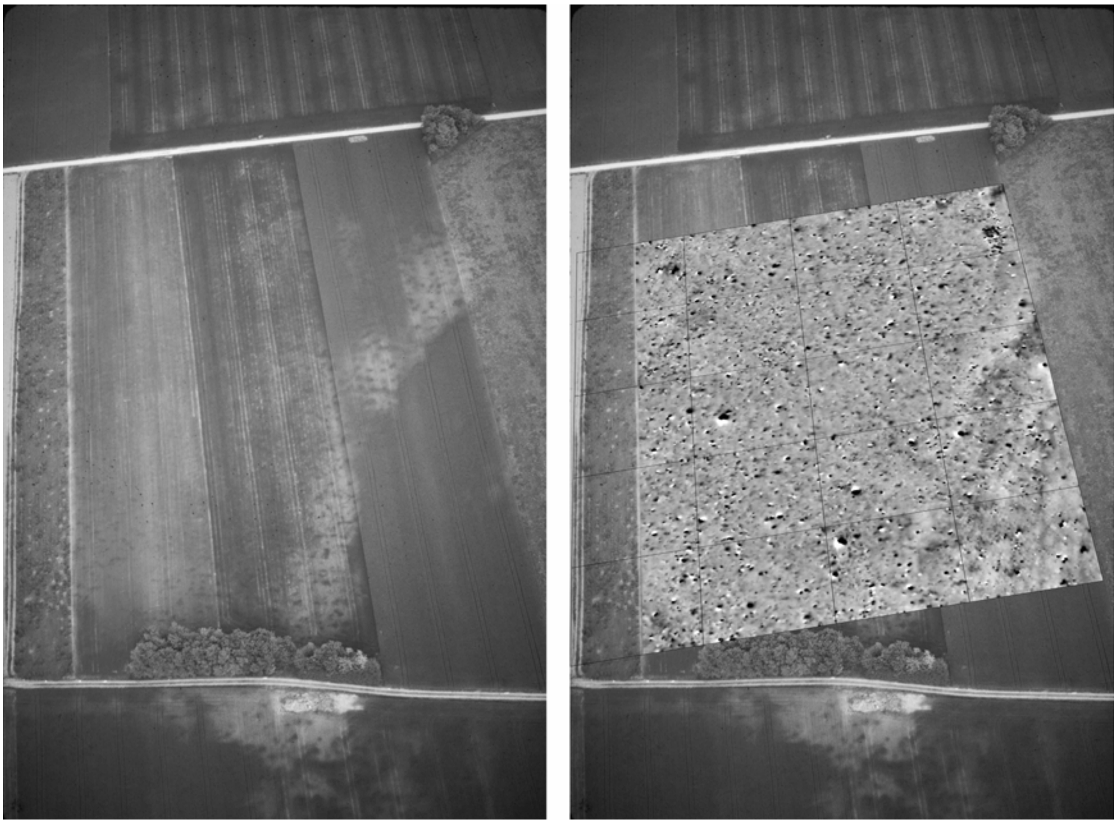

Fig. 3. Further mining zone in the northern part of the Arnhofen chert district surveyed by aerial prospection in 1992 (a) and by geophysical measurements in 2011 (b): Pit shafts as positive crop marks in aerial view supplemented by magnetometer data. BLfD ZII Aerial Archaeology, exposure data 21.05.1992 by K. Leidorf, archive no. 7136/079-04, and BLfD ZII Geophysical Prospection, Caesium Magnetometer Smartmag SM4G-Special in a duo-sensor configuration, dynamics ± 3nT in 256 greyscales, sensitivity ±10 pT, sample interval 0.5 x 0.25 m, interpolated to 0.25 x 0.25 m, 40 m grid.

Radar Survey

The interpretation of the magnetometer data can be improved by a complementary ground penetrating radar survey (Fig. 4). Similar to the findings of the magnetometer results, the detection of single emerging anomalies to a maximum depth of 240 cm revealed Neolithic pit shafts which are traceable in varying profundities depending on the alternating consistency of the different backfills. Areal overlays of pithead stocks can firstly be distinguished in the upper parts and separated from antecedent anthropogenic structures and naturally occurring geology in the lower parts.

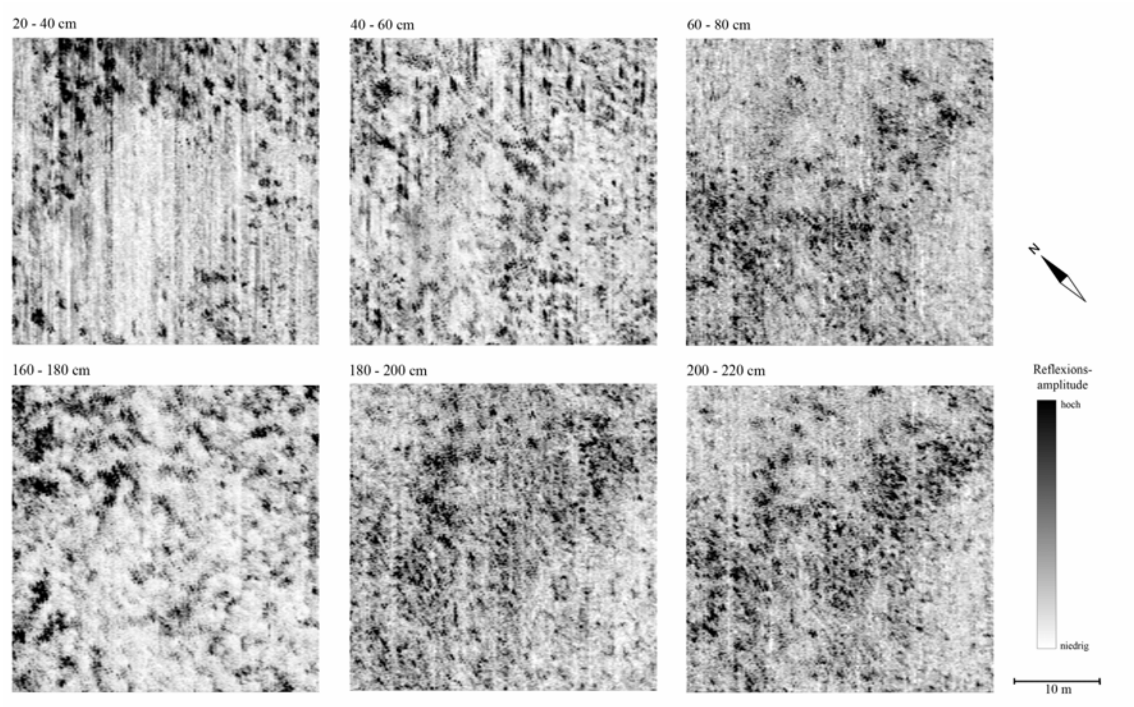

Fig. 4. Map of a complementary ground penetrating radar survey supporting the results of previous magnetometer data measurements as a detailed case study in 2012. Depth slices 20 - 80 cm and 160 - 220 cm. GSSI SIR-300 with 400 MHz-antenna, sample interval 0.02 x 0.25 m, 40 m grid.

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APPLICATION OF REMOTE SENSING TECHNIQUES AT BRÚ NA BÓINNE WORLD HERITAGE SITE, COUNTY, MEATH, IRELAND.

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The Bend of the Boyne, or Brú na Bóinne, has been an important ritual, social and economic centre for thousands of years (Fig 1). Its universal value was recognised in 1993 when it was designated a UNESCO World Heritage Site (WHS), only one of three on the island of Ireland. The international significance of Brú na Bóinne has been gradually revealed through a process of discovery and research which began over 300 years ago. Up to the present day, a considerable amount of research has been undertaken, including large-scale excavations at Newgrange and Knowth, analysis of the megalithic art, and field survey of the wider landscape. However we still lack an in-depth understanding of the site's broad range of archaeological monuments, from the Neolithic passage tombs to the Battle of the Boyne battlefield, and the landscape and communities that shaped them.

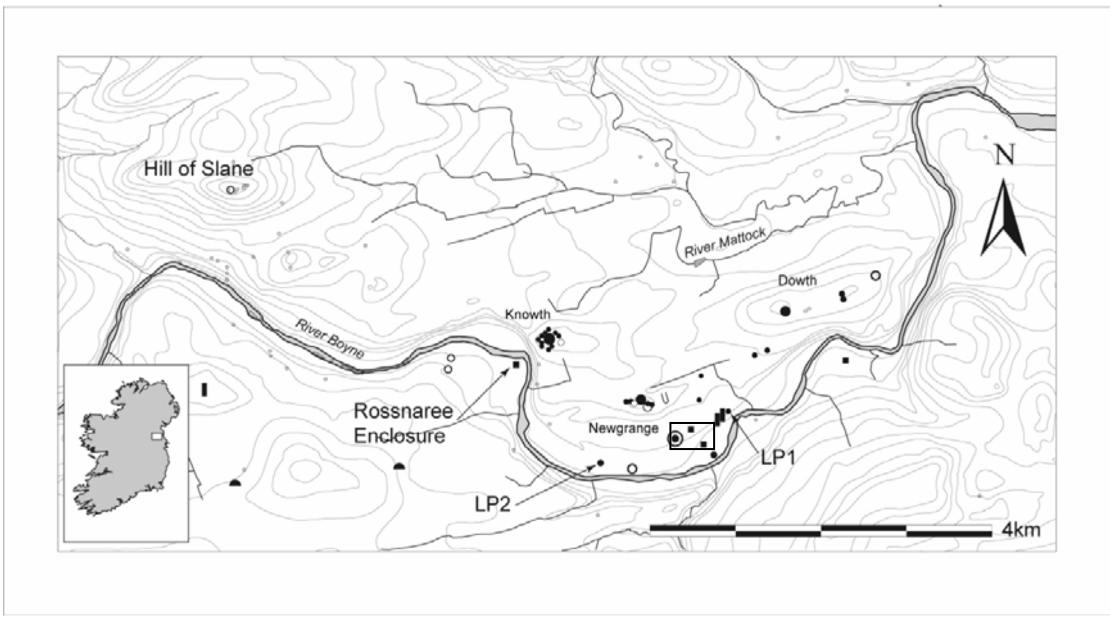

Fig 1 : Brú na Bóinne WHS with the location of Newgrange Passage Tomb and some isolated sites that have been geophysically surveyed (map : Conor Brady)

The Brú na Bóinne World Heritage Site Research Framework (Smyth, 2009) presents and discusses three related components required for the better understanding of the WHS; a Resource Assessment, a Research Agenda and a Research Strategy. The Resource Assessment summarises the current state of knowledge of more than 6,000 years of activity at Brú na Bóinne. The Research Agenda highlights the gaps in that knowledge, presented as a series of research questions — 38 in total. While these questions cover various aspects of Brú na Bóinne's long history, there are certain gaps in knowledge common to all periods. These include the nature and extent of settlement, the character of the natural environment, the level of people's interactions regionally, nationally and internationally, as well as the exact date and function of the many archaeological monuments within the WHS. The Research Strategy puts forward a plan for addressing these unanswered questions in the short to medium term. Eighteen objectives have been established, all of which recognise the need for the *systematic* collection and archiving of data for the WHS, as well as the effective dissemination of all current and future research.

One key issue that has emerged during the course of the development of the framework is support for a shift in research focus away from sites and towards landscape, in particular those landscapes that sustained and were closely associated with the Brú na Bóinne monuments. It is in this area that remote sensing techniques have an important role in further investigating the visible monuments and prospecting for associated and new features in the landscape.

To date there has been no *systematic* use of ground geophysical techniques integrated with the interpretation of satellite and airborne remote sensing data. There are a number of spatially isolated geophysical surveys which have been carried out; for research on and around visible monuments, targeted on concentrations of lithic scatters, as follow-up to interpreted LiDAR anomalies, for road developments and for commercial and private housing developments. The Brú na Bóinne landscape is largely agricultural with many large, open fields under cultivation for pasture, cereal and root crops. The area is suitable for *systematic* large-scale ground geophysical survey.

Available 8-band multispectral satellite data are being used in large-scale characterisation and assessment of the WHS landscape. Data from the Digital Globe WorldView-2 satellite, operating at an altitude of 770 km, provides half-metre panchromatic resolution and 1.8 metre multispectral resolution.

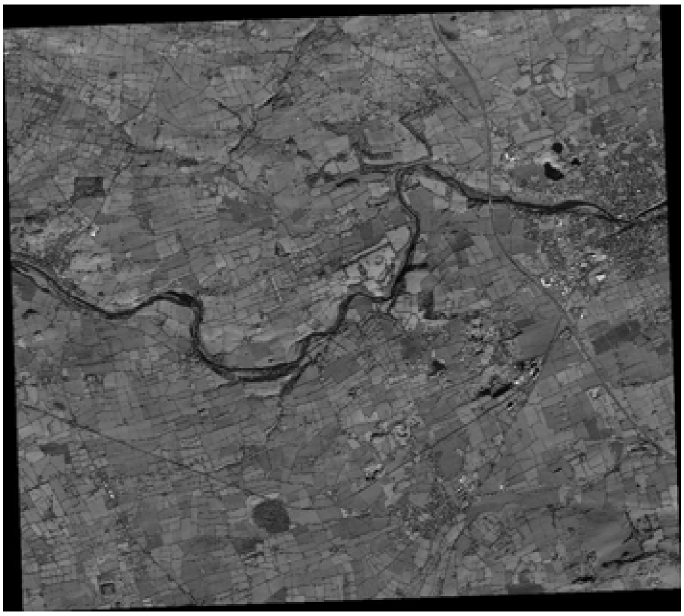

Fig 2: Worldview-2 panchromatic image of Brú na Bóinne with the location of Newgrange Passage Tomb (Data courtesy of Digital Globe).

A little closer to the ground, at about 900m, LiDAR data available on a 0.5m x 0.5m grid are being used to investigate the micro-topography of the ground surface which may reveal eroded or ploughed out archaeological features. These features can then be targeted for high resolution multi-method ground geophysical survey.

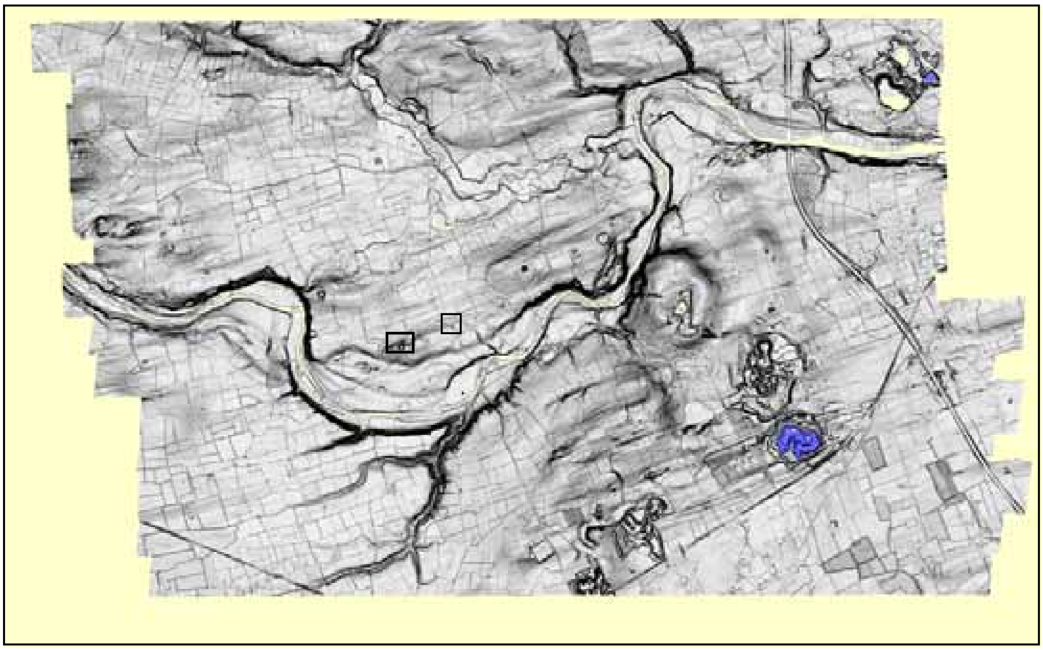

Fig 3: Slope-shaded LiDAR image of the Brú na Bóinne WHS with the Location of Newgrange Passage Tomb and Site E to the ENE. (Data courtesy of Meath County Council and the Discovery Programme)

Fig 4 : GEEP multi-sensor geophysical survey platform with Site E in the background (Photo: Kevin Barton)

On the ground, in order to survey visible sites and to prospect for possible archaeological features that are not discernable from satellite and LiDAR imagery, we need to carry out *systematic*, large-scale, multi-method geophysical surveys. To evaluate and demonstrate the potential of the latter survey strategy, we have carried out a trial using the Geophysical Exploration Equipment Platform (GEEP). The GEEP was configured with four Geometrics caesium vapour sensors spaced 1m apart and a central DUALEM multi-frequency electromagnetic array. The basic dataset comprises total magnetic field data and simultaneous conductivity sounding at six depths. The survey was carried out in the vicinity of Site E which lies some 730m ENE of Newgrange PassageTomb (Fig 3).

The trial was successful and the integrated mapping results derived from the basic dataset are presented in the poster and in a paper presented at this meeting.

ROMAN VILLAE RUSTICAE IN THE BAVARIAN PART OF NORICUM.

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Introduction

The kingdom Noricum was in economic and cultural contact with the Roman Empire long before it became a Roman Province. The transformation from a more or less independent Kingdom to its status as a Province of the Roman Empire was more a friendly takeover than a military conquest. In this sense Noricum differs from the other North-Western-Provinces. As in nearby Rhaetia, very little of the native culture persisted, with Roman technologies often replacing the Celtic customs. In Noricum, many of the local traditions survived, and through a much slower affiliation Roman and native culture transformed to new forms, as can be seen in the architecture of discovered buildings.

For a long time in the research history of Bavaria, Roman Noricum has been second to Rhaetia, a province which covers a much larger area of the Bavarian state. It is not just a matter of size that has led to Noricum taking a back seat, but also the difficult state of current research. Excavations and records of archaeological finds from both the 19th and the beginning of the 20th century are hard to relocate, and many objects have been lost over the years. There are only a few excavations recorded and very few where a whole house was excavated, like in Kay. Mostly only walls and single rooms can be identified, in three cases the bath building proves that we truly can speak of a *villa rustica*.

Unfortunately aerial photography, which is excessively used in Bavaria, is not of great use in the area of Noricum because most sites are beneath grassland. In addition the application of Airborne lidar prospecting did not result in new findings of Roman villas.

The Project

As there are lots of indicators for Roman buildings from the past centuries and many archaeological findings that have never been published, it was appropriate to complement this knowledge with geophysical prospection and edit a catalogue of all sites. This is being done within a Classics dissertation at the Ludwig-Maximilian-University in Munich in Cooperation with the Archaeological Prospection of the Bavarian State Dept. for Monuments and Sites. According to the historical research, approximately fifty sites were already identified as a Roman *villa rustica* (Fig. 1). Eight sites have already been prospected by geophysical methods during the last twenty five years. According to the current state of research, archaeological findings and accessibility for geophysical prospecting eight more should be prospected in 2012.

Geophysical Prospection

A case history of the 2012 season is Bad Endorf, which is located in the South of the Chiemsee. In 1899 an excavation of a mural structure was made, which was recorded in a description note and an imprecise drawing of the location, which made it possible to narrow the area down to two large grassland fields in the village of Bad Endorf. In these areas large scale magnetometer measurements were undertaken. The results allowed us locating the Roman villa, however the clear layout of the foundations was covered by the high magnetic anomalies of fireplaces and hypocausts. Resistivity prospecting and radar prospecting were used to get more detailed information about the stone structures (Fig. 2).

The interpretation of the geophysical data shows an architectural structure which is different from the homogeneous villa types in Rhaetia. It indicates a differentiated arrangement and layout of rooms and houses much more relating to each other.

Like at other sites in Noricum, the ancient farm has two main buildings with paved floors and hypocaust rooms. We know this from other sites as Erlstätt and Glas (Austria). Like in Glas, the main houses seem to be connected through a courtyard. It is supposed that one of the main buildings was of the farm owners and so was part of the *pars urbana,* the living area. The other one belonged to the *pars rustica* and was owned by the administrator of the *villa rustica*. The expected bath building was not found within the area which is accessible for geophysical prospection. There is just another side building in the East of the complex, which seems to be too small for a bath. But as we have a similar site in Glas, we get a good impression of this *villa rustica* and the adjacent buildings.

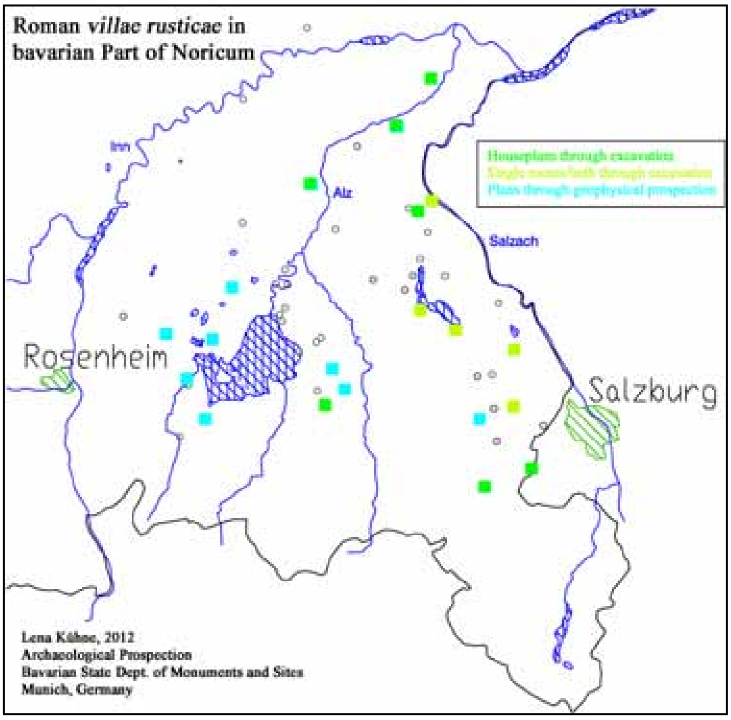

Fig. 1: Map of *villae rusticae* in Bavarian Part of the Roman Province Noricum.

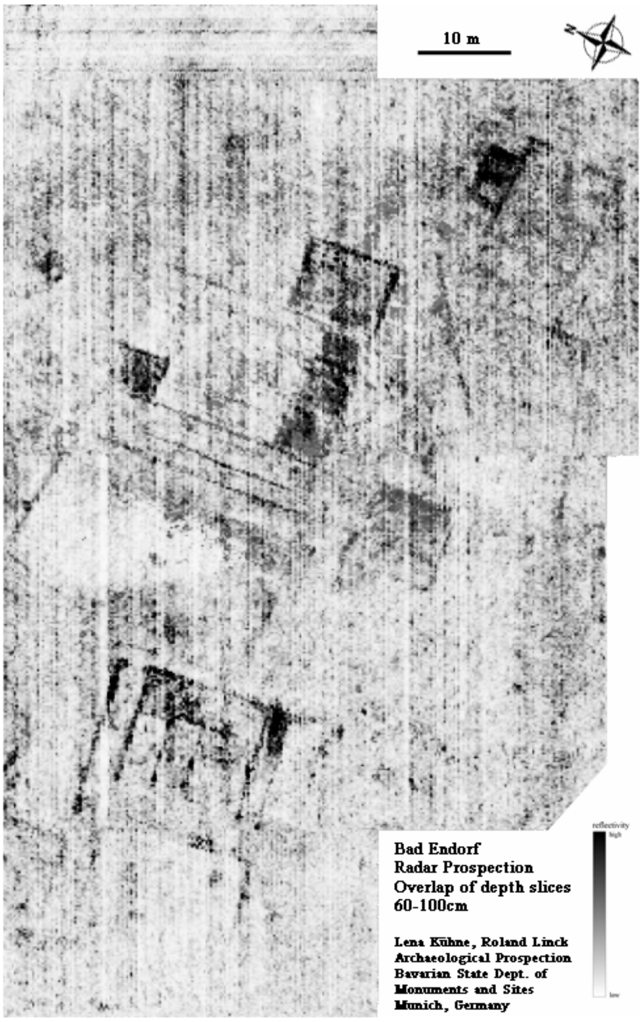

Fig. 2: Radargramm Bad Endorf. GSSI SIR-3000, 400 MHz-antenna, sample interval 2 x 25 cm, overlay of depth slices of the area. The results show two main buildings connected through a courtyard and a side building in the East. In the interior of the houses even parts of the ancient paved floors and hypocausts were detected.

Summary

In the rest of the North-Western Provinces two types of houses are known and are based on Celtic layout built with Roman building crafts but we see a different situation here. There are some of these well known types of houses, but the ancient farms in the Roman province Noricum, in Bavaria as well as in Austria, show also their own types of architecture which seems to be more influenced by Italian architecture. Maybe this is a result of the much earlier influence of Rome in Noricum, but this has to be proved by a chronology of the known *villae rusticae* in Noricum.

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THE APPLIANCE OF SCIENCE AND THE COMMUNITY.

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Universities, local authorities and other respected organisations have begun to take up the initiative to work with local people who are interested in their past. It is thanks to Time Team over the last 20 years that geophysics - more widely known as 'geofizz' – has been popularised. This has increased awareness amongst communities and has allowed people to participate in having a go at it.

The involvement of local people with their own local heritage has grown over the past decade or so where The Heritage Lottery Fund and the Local Heritage Initiative have provided money to support community archaeology projects throughout the UK. This poster presentation will demonstrate how local people have begun to gain from the full potential of using geophysical survey equipment and undertaking their own surveys in their own locality. With the appropriate training from professional practitioners in this field, local groups have been able to gain useful knowledge and experience in order to carry out their own surveys in their own time without working under the same commercial pressures professionals have to.

Cranfield University has been enthusiastically engaged in undertaking outreach work on a number of projects over the past few years. These have included the newly formed Heritage Lottery Funded Jigsaw Project (Fig 1) led by a team at Oxford Archaeology East, community led projects by the Community Archaeology Team at Nottinghamshire County Council (Fig 2), the Layers of Larkhill project and other funded initiatives within schools and with the Young Archaeologists Club. This presentation will illustrate some of their work to date.

Figure 1. The Jigsaw Project led by a team at Oxford Archaeology East

The funding has opened up access to geophysical survey equipment purchased in some cases through the Local Heritage Initiative, in particular resistivity and magnetometry has enabled people to have a go at doing these surveys, collecting and downloading data into a well known software package. This has allowed members of local Heritage Groups to go one step further by carrying out small scale excavations (1m x 1m test pits for example) to test the anomalies that they have detected and identified from their own survey under the guidance of an experienced practitioner.

By training local people to carry out their own surveys and explaining to them the basic principles behind each technique, this has allowed them to gain a greater understanding of how it works. Further to this, the elementary survey techniques are also taught to the groups in order for them to set out their own grid, how to tie the grid into the landscape without the use of expensive GPS equipment and to interpret their own results is explained in a step by step approach.

Following the initial training, continual support and advice can be sought from an experienced archaeological geophysicist to help the locals overcome problems and issues that may arise during their fieldwork. Further to this, standards used throughout the profession can be set at the grass roots level to produce meaningful datasets and results that will be of use to all in the future.

Figure 2: The Community Archaeology Team at Nottinghamshire County Council.

GEOLOGY STRIKES BACK.

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Archaeology and geology are often closely entwined when working in the Highland Border area of Scotland and it is frequently difficult to decide which is which when interpreting geophysical surveys. As an example Figure 1 shows a small part of a recent magnetic survey over a site at Lair, Glenshee, containing some hut circles (Bronze Age?) and the remains of several longhouses, (probably Pictish). A linear anomaly was found cutting the wall line of one house at a reasonably shallow angle which bears no obvious relationship to anything else found on the survey. Given that the bedrock in the area is the Dalradian and magnetic intrusions in this are not uncommon the author confidently declared it to be a geological feature. Of course he was wrong, it was archaeological, a line of burnt material below the topsoil. What this represents is as yet unknown.

Magnetic intrusions are common in the Highland Boundary area. They come in all sizes with widths from a few centimetres to tens of metres. An example is shown from a magnetic survey area at Woodhead, a few miles north of Perth (Figure 2). This was expected to be a fairly routine site containing a possible Roman signal station and some Iron Age huts which had been identified from crop marks. The archaeological features were certainly present but there was something else there too which rather spoiled the picture. The surrounding region is cut by a number of large dolerite dykes of Carboniferous age. This is obviously a hitherto unknown portion of one of them. A subsequent proton magnetometer traverse across the dyke showed a total field anomaly of about 1000nT.

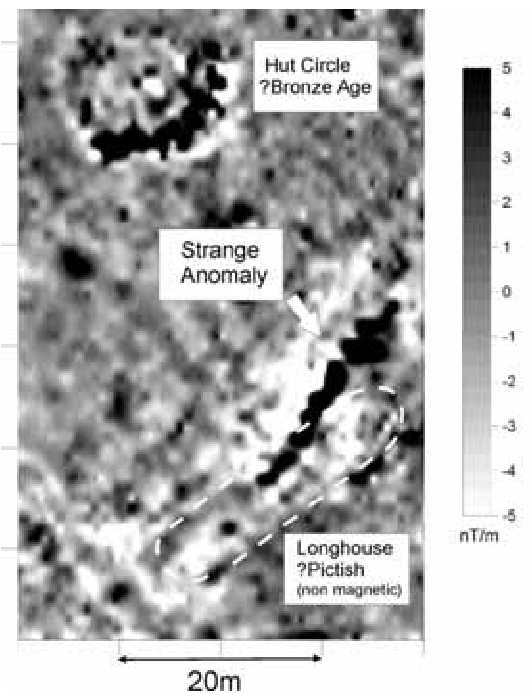

Fig 1:

Lair - A strange magnetic anomaly

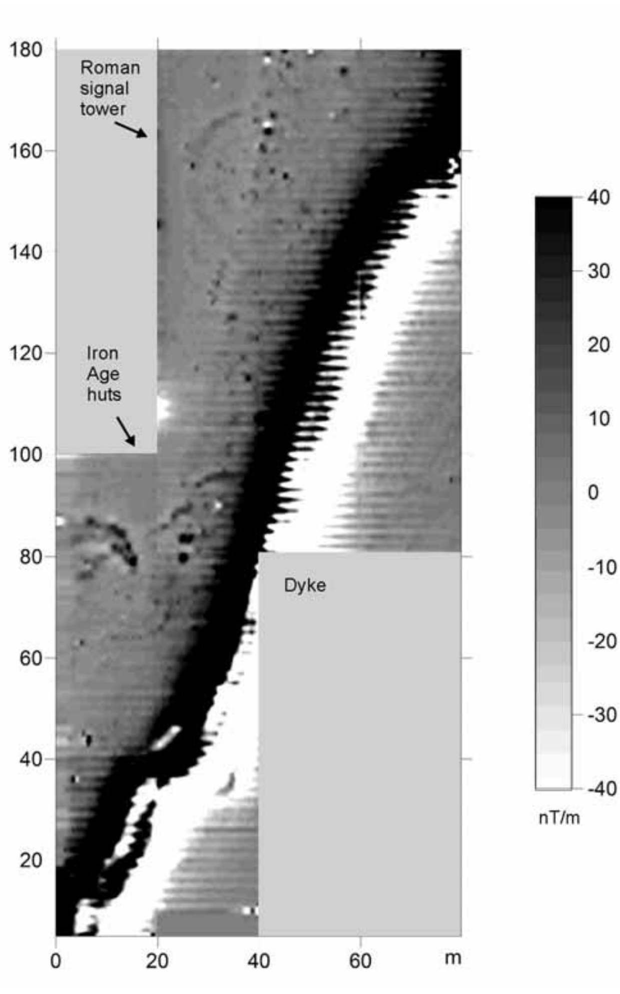

Fig 2
Woodhead - Magnetic survey with unexpected feature

The next case concerns a resistivity survey carried out on the site of what was believed to be a ploughed out cairn at Kinnettles near Forfar in Angus. The survey results (Figure 3) looked to be a little strange but a vague ovoid type of feature seemed to be visible and when excavation (at point X) turned up a carpet of big flat stones everyone was happy. This was obviously the base on which the cairn was built and also what the resistivity was picking up.

When a second excavation was carried out at the other side of the feature (shown by the line near position Y) it became obvious that there was nothing archaeological there at all. The anomalies were due to the remains of frost wedges which developed in the last ice age where sand was deposited in cracks in the glacial till produced by freeze thaw action (Figure 4). On re-examining the resistivity data the polygonal network of these cracks now appears obvious of course.

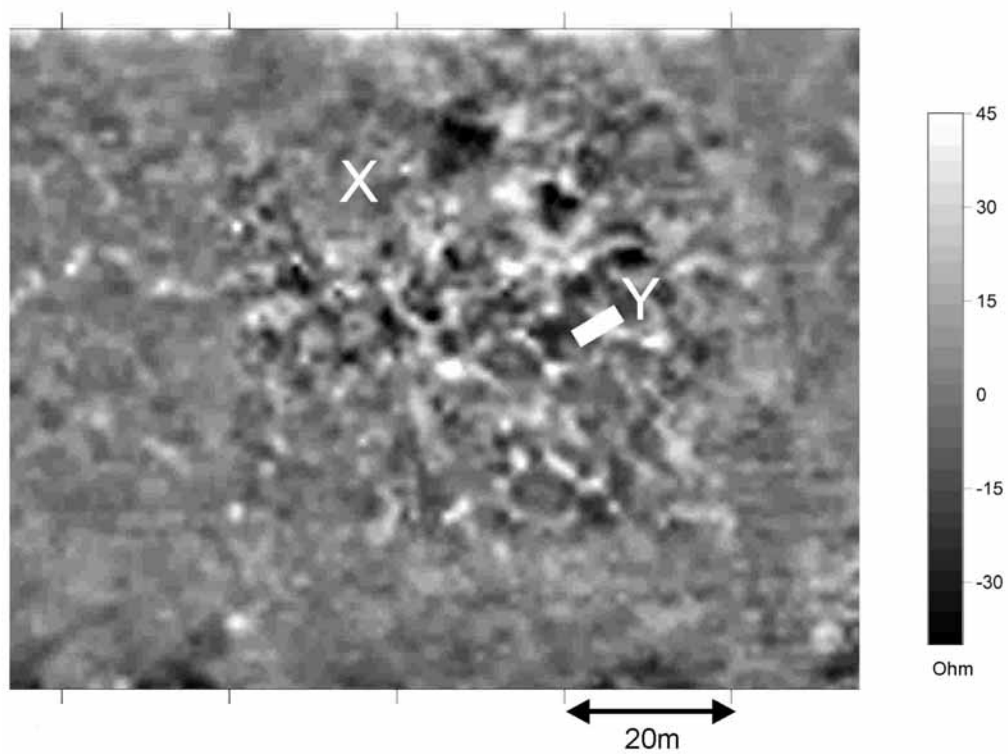

Fig 3 Kinnettles - Resistivity survey over possible cairn

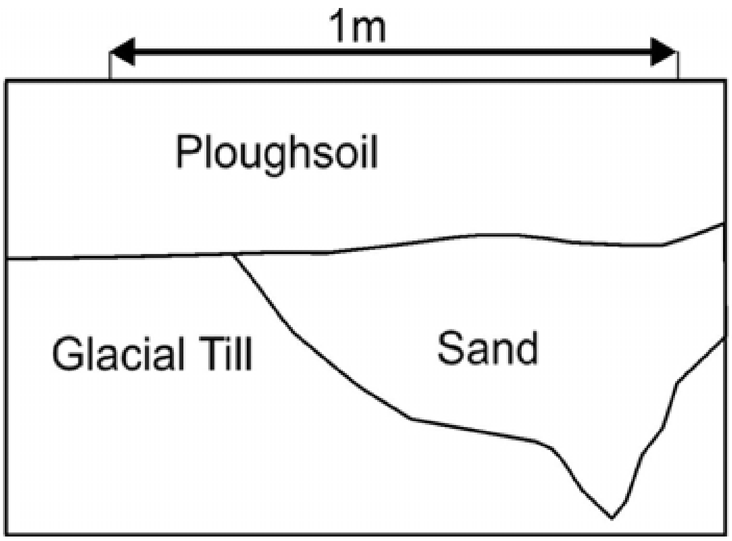

Fig 4
Kinnettles - Geological section in central part of Trench Y

A final example concerns the case of a disappearing vicus. Geophysical surveys were being carried out at the site of the Roman fort at Strageathnear Crieff in Perthshire. The team was very eager to find a vicus, (civilian settlement), outside the walls of the fort. When a zone of high frequency magnetic anomalies turned up in just about the right place everyone was convinced that we had hit the jackpot (Figure 5).

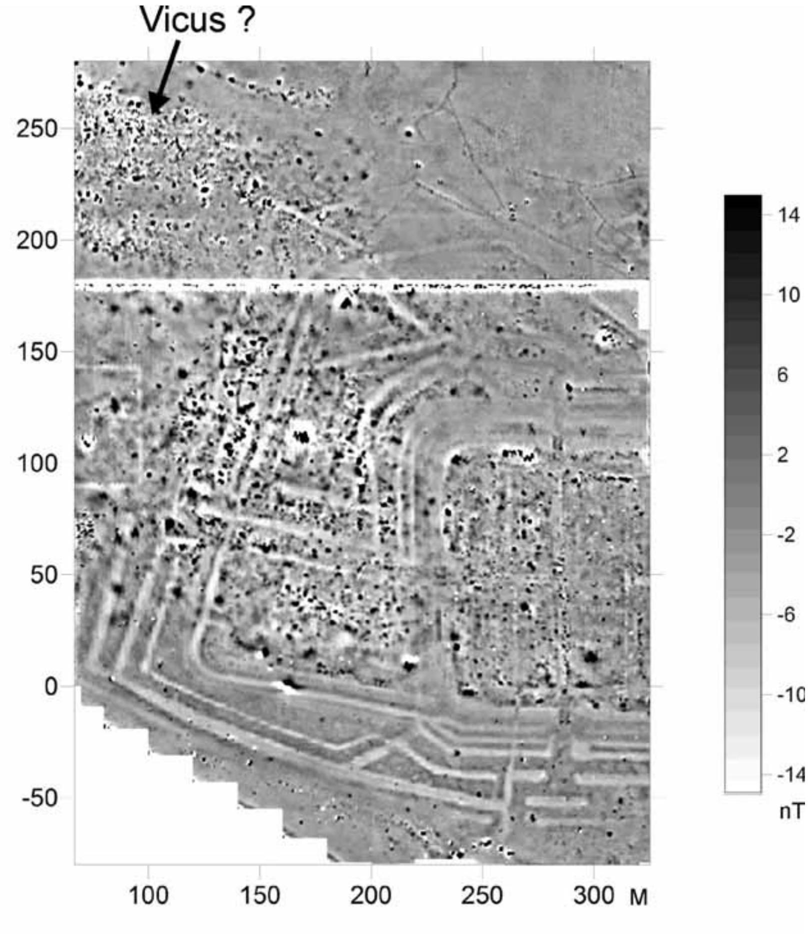

Fig 5 Magnetic survey – Strageath Roman Fort

A test excavation was carried out in which no archaeological material was found. Immediately below the turf (Figure 6), however, a pattern of lobate sediment features was visible and excavating a little deeper showed that these were in fact a network of shallow channel features with a more sandy sediment infilling of similar, but less sandy, material. These are not such obvious crack-related features as in the previous example. They appear to represent some form of highly ploughed out glacial patterned ground with magnetite in the sands causing the observed anomaly patterns. *Vale vicus*.

The above examples should not be allowed to suggest that archaeogeophysical surveys, particularly magnetics, are of limited value in the Highland border region. Nothing could be further from the case; excellent results are regularly being obtained here and in other areas with similar geological complications. When interpreting such data, however, neglect the geological environment at your peril.

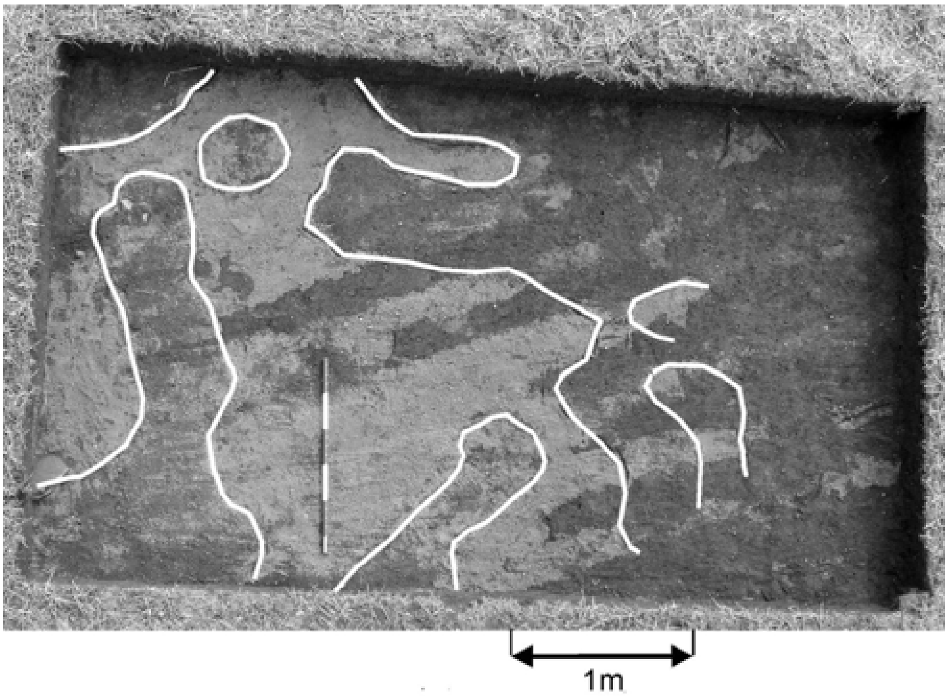

Fig 6
Strageath –
Sandlobes
beneath the
turf

Acknowledgements
I should like to thank the Roman Gask project and the Perth and Kinross Heritage Trust for permission to use some of their material.

SATELLITE-BASED GEOPHYSICAL PROSPECTION OF THE ROMAN FORTRESS OF QREIYE-ᶜAYYĀŠ IN SYRIA

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Introduction

The fortress of Qreiye is situated near the modern village of ᶜAyyāš 12 km north of the Syrian provincial capital Deir ez-Zor (Fig. 1). It was part of the Roman Limes arabicus and belongs to a multitude of similar forts along the Euphrates River. Qreiye was founded in the early 3rd century AD during the expansion of the Roman Empire towards the east. It was swiftly abandoned, however, a few decades later in the middle of the 3rd century AD during the Parthian wars (Gschwind & Hasan, 2008). The fortress illustrates the excellent opportunities such sites in the Middle East can provide for geophysical prospection, as it has not been built upon since the Roman period. Furthermore it is one of the rare examples of a Roman fortress in this area that has not been integrated into an existing settlement (Gschwind, 2005; Gschwind & Hasan, 2008). The site was previously discovered in 1929 by the French aerial archaeology pioneer Père Antoine Poidebard while conducting his own survey on archaeological sites in Syria (Poidebard, 1934). Between 2002 and 2006 the fortress has been excavated partially by a Syrian-German mission in a cooperation between the German Archaeological Institute (DAI) and the Direction Générale des Antiquités et des Musées de la Syrie (DGAMS).

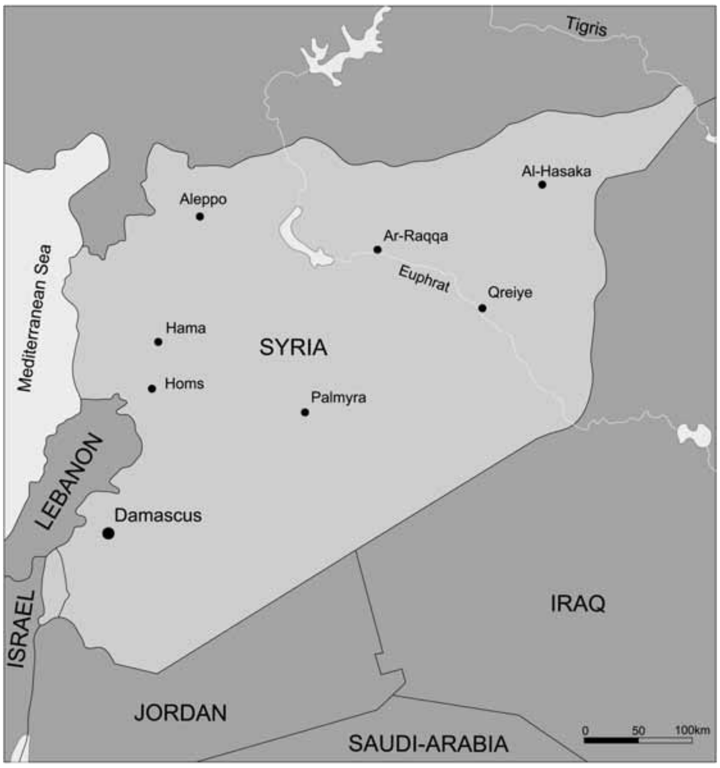

Fig. 1: Topographical map of Syria showing the location of Qreiye near Deir ez-Zor at the Euphrates River.

Method

While the fortress of Qreiye has already been surveyed by GPR in 2002 – 2005 by Sirri Seren of the Zentralanstalt für Meteorologie und Geodynamik in Vienna (Seren et al., 2009), the new research approach concentrates on satellite based methods. In addition to high-resolution optical satellite images we mainly use radar images of the German TerraSAR-X satellite (TSX). TerraSAR-X was launched in 2007. It carries a high frequency X-band SAR sensor that can be operated in three different modes and various polarisations. The Spotlight-, Stripmap- and ScanSAR-modes provide high resolution images for detailed analysis as well as wide swath data whenever a larger coverage is required. These high geometric and radiometric resolutions together with the single, dual and quad-polarisation capabilities are innovative and unique features with respect to space borne systems. In addition several incidence angle combinations are possible and double side access can be realised by satellite roll manoeuvres. The satellite is positioned in a sun-synchronous 11 day repeat orbit (Werninghaus & Buckreuss, 2010). The advantage of Synthetic Aperture Radar (SAR) to optical images is that the method is active and therefore independent of the illumination by daylight. As a result of the specific reflection conditions in the microwave spectrum, the SAR image shows even structures which are smaller than the actual resolution of the sensor (Albertz, 2009). This is a very important fact for the satellite based prospection of archaeological sites like Qreiye. Another advantage of satellite based geophysical prospection is that it can even be carried out in countries with difficult political situations, like Syria at the moment.

Results

As TerraSAR-X provides a spatial resolution of 1m in its experimental High-Resolution-Spotlight-Mode with a 300 MHz bandwidth, SAR is now a powerful tool for archaeological prospection. To enhance the signal/noise-ratio a composite image of nine data-takes of the first half of the year 2012 are used. The effect of the improvement is visible in Fig. 2. One goal of the survey in Qreiye is to determine the penetration depth of the X-band waves through a comparison of the results with the GPR depth slices.

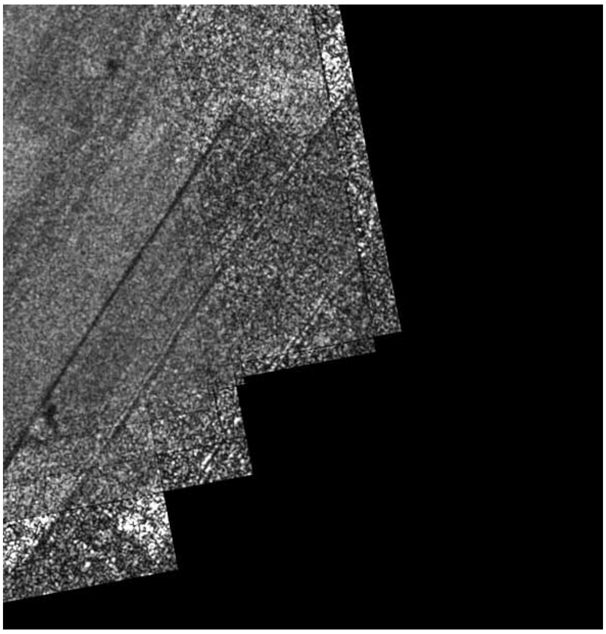

Fig. 2: Improvement of the signal/noise-ratio by stacking nine distinct SAR images. The effect can be shown very clearly at the edge of the composite image.

The fortress has a size of approximately 220 x 220 m and is surrounded by a double wall-ditch system on three sides. On the north side a steep slope towards the Euphrates forms a natural protection. While the surrounding 3 m thick wall is still visible in the topography, the internal layout can only be mapped by geophysical prospection. The GPR depth slices show a detailed layout of the buildings in the interior of the fortress (Fig. 3).

The archaeological remains, however, are only covered by a thin layer of sand. Qreiye, therefore, is an ideal test site for determining the penetration depth of TSX. The SAR-image (Fig. 4) shows several linear features. The two strong anomalies in the western part display the remaining parts of the ditches. The other two sides have already been destroyed by modern roads. Of course the surrounding wall that is still visible at the surface is clearly distinguishable too. But several structures in the interior can also be identified. They can be related to the corresponding walls of the Roman buildings visible in the GPR slices. A detailed analysis shows that only walls in the uppermost 30 cm can be positively identified in the satellite radar image. Therefore, the penetration depth of the X-band waves of TerraSAR-X is approximately 20 – 30 cm. Most of the visible archaeological structures appear as dark anomalies because the radar signal in these parts is absorbed (by the clay-brick walls) or reflected away from the sensors (in the case of the limestone foundations). Some walls, on the other hand, can be identified as light-coloured spots, indicating that in these areas the signal is reflected back to the sensor.

The bright anomalies in the areas surrounding the Roman fortress belong to the village of ᶜAyyāš and depict the modern houses and roads that have already reached the archaeological site.

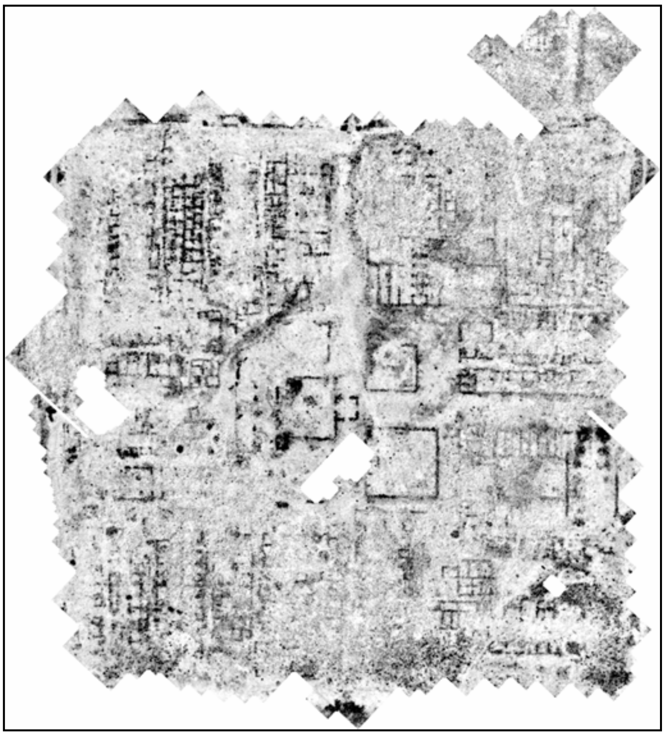

Fig. 3: GPR depth slice between 20 and 30 cm depth. GSSI SIR-3000 with 400 MHz antenna; Sensor&Software Noggin with 500 MHz antenna; PulseEKKO 1000 with 900 MHz antenna.

Fig. 4: Composite TerraSAR-X image of the Roman fortress of Qreiye. Overlay with the digital interpretation of the results. Image parameters: High-resolution Spotlight mode; 300 MHz experimental mode; spatial resolution: 1 m. Black = no reflection back to the sensor; white = huge reflection back to the sensors.

Conclusion

The presented results show that the launch of the new generation of SAR satellites enables us to do detailed archaeological prospection by satellite radar. In addition to this prospection, of course, confirmation of selected satellite findings should then be sought through the deployment of other geophysical methods such as magnetometry, resistivity or ground-penetrating radar. One of the main results is the discovery that even high frequency X-band waves have a slight penetration depth of around 20 cm. Consequently even buried archaeological remains can be detected by this new method.

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SHOULD ARCHAEOLOGISTS BE CONCERNED ABOUT NATURALLY VARYING MAGNETIC FIELDS?

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Magnetic surveys of archaeological sites can be influenced by the natural time variations of the Earth's magnetic field, and to a lesser extent its spatial variations. The influence of the natural time variations could be especially problematic for single sensor surveys with limited base station coverage, and it is this aspect we address in this presentation. At any one location in the UK the magnetic field varies by 10s of nanoTeslas (nT) every single day, and by 100 to 1000s of nT during magnetic storms. We quantify the global characteristics of the time-varying field using hourly standard deviations from approximately 150 sites throughout the world and spanning over 40 years. We illustrate in detail how they vary with location, time of day, month and phase of the solar activity cycle.

The most vulnerable magnetic surveys are those done at archaeological sites in or near the high latitude auroral zones, especially during the local night time (fortunately unlikely from a practical point of view) in March and October in the maximum and descending phases of the approximately 11-year solar activity cycle. Surveys done close to the dip equator are also vulnerable. We describe briefly the causes of these patterns. The existence of spatially incoherent signals in archaeological magnetic surveys may sometimes be difficult to deal with in the post-survey analysis and independent data, from a base station or from a nearby observatory or variometer station, could be helpful in this respect. It should be noted that the forthcoming maximum in solar activity is expected in 2013/14.

Details are provided of the network of observatories and variometer stations that could help isolate and remove these time-varying signals from archaeological magnetic survey data by providing substitute base station data in near real time. The World Data Centre for Geomagnetism operated by the

British Geological Survey in Edinburgh and available online at www.wdc.bgs.ac.uk, is a good first point of contact for magnetic data and metadata from observatories around the world. In the UK continuous magnetic data series are available from the observatories operated by the BGS at Lerwick in Shetland, Eskdalemuir in Dumfries and Galloway and Hartland in Devon.

GEOPHYSICAL INVESTIGATION IN DAKHLEH OASIS (EGYPT): DISCOVERY OF AN UNKNOWN SETTLEMENT AT AYN BIRBIYEH.

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The site of Ayn Birbiyeh has been excavated by the Dakhleh Oasis Project (Canada) since the 1980s and has never been considered by researchers as anything more than an isolated Roman-age temple (marked as 1 in Fig.2). Magnetic prospection in 1998, covering an area of about 0.4 ha in front of the temple facade, revealed no traces of architecture of any kind, while an electrical resistivity survey of the same area helped to localize a massive gate on the temple axis, leading into the temenos (excavated by A.J. Mills in 2005 /2006). The extent of the pottery scatter connected with the site suggested otherwise. It demonstrated that building activity had not been limited to just the temple and that the inhabited territory could have extended far beyond the present temple mound, potentially covering up to 1 km^2 as demonstrated by a ground survey. Remains of stone structures in the eastern part of the site were identified during field walking, situated on flat ground at the base of the temple mound. One of the structures (marked as 2 in Fig. 2) was excavated in the 2010-2011 season (by A.Zieliński and A.J. Mills); it appears to have been a platform under a small shrine(?), situated on the long axis of the previously excavated temple.

Fig. 1. The site of Ayn Birbiyeh seen from the east.

Difficulties with carrying out excavations at Ayn Birbiyeh, caused by extremely hardened soil, prompted the use of geophysical methods to explore the prospective ancient settlement. Testing of the magnetic method carried out in the eastern and southeastern parts of the site resulted in the mapping of streets and squares, as well as buildings, including their inner layout in many places. A combination of the magnetic and electrical resistivity methods provided data sufficient for identifying building material (mud brick and stone;

Fig. 3). In the course of three short survey seasons (2010-2012) magnetic measurements covered nearly 5 ha, while the resistance survey covered only 0.5ha due to the extreme hardness of the ground, which excessively extended the time needed for the work. To take measurements a hole had to be made in the ground, either using an iron rod and hammer or a drill powered from a generator; the hole was then filled with water and only then was the probe inserted (Fig. 4).

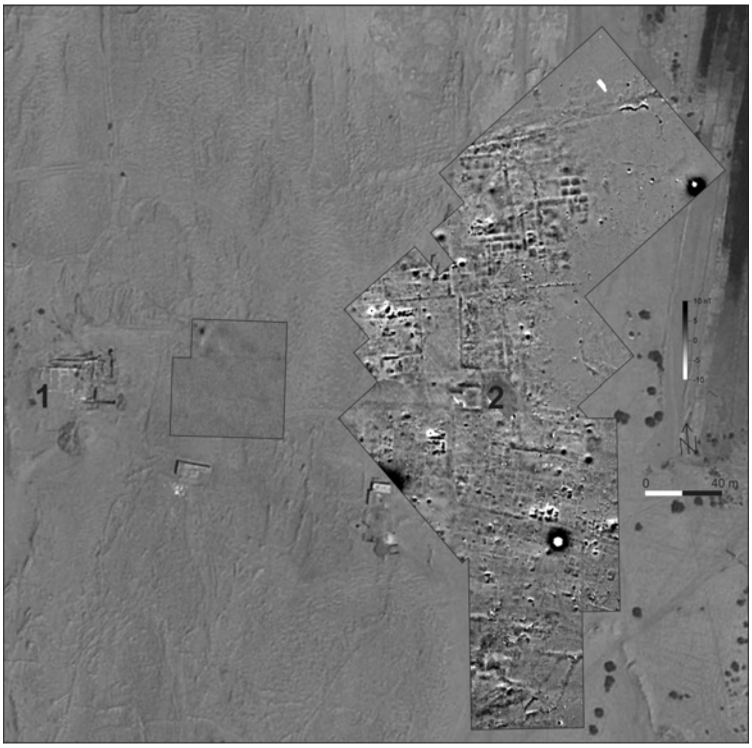

Fig. 2.
Magnetic map of the western part of the site superimposed on a Google Earthpicture. 1 – Roman-age temple; 2 – platform of ashrine(?), Roman period. Measurements by T. Herbich and D. Święch; dataprocessing by T. Herbich. Fluxgategradiometers Geoscan Resaerch FM256, sampling grid 0.25 x 0.50m interpolated to 0.25 x 0.25 m; parallel mode, low pass filter.

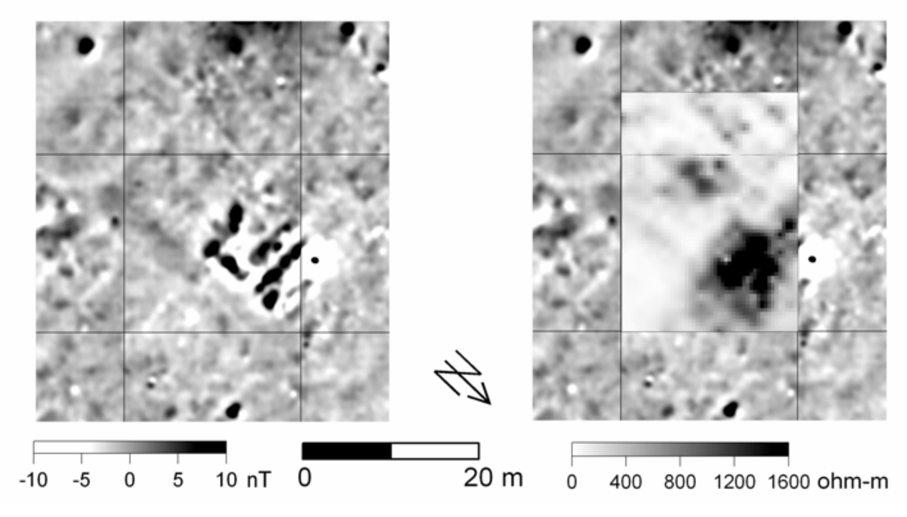

Fig. 3. Magnetic map (left) and resistivity map superimposed on the magnetic map (right). Linear features of low magnetic values in the upper part of the map can indicate both mud and stone structures. The resistivity survey showed that the structures are characterized by a high.

Traces of architectural remains were noted on 3 ha in the eastern and southeastern parts of the site (Fig. 2), leaving no doubt that the temple was part of a sizable settlement with differentiated architecture. The temple clearly determined the orientation of the buildings with the walls radially oriented toward it. The mapping also revealed apparently open ground between the temple and the excavated stone structure, which faced one another. It seems to have been a kind of a processional way between the two structures.

Archaeological verification of the area surveyed in the southeastern part of the site (in 2012) revealed remains of mud-brick architecture of a domestic character (Fig.5). Measurements by the magnetic method in a limited area to the west of the temple did not record any architectural remains other than the two already identified tombs.

Fig. 4. Resistivity survey. On the left a team making and watering holes in the ground.

Fig. 5. Remains of mud-brick architecture of a domestic character in the southern part of the site (excavation and photo by A. Zielinski).

MAGNETIC AND ELECTROMAGNETIC MEASUREMENT SYSTEMS FOR LARGE AREA SURVEYS.

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A GEOPHYSICAL SURVEY OF THE CASTLE SITE, SAFFRON WALDEN, ESSEX, UK

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Introduction. Saffron Walden, a small market town in the extreme northwest of Essex, lies on the northwest slope of the extension of the Chiltern Hills into East Anglia within the drainage basin of the River Cam [Bassett, 1980]. Fig. 1 shows the wider area surrounding the castle site on Bury Hill, a promontory between two streams, the King's and Madgate Slades, also occupied by St Mary's Church. The outline of the inner bailey is reflected in the modern street pattern.

Figure 1. **Saffron Walden Castle**.Image area 420 x 220 m, aligned to Ordnance Survey Grid [Google Earth]. The inner bailey area is occupied by the ruins of the keep in grounds now shared with Saffron Walden Museum and known as Bury Hill, scheduled ancient monument 20671. Castle Hill Tennis Club occupies its western section.

Previous work.

A detailed summary of archaeological investigations and research in the town between 1972 and 1980 is available [Bassett, 1982]. In 1973, a series of trenches was dug in the immediate vicinity of the keep to investigate the extent of damage to mediaeval stratified layers, which was found to be considerable. Also in 1973, Trench E was an attempt to relocate an area of 'masonry footings' reported by Maynard in 1911[1]; it does not appear to have been successful.

In December 1997, on behalf of Essex County Council most of the accessible area round the keep was surveyed by GSB Prospection, in non-

1 Guy Maynard, late Curator of Saffron Walden Museum. Unpublished notes of observations during work on the town sewerage system 1911-13.

ideal physical conditions, using ground resistance at a sample spacing of 1 m [GSB, 1997]. Limited structural features are identified in the report, but others can now be recognised following the 2012 work.

2012 Survey.

On behalf of Saffron Walden Museum a resurvey of the Castle Hill site was carried out using ground penetrating radar and ground resistance. The area covered by GSB in 1997 was reconstructed and used as a basis. Two GPR units were used: a Mala 500 MHz system within a battery-powered cart for the larger section and part of the tennis courts, and a Noggin Smart Cart 250 for the remainder, all at a track spacing of 0.5m and 20 (Mala) or 40 (Noggin) samples/metre along-track. The area immediately west and south of the ruins was investigated with ground resistance at 1 x 1 m and 1 x 0.5 m sample spacing.

Results.

GPR results are shown as timeslice magnitudes (i.e. full-wave rectification); the main post-processing is to normalise rectified RMS value over the full timeslice range which ensures optimum contrast at both high (short time delay) and low-amplitude parts of the timeslice range, this set at approximately 60 ns throughout. Fig. 2 shows a representative slice in the keep section, the image aligned to OS Grid.

Figure 2. GPR timeslice (Mala 500 MHz instrument) at 34 ns (≈ 1.7m).

Large-scale elliptical features seem to relate to the keep, and may indicate surviving remains of surrounding earthworks: the keep itself would have been on a mound raised to the height of the first floor, with the now-exposed ground floor below-surface. The main entrance was to the first floor, through surviving fragments of a forebuilding, visible at its northwest corner. The second smaller ellipse to the southwest is reflected in the modern surface topography. The most noticeable structural features are probably evidence of surviving wall foundations related to a causeway into the building – there is also indication of hard surfacing between the foundation lines. The vertical GPR profile suggests a crossing over a ditch or dry moat.

Fig. 3 shows the 2012 ground resistance result, superimposed on a GPR timeslice. The groundplan of the keep and 1973 trench positions are included. This detects very strongly the entranceway feature of Fig. 2 as lines of significantly higher resistance than average, characteristic of a non-conducting material relatively near to the surface, given the ≈0.75 m penetration expected from the technique. These features prompted an expansion of the GPR survey to the west: Figs. 4a and b are the outcome.

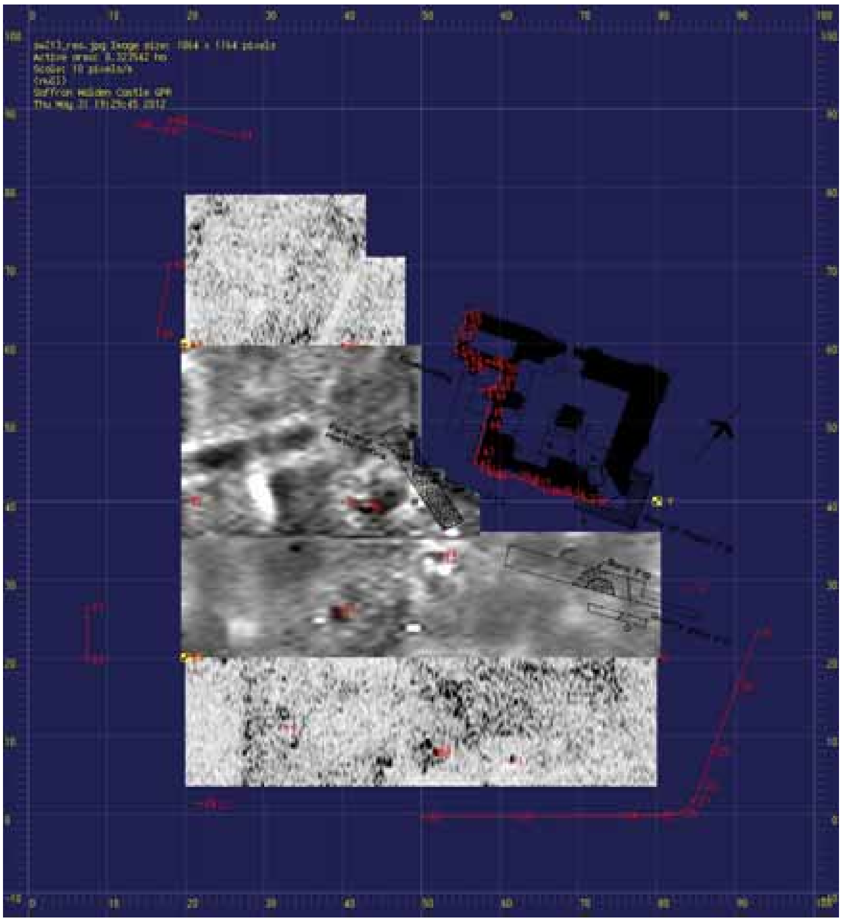
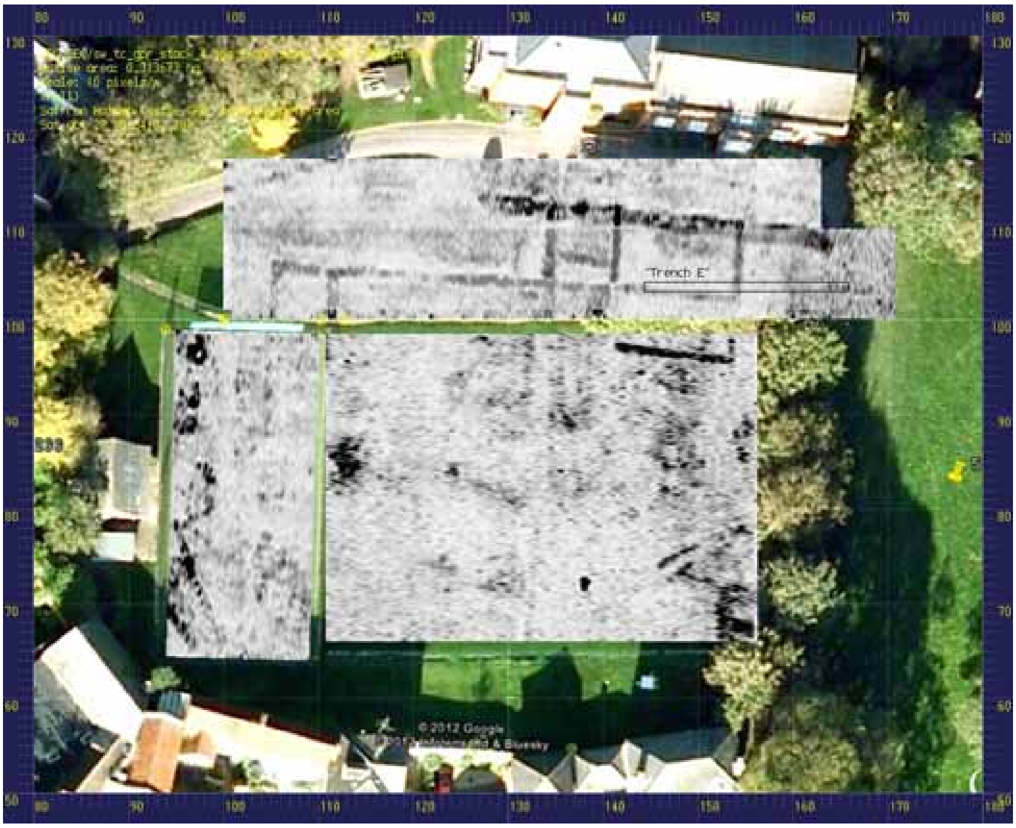


Figure 3. **Ground resistance.** White indicates higher resistance than average, black lower. The survey grid is based on GSB's from 1997. Grid axes in metres, arbitrary origin. Numbered survey points locate site features.



Figures 4a (above) & b. Composite GPR timeslices for the tennis courts area. Survey grid aligned to tennis courts north fence. Background image Google Earth. The location of 'Trench E' from the 1973 excavations is indicated.

Discussion

The most productive part of the survey turns out to be what appears in Figure 4. The entranceway foundation lines of Figs. 2 and 3 do not appear to continue into the courts area, supporting the causeway theory.

We appear to have the first real evidence of the foundations of the mediaeval manor house known to have existed on the site. In Fig. 4a, a near-surface timeslice, the extreme southwest corner contains what may be evidence of wall lines, and a semicircular bastion. In 2010, in the hole for a septic tank immediately north of the tennis club pavilion (west of the courts), 'Very robbed-out remains of a possible wall foundation [were seen, and] there was quite a lot of tile rubble in the overlying backfill, including two pieces of worked stone'. [Ennis, 2012].

The foundations complex appears to be centred on a rectangular space, a courtyard or large hall, interior dimensions 21.5 x 15.5 m (70.5 x 51 ft). Not visible on this image there is indication of a narrow entrance-way 11.5 m from the east wall. The side wings are approximately 5 m wide internally; the southwest corner of the west wing has a triangular cutoff, its short sides each about 2.5 m and possibly the base of a stairwell. The south wall overall is a very substantial feature, at least 1.4 m wide, but thins significantly at its eastern end. Also towards the east end and centred on the short axis is a circular feature, approximately 4 m in diameter: if a hall, we conjecture this is a hearth. Foundations continue to the north and west extremities of the survey area, so their full extent remains unknown.

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Acknowledgements

Michael de Bootman for loan of Noggin Smart Cart GPR system.

Members of Saffron Walden Museum Society for assistance during survey work.

UNRAVELLING PALAEOHYDROLOGY: REVEALING PREHISTORIC LANDSCAPES WITH A MULTI-RECEIVER ELECTROMAGNETIC INDUCTION SURVEY.

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Near surface geophysical techniques are becoming an indispensable part of archaeological research. Over the past decades, there has been an enormous increase in geophysical surveys for archaeological prospection. Initiated mainly in the United Kingdom, this evolution has now spread over the European continent where the Malta convention is stimulating the use of non-invasive survey types. Today, the geophysical investigation of large areas at high resolutions for detecting archaeological features is no longer an exception (e.g. Gaffney et al., 2012, Keay et al., 2009, Kvamme, 2003).

However, the focus often solemnly lies on inventorying the archaeological landscape without taking into account the pedological or geomorphological variations of the natural environment. Information about these landscape characteristics are of particular importance when ephemeral archaeology is targeted. Especially for studying Palaeolithic and Mesolithic societies, a thorough understanding of the palaeolandscape is crucial, as this helps identifying areas with a higher likelihood for detecting traces of such occupations. When we try to gain insight into the dynamics of these societies, this information, combined with other palaeoenvironmental, data, helps to understand settlement patterns and evolution throughout different periods. Hereby, alluvial and lacustrine environments are key areas that play an important role in past, and present, human-landscape interactions (Howard and Macklin, 1999). For palaeolandscape reconstructions, these areas pose additional challenges, especially as sediment cover can mask past landscape features.

Although geophysical methods allow efficiently gathering high resolution information about the subsurface, only a few methods enable capturing soil variability. Of these methods, techniques that map the electrical variations of the soil have the highest potential in the often clay-rich and waterlogged sedimentation areas in lacustrine and alluvial environments. The non-invasive character of electromagnetic induction surveying, which requires no physical contact with the measured soil, makes this survey method well suited for such palaeotopographical surveys. When made mobile, this approach allows mapping large areas at high resolutions, equivalent to standards used in geophysical prospection for purely archaeological features.

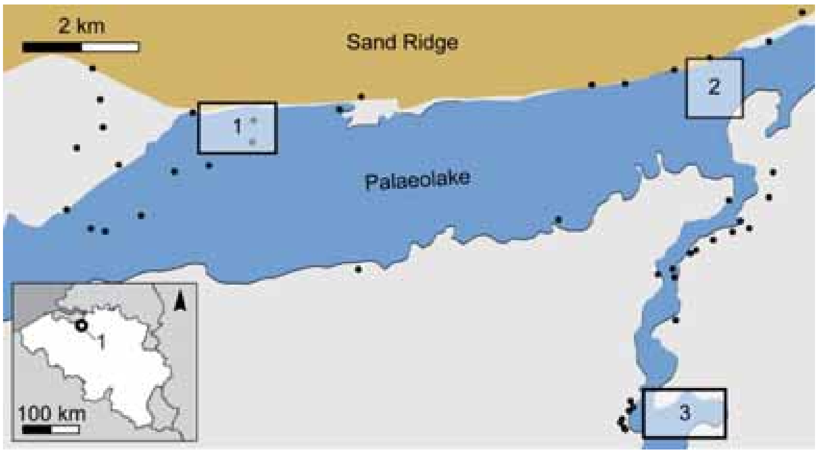

Figure 1: Schematic representation of the Moervaart palaeolake showing the different Final-Palaeolithic to Early Mesolithic sites as dots and the geophysical survey areas (1-3). Inset: location of the study area in Belgium.

To assess the relationship between the environment of a Late Glacial palaeolake (‘Moervaart’, Belgium (Fig. 1)) and the numerous prehistoric settlements in its vicinity, detailed insight into the complex palaeotopography of the area was needed. We applied an integrated survey methodology whereby extensive mapping campaigns were set up to detect and characterise buried river systems (Bats et al. 2009). While coring was used to detect large-scale variations in the palaeolake morphology, mobile multi-receiver electromagnetic induction (EMI) survey was applied in more complex areas. This enabled continuously mapping soil apparent electrical conductivity (ECa), which is mainly influenced by soil texture. The high resolution of these EMI surveys, conducted in a 2.0 m x 0.25 m grid, avoids spatial interpolation error. We used a Dualem-21S EMI sensor with four receiver coils that simultaneously measure the ECa of different soil volumes (Simpson et al. 2009). Additionally, we have developed a method to model the depth to predefined soil horizons by comparing the ECa maps generated by each coil pair while integrating auger calibration data (Saey et al. 2008 and De Smedt et al, 2011). This allowed accurately modelling the palaeotopography and buried geomorphological features (De Smedt et al. In Press).

Around two known Final-Palaeolithic and Early Mesolithic sites in the area (survey zone 1 in Fig. 1), an area of 60 ha was mapped with EMI (Fig. 2). A complex river system was detected, which was characterised by large depth variability and channel types that vary from straight to braided. While the lateral continuity of the mobile EMI survey made a detailed interpretation of the palaeolandscape possible, the vertical potential added by the multi-layer ECa dataset facilitated evaluating the impact of these features on the former landscape by modelling the palaeotopography (Fig. 2, insets). Based on this palaeotopographical model, ^{14}C-samples were taken that allowed dating different phases of the detected river system, linking these to the prehistoric occupation of the area (De Smedt et al., In Press).

This combination of multi-receiver EMI data with coring and ^{14}C datings enabled a detailed reconstruction of the changing Final Palaeolithic to Mesolithic landscape. These results show the potential of geophysical surveys as a basis for large-scale geoarchaeological research and as a way to map the archaeological and natural aspects of past landscapes.

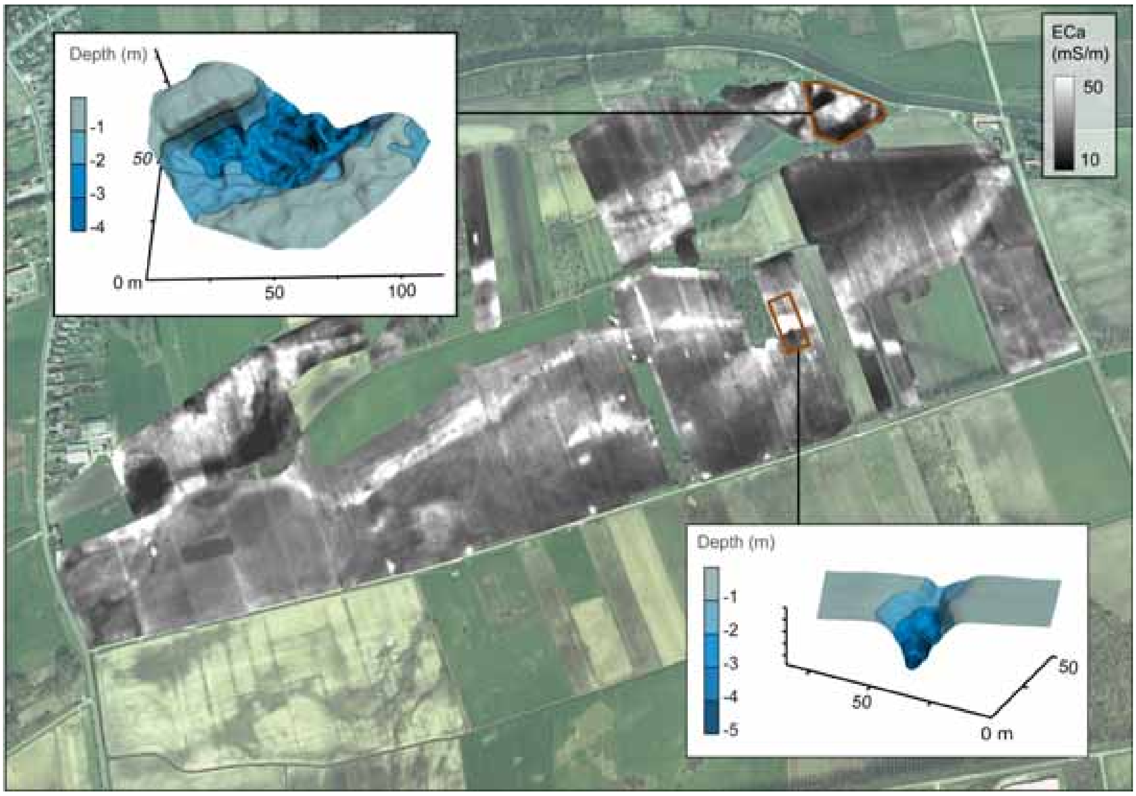

Figure 2: ECa data representative for a soil depth down to 1.5 m below the surface and orthophotograph of the survey area. The insets show outtakes from the palaeotopographical model.

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We attribute some of this to confidence in the construction sector but also due to instruments which run faster, have increased functions and make data acquisition easier, which in turn results in a lower overall cost for field work.

Examples of this are:

1. MiniExplore from GF Instrument

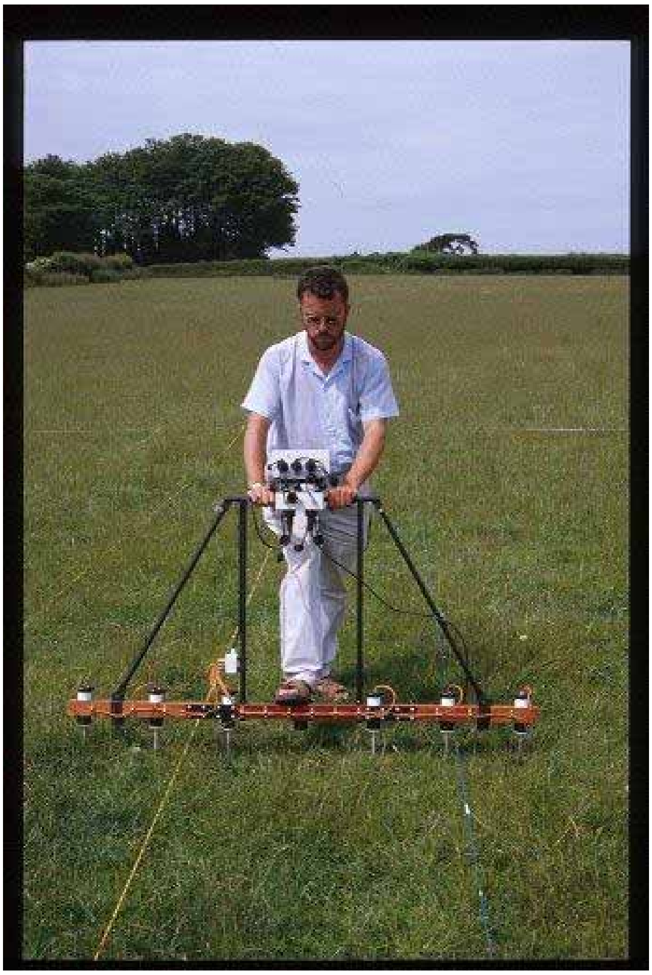
The MiniExplorer is designed for agriculture, forestry or archaeology applications providing detailed results at depths up to 1.8m. The instrument allows simultaneous measurement with 3 depth ranges (0.5, 1, & 1.8M) making this an ideal complement to the traditional surveying techniques. Lightweight, fast and GPS compatible this new product will offer increased knowledge of the subsurface. Sales are rental of the Mimi Explorer are available.

Picture of Mini Explorer @ Rathcroughan Mound

2. Bartington Grad 601-2

The Bartington gradiometer needs little introduction and has over recent years been the magnetometer of choice in Archaeology. Allied Associates have several instruments in their rental pool to support long and short duration hire.

Picture of Bartington Mag



Picture of RM-15

3. Geoscan Research RM15

Another well know and established archaeology survey instrument, the Geoscan Research RM15, is the larger resistance meter which provides increased depth due to multiplexing multi-probe, twin and other arrays thus producing more data from the same area. The RM15 advanced can be hired from Allied Associates.

4. GSSI Utilityscan DF.

Picture of GSSI Utilityscan DF

Ground Probing Radar (GPR), a relative newcomer to archaeology, has however seen rapid growth in part due to the speed of acquisition but also due to the range of functions available to archaeologists. GPR is capable of deep scanning, for ditches, shallower scanning for crypts or tombs or very near scanning on walls and floors (mosaics). A recent development by GSSI, the world's leading manufacturer of GPR, has seen the introduction of a dual frequency radar system combining both 800 and 300-Mhz in a single case, both antennas being digital. Designed initially for utility applications the interesting development is the patent pending data merging feature which is effect allows shallow and deep data to be displayed simultaneously during data collection. This valuable ability allows the operator to view shallow and deep results at the same time on the same screen without the need to change antennas or by way of post processing. The use in archaeology is untested at this time but the merits are clear to see. Sales and rental are available form Allied Associates.

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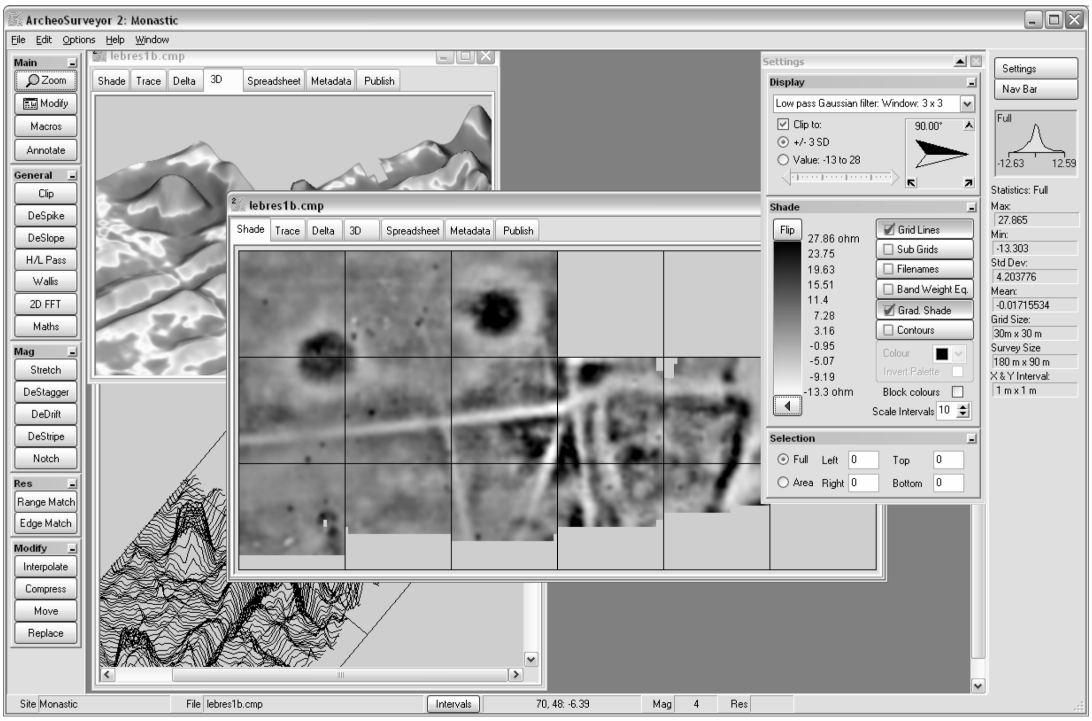

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The new RM85 Resistance Meter is now available. This replaces our well-known RM15 Resistance meter.

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An optional integral programmable Multiplexer card is available for either BASIC or ADVANCED models. This allows the RM85 to automatically configure and log data from multi-probe arrays – the number of measurement lines increases from the standard 4 up to 8. Eight different programs can be defined, each consisting of up to 16 configurations. Compared with the RM15/MPX15 system the new RM85 with integral Multiplexer card is now much lighter and weighs 0.55kg less.

The ADVANCED model can also be used in Wheel Mode where it is mounted on an MSP40 Mobile Sensor Platform (with spiked wheels in place of the probes) for fast, detailed resistance mapping and, optionally, simultaneous magnetic surveys with the FM256. A real time resistance reading output is available for the ADVANCED model for connecting to external wheeled systems. There is also a GPS logging option for the ADVANCED model that records GPS position with each reading (user supplied GPS unit) and provides real time monitoring / feedback of GPS signal Quality and DOP.

Flash memory is used to store readings: 2745600 for the BASIC model, 5491200 for the ADVANCED model. If the GPS option is fitted then the reading capacity will be 164,000 readings; this is sufficient for surveying 2ha at a 0.25m sample interval with an MSP40 system (logging alpha and beta measurements). Data can be downloaded using either a USB or RS232 connection at up to 115200 baud. There is an external compartment for the NiMH battery pack with fast charging and LED status. An expansion port can connect and communicate with external modules such as an interface for a wheeled array.

The RM85 has improved noise rejection capability whilst providing much faster speeds compared to an RM15. In probe mode, survey time can be almost halved for Twin arrays, especially when multiplexed. This is due to changes to the multi-pole measurement filters, a wider range of operating frequencies, a wider range of Auto-Log delays times, and the addition of Speed Boost and Insertion Delay settings. As the reading settles Speed Boost logs data at an earlier but predictable part of the waveform. Insertion Delay allows the user to set a time to get all the probes correctly inserted into the ground but then use a fast Auto-Log Delay time for the multiplex steps; this can be useful in dry conditions. The RM85 also offers significant speed improvements with wheeled arrays, such as the MSP40, compared to an RM15 based system: – 0.3s/m whilst logging alpha and beta readings at 4 samples/m or 0.6s/m whilst logging alpha, beta and gamma plus GPS position.

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Groundvue GPRs were initially developed on an archaeological training site as a collaboration between radar experts and archaeologists. They continue to incorporate design features helpful to archaeologists. They are robust, adaptable and can be used safely over uneven ground. We are proud to sponsor the Detection of Archaeological Residues using remote sensing Techniques (DART) research project by providing them with a Groundvue 3 on a trolley that can tackle a ploughed field.

The same antenna (or antennas) can be used from a trolley, on a vehicle or hand towed over irregular surfaces, in which case we provide a special fitment to hold the control systems. Why hire or buy several systems when you can use the same system in a multiplicity of ways?

Data quality is very high: we see it as important to keep post processing to a minimum. Data collection rates are rapid: stacking is carried out automatically in the antennas and so does not need to be applied via software either during the survey or during post-processing. This also enables our speed of data collection: stacking carried out in a software routine slows down data collection significantly.

Not only do we have the widest range of GPR antenna frequencies available anywhere in the world, including the highest (6GHz) and lowest (10MHz), we also make the only multi-channel that can be used in modular format as anything from a single channel to a large array.

Our multi-channel is the fastest data collecting GPR in the world, operating at road traffic speeds (dependant on the ground surface) which is why it is the system used by the UK Transport Research Laboratory. Most systems trigger their antennas sequentially in order to avoid antenna cross-talk. This means that multi-channels are slower than single channel systems and slow down even further with the addition of GPS. We have developed simultaneously triggered antennas which do not drop in speed either for additional antennas or for GPS or Total Station channels being added in. Simultaneous triggering also allows the automatic and continuous calibration of transmission velocity over large distances by using a single transmitter alongside multiple receivers. Don't take our word for this – challenge us and we will demonstrate our capability.

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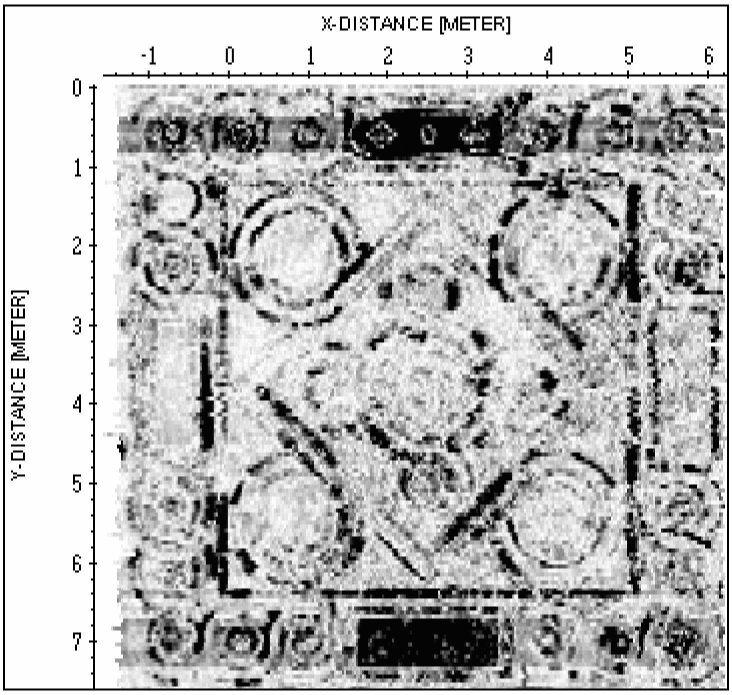
- Groundvue 5 (4GHz) for detailed target definition; &
- Groundvue 2 (50MHz) for wetland investigations.

Of these, Groundvue 3 is the most commonly used for outdoor fieldwork except where groundwater is a major factor. Groundvues 5 (4GHz) and 5C (6GHz) are used either in standing buildings or on features such as the 13th C Cosmati mosaic in Westminster Abbey. There is no higher definition radar available anywhere. Groundvue 2 is used worldwide for either deep exploration (e.g. Supreme Council for Antiquities, Egypt) or where significant waterlogging is a factor (e.g. Atlas Geophysical at Lough Mourne).

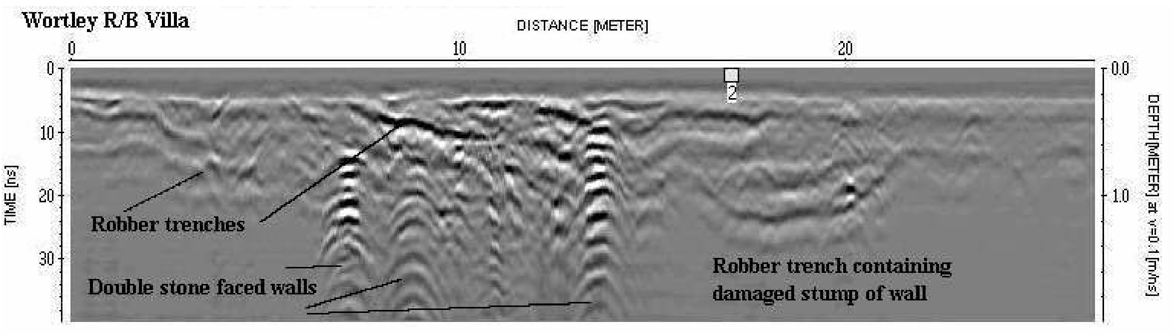


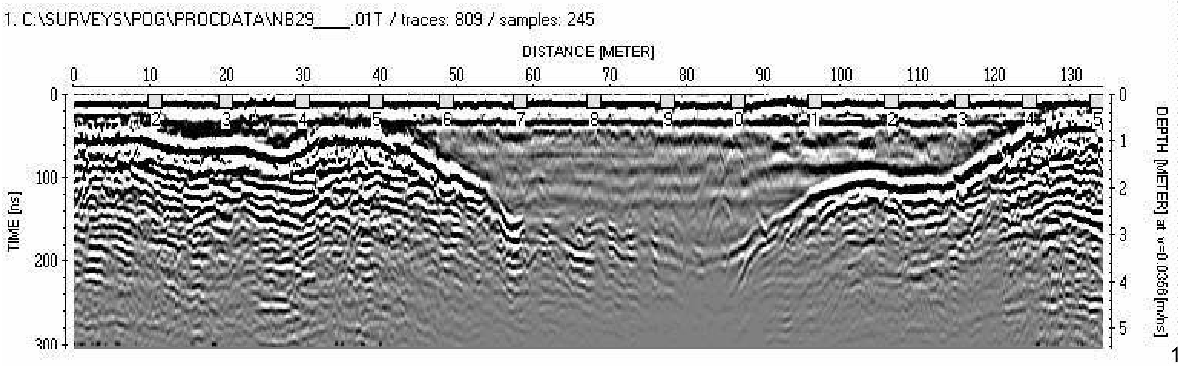
All of the Groundvue GPRs used for archaeological applications comply fully with current European legislation. Our data is compatible with a number of international analytical packages including Dean Goodman's GPR-Slice, ReflexW and GPRSoftPro.

Groundvue GPRs are available for purchase or hire and we can field experienced survey teams or recommend a reliable survey provider from our clients. The company provides training in GPR techniques, both for beginners and for more experienced users. We are happy to provide technical advice before, during or after an investigation.

Specialist design and research work is carried out in collaboration with European Universities and other Research Organisation partners. Technical enquiries for new GPR designs and developments are welcome.

If we can, we will also carry out minor adaptations that are useful to you. We enjoy building your GPR around you!





FOERSTER FLUXGATE MAGNETOMETER - FEREX 4.032 DATALOGGER

2 Bonehill Mews, Lichfield Street, Fazely, Tamworth, Staffordshire

www.foerstergroup.co.uk *sales@foersteruk.com*

Magnetometers are sensory devices for the measurement of the magnetic flux density.

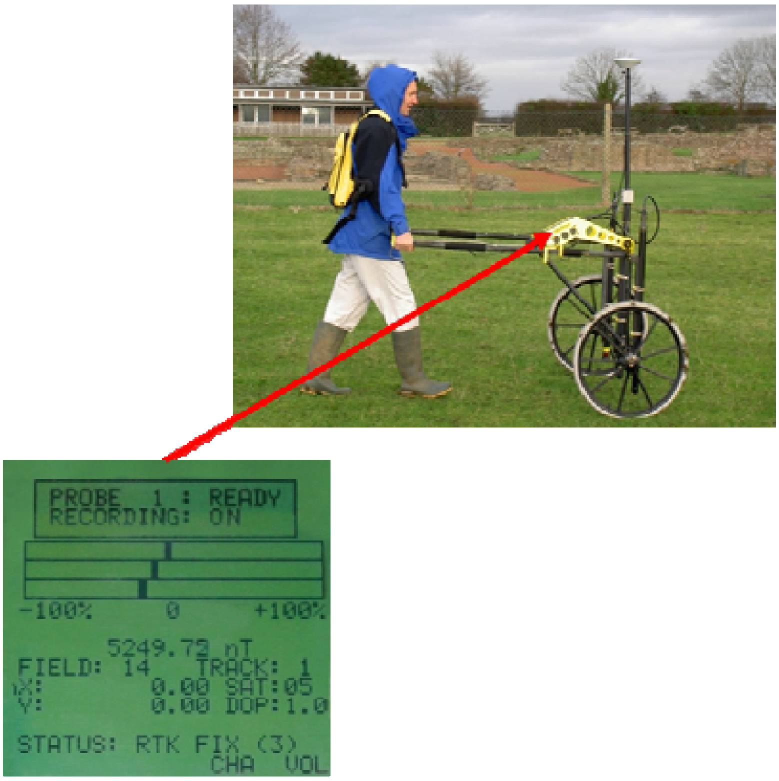
They are well known in the Commercial and Research Archaeology field and can come in to types such as an absolute Scalar Magnetometer such as Caesium Vapour (magnitude of total field) and differential (magnitude of Vertical Gradient) sensors.

While Caesium Vapour type sensors offer very high resolution it comes at a price premium.

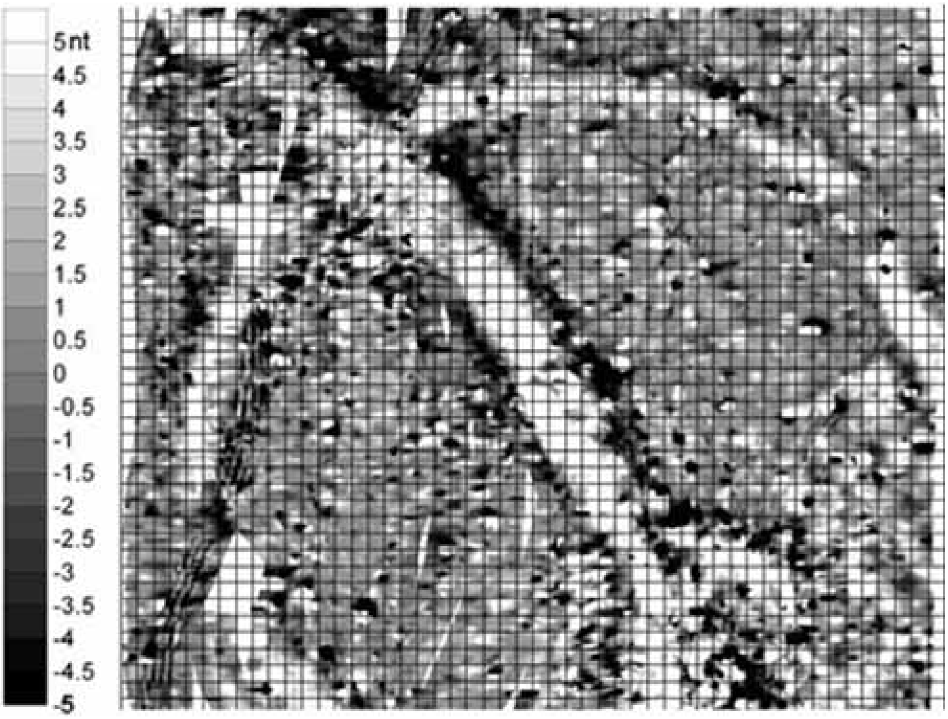
When surveying it is very often required to detect fields in the order of 5 -15nT. Foerster have produced a Fluxgate sensor that can produce a resolution of 0.1nT that has been demonstrated in many published trials and surveys to produce excellent magnetic data when applied to Geophysical surveys used for Archaeology.

The Ferex 4.032 is the latest generation of Differential Magnetometer from Foerster and represents a very cost effective solution for large area magnetic surveys. It offers many benefits to the surveyor by providing an integrated Datalogger for data storage which also offers the possibility of connection to a Differential GPS Navigation System for recording of high precision positional information. It also offers easy handling and high reliability under all weather conditions.

At the heart of the system is the Foerster Probe which can be supplied with differential sensor spacing's of 400, 650 or 1600mm. The sensors are aligned using special tension band technology which guarantees perfect alignment of the two fluxgate sensors which is critical for complete compensation of the Earth's magnetic field. The strength of the Gradiometer arrangement is the ability to detect small magnetic anomalies and



compensate disturbing influences from large anomalies at large distance to probe. Small magnetic anomalies close to the probe/surface will be displayed with high special resolution and high contrast.



The standard Con650 meets the following specification.

· Measuring uncertainty <2 % ref. ±10,000nT

· Resolution < 0,2nT

· Noise < 0.25 nTpp

· Stability better than 1 nT

· Temperature drift < 1 nT/ K

· Band width 240 Hz

· Sample rate 20 Hz

· Measuring range ± 10 000 nT

· Linearity < 1 nT ref. to max. measuring range

The data logger allows for the connection of 4 probes and has interfaces for external triggering of the recorded data (via pulse encoder), Global positioning system and download of stored data. It allows for use with the Foerster Push Cart which significantly reduces survey time (by increasing acreage) and labour costs by offering a navigational aid (GPS System only) thus eliminating the need to mark out grids.

The data recording is carried out as a raster scan, with a length, width spacing and data point distance being set by the operator. The Magnetic data together with the X/Y (plus GPS data if used) position within the field is stored on an internal flash memory for later download.

The data can be downloaded and evaluated with the Foerster Data2Line Geo software which employs application specific filtering modes. It also allows for exporting of results for other software packages.

FEREX 4.032 DLG magnetometer survey atLOS ADAES historic site, Natchitoches-Louisiana, USA 18. –22. May 2009

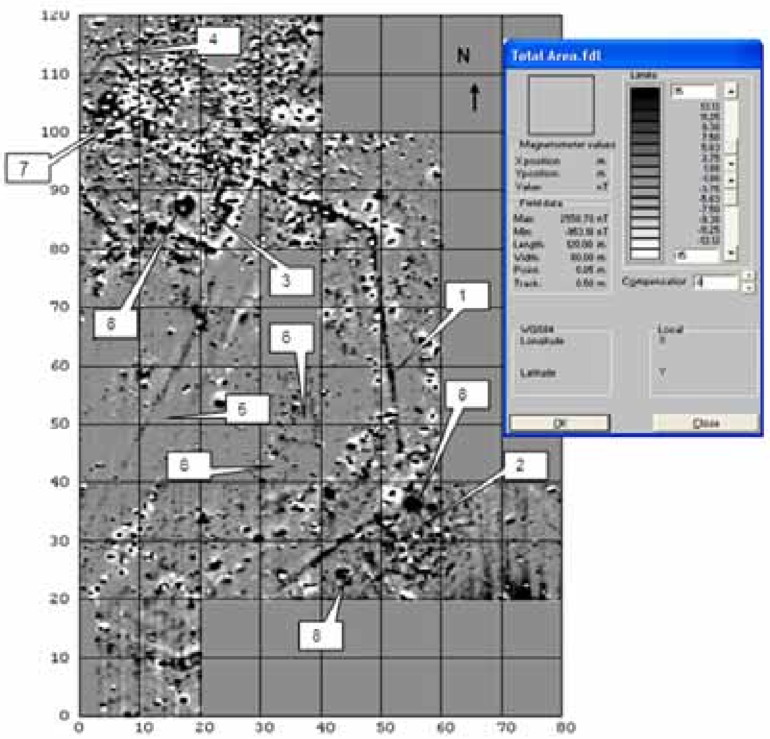


Image of the magnetic raw data

(1) position of the former palisades, destroyed by fire,heat impact on soil (5…15 nT)

(2) remains of the south-east bastion, covered with clutter

(3) foundation structures in the area of the governors house

(4) remains of the north-west bastion (5…15 nT)

(5) structures of the Parish Park Road from early 20th century (0…10 nT)

(6) structures in the former housing area (0…5 nT)

(7) ferrous clutter, vertical re-bars/stakes (> 150 nT)

(8) mono polar anomalies (< 20 nT), might be pits or wells

The FEREX DATALOGGER comes in two formats 4.032 standard and 4.032 GPS (Karto).

Both units offer the following features

- Memory 20 MB
- per value 3 Byte
- Max. no. of channels 4
- File export formats csv, xyz,txt ,fdl bmp
- Light weight, robust construction
- Ergonomic design
- Selectable probe distance
- Balanced for use with probes and data logger
- Limited vibration behaviour

SENSYS GMBH

Rabenfelde 5, 15526 Bad Saarow, Germany

www.sensys.de *wsuess@sensys.de*

Systems for non-invasive geomagnetic and electromagnetic surveys in archaeology.

Based in Germany, SENSYS is specialized in the development and production of non-invasive geomagnetic and electromagnetic survey systems for various applications like rural and urban archaeological prospection. The product range varies from handheld magnetometer devices with one to five probes to vehicle towed multi channel systems with up to 32 magnetometer probes. These systems allow for detection in depths up to 3.5 to 4 m.

Especially for urban surveys, SENSYS introduced active multi coil systems to filter out surface noise caused by pavements and infrastructure. Thus objects and structures in depths up to 2.5 m can be unveiled.

SENSYS was founded in 1990 by Dr. Andreas Fischer. Ever since he is leading the company with passion, creativity and the right sense for smart solutions. Over the years he established a solid and well experienced team of developers and engineers who present a comprehensive and innovative team taking care of customer needs.

SENSYS is increasingly growing and aims to assure the full product life cycle by keeping competence, knowledge and experience in-house. Thus SENSYS assures highest level of quality and know-how in all its products.

Products like the data logger DLM98, the analysis software MAGNETO, the 5-channel push carts or the vehicle towed MX systems are well introduced to the market and are used by various customer groups worldwide.

Putting the customer into focus, SENSYS not only distributes its systems around the world, but also offers its customers the rental of all systems as well as support and training during their work in the field.

For information on SENSYS products and services please contact:

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FORTHCOMING NSGG EVENTS IN 2013

Borehole geophysics (joint meeting with Thames Valley Group)

Equipment Exhibition (May 2013)

Joint Postgraduate Symposium with the British Geophysical Association

UXO geophysics (December 2013)

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

OTHER CONFERENCES OF INTEREST IN 2013

Jorg Fassbinder will chair a session entitled "Remote sensing (long and short range)" at the Computer Applications and Quantitative Methods in Archaeology (CAA) 2013 Conference "Across Space and Time" to be held at the University Club of Western Australia in Perth, Australia between the 25th and 28th March 2013: http://www.caa2013.org/drupal/

The First International Conference on Remote Sensing and Geo-information of Environment will be held in Pafos, Cyprus between the 8th and 10th April 2013: http://www.cyprusremotesensing.com/rscy2013/.

The 10th International Conference on Archaeological Prospection will be hosted by the Austrian Academy of Sciences in Vienna, Austria between the 29th May and 2nd June 2013: http://ap2013.univie.ac.at/.

ACKNOWLEDGEMENTS

I am grateful to Carla Piper of the English Heritage (EH) Heritage Protection Department Administration Team for editing this abstracts booklet and administrative assistance as well as my colleagues in the Geophysics Team for their help. I am also grateful to EH for funding the production of the abstracts booklet and for allowing us time to organise the meeting. Thanks are due to Louise Dyer and the staff at the Geological Society for help facilitating proceedings and Oliver Kuras and the NSGG committee for help as plans have taken shape and today. My gratitude is also due to Sara Anders and Jamie Pringle for mounting digital versions of the conference documents on the Geological Society and NSGG websites respectively and the ISAP committee for offering a prize for the best poster.

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.